PROCEEDINGS OF THE SYMPOSIUM ON PROBLEMS OF INDIAN ARID ZONE

JODHPUR

(23rd Nov. to 2nd Dec. 1964)

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INTRODUCTORY SPEECH

by

M. G. Raja Ram

Joint Secretary, Ministry of Education, Government of India

The Hon'ble Deputy Minister for Agriculture, Your Excellency, distinguished delegates from India and abroad, ladies and gentlemen,

It gives me a great pleasure to extend to you all a hearty welcome and we are grateful that you have readily responded to our invitation to attend this function.

The Hon'ble Deputy Minister, Sir, we are extremely grateful to you for having so kindly consented to inaugurate this symposium on the " Problems of Indian Arid Zone", which has been arranged with the collaboration of UNESCO and facilities afforded by the Ministry of Food and Agriculture.

The arid zone problems of this country attracted attention early in 1952 and the National Institute of Sciences of India took the initiative to organize a symposium on the Rajputana Desert. The conclusions arrived at that symposium were published and the opinion then current was that the desert was expanding at the rate of one mile a year into the fertile Indo-Gangetic plains. It was also recommended that appropriate steps should be taken to arrest the march of the desert. More than a decade has passed since that symposium on Rajputana Desert was organized. Meanwhile, substantial progress has been made in the study of various problems pertaining to the arid and semi-arid areas in India as well as in many countries abroad. Therefore, it was considered that it was quite appropriate to review various problems connected with the arid zones and the Ministry of Education took up the question of organizing another symposium on the " Problems of Indian Arid Zone ". The Ministry of Education has been holding summer schools and symposia on various scientific subjects which are of topical interest.

The arid zone problems are many and varied. Meagre availability of water, intense heat and wind erosion hazards impose severe constraint on plant, animal and human life. The pattern of life in the desert area is nomadic, semi-nomadic or with a precarious semi-settled existence. Naturally, the arid conditions have condemned whole populations in these areas to a low standard of living. For this state of affairs man is also partly responsible for he has misused natural resources which he has exploited indiscriminately. Now, man is beginning to realize the serious problems and is taking advantage of the advancement of the various scientific and technological disciplines which could be utilized for proper husbanding of the available resources. This process is, no doubt, slow but it can bring about a substantial improvement in the living conditions steadily.

Various papers have been contributed by scientists to this symposium and these include problems connected with hydrology, plant ecology, wind and solar energy, climatology, soil erosion, soil salinity, conservation of natural resources, applied geology, etc. This symposium is organized with the collaboration of UNESCO and practically all scientific disciplines in a sense come into account as there is hardly any scientific discipline that does not contribute towards a solution of the varied problems of the arid areas in this country.

I am sure the presence of eminent scientists, who have taken the trouble of coming from other countries including members of the UNESCO Advisory Committee for Arid Zone Research, will certainly ensure that the discussions at this symposium would be most fruitful. The rapid development of communications and the steady growth of understanding have conduced to a great extent for collaboration among scientists in the rapid advances that science and technology have made during the last two or three decades.

UNESCO's participation in this symposium is undoubtedly a step in the right direction for greater collaboration amongst the research workers engaged in the study of fundamental and applied problems of the arid zones. There is no doubt that the Indian participants in this symposium will benefit to a very great extent by discussions with the scientists who have come from abroad.

We all know that the economy of our country is in the take-off stage, but the arid areas in our country are still in the pre-take-off stage. We are, therefore, very anxious that these areas also should make rapid advances in the planned direction of economy and social development. This, we are conscious, can be achieved fast only by introduction of scientific and technological processes. This symposium will, no doubt, discuss these aspects in greater detail.

We have here the Central Arid Zone Research Institute which is a pioneer institute of this kind in this country specifically set up for the study of the arid zone problems of this area. This Institute has done since its inception considerable amount of work under the able guidance of Dr Raheja and it is a very happy feature that this symposium on arid zone problems has been arranged at this Institute and with him as Director.

May I now request Dr. Evstafiev to address us on behalf of UNESCO and then I shall request the Hon'ble Deputy Minister to inaugurate the Symposium.

ADDRESS

by

A. G. Evstafiev

Director, UNESCO, South-East Cooperation Office, New Delhi

Your Excellency, Delegates, Members of Advisory Committee, ladies and gentlemen,

It is a great pleasure for me to greet you on behalf of UNESCO on the occasion of the inauguration of this international symposium on the "Problems of Indian Arid Zone".

It is a very special privilege and an honour to express, on behalf of the Director-General, sincere appreciation to the Government of India for its sponsorship of this symposium and for the hospitality which is being extended to the visiting scientists who are assembled to participate in the symposium.

I would specially like to express our thanks to Dr P. C. Raheja, Director, Central Arid Zone Research Institute, Jodhpur, for the personal support he and his colleagues have given, since the initial stages, when the idea of convening this symposium was first mooted, and to the authorities of the government departments and organizers who have given so much of their valuable time in the preparation of this meeting.

May I now say a few words about the part UNESCO plays in the promotion of international scientific cooperation and about the importance we attach to the arid land research.

Arid and semi-arid regions cover more than a third of the land surface of the earth while cultivated land represents barely a tenth.

The necessity for urgently developing and exploiting the resources of areas which man has so far neglected has become a major concern for UNESCO.

The problems involved in developing these areas, in India as elsewhere, are many and are conditioned by economic, social and political considerations.

The answer to these problems depends on basic scientific and technical research in fields, such as physics and chemistry, geology and hydrology, biology, pedology, ecology and sociology.

It was in December 1948 in Beirut that the UNESCO General Conference adopted a resolution, proposed by the Indian delegation, which authorized the Director-General to investigate various proposals concerning the establishment of an International Institute for Arid Zone Research. The question was later considered at Lake Success in 1949 on the occasion of the United Nations Conference on Conservation and Utilization of Natural Resources; and in December of that year a committee of experts was convened in Paris to make a detailed programme for a UNESCO Arid Zone programme. The committee recommended that UNESCO should formulate and execute a programme for assisting arid zone research.

UNESCO Arid Lands programme dates back to 1951 with the creation of an International Advisory Committee on Arid Lands Research.

Subsequent to a resolution adopted by the General Conference of UNESCO at its ninth session in New Delhi in November 1956, the programme expanded considerably. During the period 1957-63 it became a major project.

The work plan was concentrated in each of these years on one major group of research problems; in 1952, it was hydrology and underground water; in 1953, plant ecology; in 1954, energy sources with special reference to solar and wind energy; in 1955 human and animal ecology, and in 1956, climatology and micro-climatology.

In 1952 a symposium on the Rajasthan Desert was proposed by the National Institute of Sciences in India. This suggestion was immediately approved by UNESCO. The object was to provide information to India's representatives who were later to attend other international symposia organized by UNESCO.

The second symposium on "Wind and Solar Energy" was held in the National Physical Laboratory in New Delhi in 1954. The second symposium, like the present one, flowed from the establishment of the International Advisory Committee for Arid Zone Research which met that year in New Delhi.

The third UNESCO symposium in India was on "Environmental Physiology and Psychology in Arid Lands". This was held in 1962 at the Central Drug Research Institute, Lucknow.

The fourth UNESCO symposium held in India, and of interest to arid zone scientists and technologists, was on "Water Evaporation Control". It was organized jointly by UNESCO and the Indian Council of Scientific & Industrial Research at the National Chemical Laboratory, Poona, in 1962.

This year, after a decade, the International Advisory Committee will meet again in India, at Jodhpur, at the conclusion of this symposium. This symposium is the fifth UNESCO-sponsored symposium on arid lands to be held in India. I am happy to say that the symposium coincides also with the opening here today of the new building of the Central Arid Zone Research Institute where UNESCO in the Expanded Programme of Technical Assistance for

1963-64 provided expert assistance, equipment and fellowships.

The six-year period of the major project is now coming to an end; but this has not meant any slackening in the action taken to assist research in the arid zones. Apart from consideration of particular subjects, other work of special interest has been undertaken: the survey of institutions of arid zone research, preparation of maps showing the distribution of similar climatic conditions in these areas, research on the utilization of saline water, etc.

The research and training activities undertaken as a part of the major project are, as you know, further supplemented and extended by the United Nations Technical Assistance programme which seeks to promote economic development.

It is a great satisfaction to see today renewed and continuing efforts by scientists from the region and from other parts of the world. The renewal of contacts between sientists in various disciplines of arid zone research, assembled here today, is a prospect which is deeply encouraging. It is also indicative of UNESCO's long-standing interest in the problems of arid lands.

This review of research on the Problems of Indian Arid Zone will bring together, we hope, as such uptodate information as possible; it will reveal inadequacies, so that further work may be stimulated; and it will help discover inconsistencies or conflicts of evidence. This symposium will, I am sure, help to define more adequate concepts than those which have served in the past.

I have no doubt that with so many outstanding scientists present here we shall have a fruitful and successful meeting. We are looking forward with confidence to your contribution to this symposium and to further arid zone research.

Once again, on behalf of the Director-General and on my own behalf, I wish the participants every success in the accomplishment of their tasks. I am sure that they will enjoy their stay here. I know that they will enjoy the hospitality of Jodhpur.

INAUGURAL ADDRESS

by

SHAH NAWAZ KHAN

Union Deputy Minister for Agriculture, Government of India

YOUR EXCELLENCY, MEMBERS OF THE UNESCO SCIENTIFIC ADVISORY COMMITTEE FOR ARID ZONE RESEARCH, DISTINGUISHED DELEGATES, LADIES AND GENTLEMEN,

I have great pleasure in welcoming you to this Symposium on "Problems of Indian Arid Zone". It is appropriate that the symposium has been organized by the Ministry of Education at the Central Arid Zone Research Institute, Jodhpur, which is situated in the large arid tract known as '*Thar*' desert and which is working on problems of the arid and semi-arid areas of the country. Government of India are grateful to the UNESCO for making it possible for the members of the Scientific Advisory Committee for Arid Zone Research and other eminent scientists working on arid zone problems to take part in the symposium and share with our scientists their knowledge and experience in improving the resources and living conditions in this desert area.

The National Institute of Sciences held a symposium in 1952 to review the basic information on what this desert is, how it came into existence, what its behaviour is and why and how it is spreading, that is, if we assume that it is spreading according to the popular notion. From a wide variety of contribution to the symposium it was concluded that the evidence by and large indicated that the desert is spreading into the fertile plains of the Indo-Gangetic basin. In this hot desert evaporation far exceeds precipitation. There is little moisture here to support vegetation. The river system is said to have dried up during historic times as the Sarasvati was undoubtedly a mighty river in the Vedic period. The population in the western part of the Sarasvati Valley became nomadic towards the first millennium A.D. The desert conditions have been accentuated by the work of man in clearing and burning forests for cultivation or for use as firewood. Agricultural practices, conducive to soil erosion, may also have been responsible for the deterioration of the soils. The flora of the desert was initially not so poor, but locusts, goats and sheep have contributed to its deterioration. However, there was general consensus of opinion amongst the scientists that the production potential of resources can be substantially raised by improved techniques of management of land, water, vegetation and livestock and exploitation of the abundant mineral resources. The importance of research and the utilization of resources under a central authority to coordinate all activities according to a unified master plan for centralized direction, operation and superintendence was emphasized.

The growing complexity of scientific research demands that the progress of the investigations should be periodically reviewed. Such a review synthesizes the knowledge in various fields and stimulates rapid advances in technology and provides information on new methods of achieving rapid development. Although application of new methods depends upon the financial resources of the States, the effort to synthesize knowledge by itself is an achievement for future success of the projects yet to be initiated.

The UNESCO has been arranging symposia on various subjects in different countries on problems of arid zones. Voluminous information has been collected in the reviews published by the Arid Zone Unit of that organization. This literature is proving of immense value to research workers in advancing the knowledge of techniques which can be applied on a large scale to boost up production and increase the meagre resources of arid lands. In India, besides the Central Arid Zone Research Institute, several organizations and Central and State departments have been engaged in research and development of resources for the past decade. It is in the fitness of things that another review be undertaken of the progress achieved in different fields of research. This is the principal objective of this meeting.

Rajasthan, though rich in mineral wealth, lacks basic minerals which have so far retarded the development of large-scale mining activity. In 1958 the total output of mineral was valued at Rs 5·8 crores, 37 per cent of which was contributed by building stones and 13 per cent by salt. The other minerals mined are lead, zinc, mica, gypsum, bentonite and fuller's earth. It is expected that mining will contribute about Rs 16 crores in 1971 as against Rs 6 crores in 1961.

Besides the exploitation of mineral resources, another field in which progress has been achieved is the industrial sector. Prior to integration of the covenanting States the financial and technical know-how of the resources of the State were very limited, and, therefore, industrial development could be initiated only in the Second Five Year Plan. Industrial surveys have been conducted in all the districts of the State and project reports are now available for primary as well as secondary industries. There is scope for developing textile industries based on long-staple cotton to be produced in the Rajasthan Canal Project area and wool produced in Bikaner and other districts.

So far processing industries based on livestock products are practically non-existent. There is also scope for mineral-based industries as ores of lead, zinc, copper, cadmium, gypsum and limestone exist which can be exploited on a factory scale for manufacture of cement and other products. In the development of chemical industries some of the scientists gathered here can give valuable advice. Since the scope for increasing the income from agriculture for the rapidly increasing population is limited, there is need to lay emphasis on small-scale industry and this symposium could usefully devote some time to this aspect.

The sources of conventional power in desert areas are very limited. Hydroelectric and atomic power generation programmes are in an advanced stage of development. However, solar energy can be successfully harnessed in desert areas as the number of cloudy days are very few. This can provide energy in very small units for domestic consumption as well as for small-scale industry. The harnessing of this power can revolutionize industry in the desert areas where cost of transmission, installation and distribution is very high. While Canada, Israel and few other countries are conducting researches on solar energy, this aspect has not yet received adequate attention in this country.

While wind can be harnessed to provide energy in the desert regions during the summer months, it is also a menace as it causes wind erosion, thus shifting soil over long distances and rendering it infertile and drying up vegetation. It also causes increased evaporation from water surfaces and the soil. Detailed investigations on wind erosion, based upon wind tunnel studies, have been conducted in Canada and the USA. As a consequence cultivation practices have been evolved to check erosion of land and reduce loss of moisture from the soil. Where agriculture and animal husbandry in the 'dust bowl' region of North America was hazardous, it has become stabilized and prosperous by the adoption of new practices. Research on these problems should be intensified to enable us to sustain the fertility of lands and increase the production of crops, grasses and tree species.

The water relations of vegetation are of fundamental importance in an arid environment. The entire crop production, grazing, firewood and timber production depend upon conservative use of water by the vegetation. Climate is the key resource, soil is the storehouse for moisture, plant is the synthesizer of water, minerals and carbon dioxide from the atmosphere. Although only drought-hardy vegetation thrives in the desert, it is paradoxical that drought-hardy species expend water wastefully whenever water is readily available in the soil. There is, therefore, need to select varieties and species which are capable of producing a large amount of plant material without heavy transpiration and will mature in the shortest possible time to escape the hazards of drought. Climatologists, soil scientists, plant physiologists, hydrologists, ecologists, agronomists and silviculturists can study these complex problems in a systematic manner. Very preliminary coordinated investigations have been initiated at this Institute. This is a very fruitful field for conducting research in all the arid and semi-arid areas of the country.

Industrial crops offer much scope for cultivation in the arid zone. Some of these crops have low water requirements, are drought-hardy and need less of nutrients. Two of these crops which have great potentialities are groundnut and *Guar*. The introduction of groundnut would increase income of the farmers, support an oil-pressing industry, provide oil-cake for cattle feed and oil for *Vanaspati* and soap industry. *Guar* is exported in large quantities for the production of *Guar* gum. Increased production of *Guar* offers scope of setting up this industry in the arid zone. The residues can be efficiently utilized in the cattle feed mixing industry. I am glad that the Institute has started work on these problems and suitable varieties of these crops are being introduced.

Plant introduction from homoclimatic regions should replace some of the less productive species of crops, trees and grasses suited to the environment. Within the short space of four years 108 species of *Eucalyptus*, 37 species of *Acacia* and 33 species of miscellaneous genera of trees and a large number of varieties of crops have been introduced for trial and testing. In the introduction of grasses there has been comparatively little success. There should be sustained effort to introduce crops, shrub and tree species which can provide the base for industrial growth in this region.

The peculiarity of the pests of the arid region is the high degree of water stress which these animals can stand. The Indian Desert gerbil, a kind of desert rat, can live on very highly parched diet for 16 months without a trace of water. These animals draw their sustenance from roots, seeds and fruits of plant species abundantly growing in the desert areas which causes high degree of denudation. Locusts pass part of their life where water is scarce and multiply at a tremendous rate. The problems of locust biology, ecology and control have been under study for the past three decades, but problems of rodents, insects and pathological diseases deserve more attention than has been devoted so far.

You have a wide range of subjects for discussion before you. These relate to survey of basic resources; utilization of these resources more efficiently; harnessing solar energy and wind power; reclamation of saline and alkali lands; desalination of brackish water and its use on the farm; hydrological surveys and exploitation of ground-water; efficient application of water for crop production and conservation of rainfall for maximum production of crops, pasture and forest trees; improvement of animals and increasing their production; control of pests of vegetation; socio-economic problems of nomads and settled farming communities. I wish you all success in these deliberations and trust these would prove fruitful and indicate the gaps in our knowledge and lead to satisfactory solutions.

VOTE OF THANKS

by

P. C. RAHEJA
Director, Central Arid Zone Research Institute, Jodhpur

DEPUTY MINISTER FOR AGRICULTURE, YOUR EXCELLENCY, LADIES AND GENTLEMEN,

It is a great previlege to be called upon to direct the proceedings of the symposium on " Problems of Indian Arid Zone ". This is the second symposium which will review the progress of research and development in the desert areas of the country and formulate proposals for expansion of research in various fields. During the past decade the Government of India and State Government have taken a very keen interest in the development of the backward desert areas of the country. As a consequence of the first symposium the Central Government set up the Central Arid Zone Research Institute on the model of the Desert Research Institute, Mataria, Egypt, and the Institute for Arid Zone Research, Beersheva, Israel. But the scope of the work of this Institute has been much enlarged than that of the other similar institutes.

In India the problems of rehabilitation of the natural resources are twofold. The technical problems are easy to handle and grapple with. The social problems are more intractable than the technical problems. The social and economic thinking of the people is the consequence of the long experience of living with the scarce and deteriorating resources. The rapidly increasing human and livestock population poses a serious handicap. A large mass of illiterate rural population has to be educated into new thinking and newer technical knowledge. This means breaking away from the orthodox way of thinking and acting. The community project works started in the various Development Blocks have not been able to change this outlook. In fact, the knowledge about agriculture and animal husbandry imparted to the farmers is the same as in other parts of the country. The workers of the Development Blocks need to be educated differently as the techniques of rehabilitating the resources are altogether different from the more favourably situated arable areas of the country. The starting of the Human Factor Studies Division in the Institute is a step which will help to resolve and focus attention on socio-economic problems of the arid zone in the country and lay emphasis on extension education of a different type.

The progress of rehabilitating resources in the desert areas of Israel has received world-wide attention. The whole economy of Israel is capital-intensive. The capital in most of the other Asian and African countries is a scarce commodity. Therefore, the techniques of getting the most out of the resources of the desert in the developing countries have to be different from that in Israel. These techniques have to be labour-intensive rather than capital-intensive. We have much to learn from investigations conducted on use of solar energy, desalination of saline waters, spray irrigation, poultry production and manufacture of byproducts of salt industry in progress in Israel.

In Australia primary industries of wheat, sheep and beef production have contributed very largely to the prosperity of that country. In a relatively newly opened country where extensive land resources exist and opportunities are available to all people on a large scale, the problem was different from that in India where the per capita land is limited. But there is much to learn from these. Firstly, very intensive research on pasture land development has been carried out on large broad pasture types in Mediterranean, semi-arid, arid, northern monsoon and tropical climatic regions. Pastoral laboratories are constantly studying the problems of range management and livestock production. Breeding of sheep for superior quality and high wool production is receiving attention side by side with the study of the physiology and nutrition of animals. Secondly, large-scale land research and regional surveys of natural resources have been started based on aerial photo-interpretation. Thirdly, the ecology of wild life and the equilibrium between natural vegetation and wild life are extensively being studied to increase production in arable farming and livestock industry. Fourthly, the control of evaporation from large water surfaces, desalination of saline waters and harnessing of solar energy are under intensive study. Fifthly, the problem of soil-water-plant environment relationship is being investigated from the aspect of plant production and efficient use of rainwater. These involve eco-climatological and micro-climatological research. The co-operation of the Australian Government has been given in a very large measure in various scientific fields and we are profiting by it.

In the USA the development of arid zone has largely been associated with the development of beef and dairy industry which has entailed evolving range management practices to increase production from livestock. This has incidentally conserved soil and other vegetation resources in a large measure. These practices are now under test at the Institute in a very intensive Range Management and Soil Conservation Project covering an area of 5500 acres which is yielding valuable results. The strains of desert grasses have been selected, of which the production per unit area is very large.

In Algeria, Tunis and Morocco several French institutions have conducted hydrographic, ecological and land surveys. Socio-economic problems of nomads and settled farmers have been investigated. The Institute is keeping in close touch with these organizations to learn the new techniques and obtain new information for developing our programmes.

The hydro-geological studies conducted by the Desert Research Institute, Metaria, are of outstanding nature. The programme of plant introduction, soil classification and sand-dune stabilization is making good headway. They have recently started investigations on solar energy and assay of medicinal plant from the desert region.

The scientific reviews and proceedings of various symposia published by the Arid Zone of the UNESCO has broadened the outlook of research workers in different countries and brought them closer. The UNESCO has also aided the developing countries in setting up institutions to solve the problems of arid zone. In fact, this world organization has played the role of catalyst in this field.

In all the arid areas of the world conservation of resources and their most efficient utilization have conducted to prosperity and increased the standard of living of the people. The introduction of automation and use of atomic power in industry are fast changing the wage structure, and farmers and nomads in the arid zone would not be content to live a hazardous life and continue to sustain themselves on low income in times to come. It is essential to integrate industry and agriculture in the near future. We have to make a great lea-way in this direction. Possibly, harnessing of solar energy for running cottage industries can solve the problem of unemployment and under-employment and raise income of the people in these tracts. The Ministries of Education, Industry and Agriculture must pool their resources and knowledge to resolve the problems which confront us in this field. The FAO, at one stage, was prepared to finance such projects. A coordinated programme originating from this symposium could possibly be started in the Fourth Five Year Plan with technical assistance from the UNESCO and the FAO to step up the standard of living of the people.

Fellow delegates, we have a very large programme. I shall need your kind cooperation in completing this work. We have requested several of the distinguished delegates to preside over the various sessions. I trust, they will accede to our request. The Ministry of Education has also arranged two field trips to give the idea of the nature of the terrain, land-forms, kinds of soils, hydrological features and types of vegetations from very dry areas in Bikaner to the humid region of Mt Abu. Short visit to one of the oldest Community Development Blocks at Sumerpur has also been arranged through the kind courtesy of the Block Development Officer. Father Santapau and Mr C. S. Christian have kindly consented to deliver lectures in the evening. On 1st December general discussions will be held on four topics: (a) Aerial Photo-Interpretation for Survey of Natural Resources; (b) Productivity of Arid Lands for Farming and Animal Husbandry; (c) Aridity, Causes, Criteria and Control; and (d) Impact of Man on Arid Land—Retrospect and Prospect. We shall have plenary session on 2nd December 1964. It is possible that you may have experienced a little inconvenience, but you will kindly bear with us as we have recently shifted to our new premises and the arrangements have not been as perfect as we wished to be.

Sir, I would now like to introduce to you various delegates who are attending the symposium.

REPORT ON SYMPOSIUM

"PROBLEMS OF INDIAN ARID ZONE"

by

P. C. RAHEJA

Director, Central Arid Zone Research Institute, Jodhpur

THE Symposium, jointly organized by the Ministry of Education and the United Nations Education, Scientific and Cultural Organization, was held from 23rd to 30th November 1964 at the Central Arid Zone Research Institute, Jodhpur. It was inaugurated by the Union Dy. Minister for Agriculture, Shri Shah Nawaz Khan. Dr P. C. Raheja directed the proceedings of the symposium.

Five sessions were devoted to major subjects related to " Analysis of Basic Resources ", three sessions to " Utilization of Resources ", one session each to " Pests and Their Control " and " Ecology of Human Factor ". The number of papers presented at the symposium were 86. Besides, four sessions were held for discussion of the general topics, namely (a) Aerial Photo-Interpretation for Survey of Natural Resources; (b) Productivity of Arid Lands for Farming and Animal Husbandry; (c) Aridity, Causes, Criteria and Control; and (d) Impact of Man on Arid Land — Retrospect and Prospect.

SUBJECT MATTER OF DISCUSSIONS

The summary of the papers presented in the various sessions is given below:

A. ANALYSIS OF BASIC RESOURCES

The entire area stretching from the Sahara to the Thar appears to be a meteorologically homogeneous one. This evidence supports the view that the Thar desert is not an isolated desert. Besides, physiographic and anthropogeographical conditions of the region are comparable to identical phases in contiguous hot deserts.

The arid region of north-west India extends for 640 km from north-west to south-east with an average width of 300 km from west to east. It has well-defined boundry in the east marked by the Aravalli Range.

The topography of western Rajasthan is not a result of superficial or biogenic agencies, but is attributed to geological processes largely in the nature of the sheet movements leading to peneplanation, rapid changes in the drainage system, enormous accumulation of loose rocky materials, deepening of water-table and consequent famishing of vegetation, and thereby accentuation of desertic conditions. A thick sedimentary sequence ranging in age from Early Palaeozoic (or even older) to Middle Eocene is exposed in the western Rajasthan desert. The sedimentation, with many intervening breaks, continued up to Late Palaeozoic times till the major uplift and erosion which preceded the next major marine transgression in the Jurassic. The study of the geomorphology of the southern arid zone has shown that two cycles of erosional surfaces are present, one of which is responsible for the accordance of the summits in this area which consist of domes, whalebacks, flat domes, inselbergs, koppies, pediments and pediment passes.

The dunes met with are of two categories, namely complex and simple. Complexities of dune morphology are very common. The general orientation of dunes is in SW-NE and in other areas NW-SE or W-E direction. The wind regime is the most dominant factor determining the axial direction of dunes in the region. The dunes of this region are of semi-stabilized and usually of less active nature. The sand has been derived largely from the dry stream channels. The attitude of the Aravallis is not a formidable barrier in the creep of the desert towards east as sand is shifting through a number of gaps and forming dunes and covering fertile alluvial plain with blown sands in the districts of Churu, Jaipur, Sikar and Jhunjhunu.

In western Rajasthan, before the aridity set in, the streams were alive and carried sufficient silt into the sea. Thereafter, the run-off decreased and these streams now flow subterraneally along these dead channels. The confluences of the main channels now form salt basins. This process is still in progress as new salt basins are being formed on lower reaches on the smaller tributaries.

Amongst the Mesozoic sediments, the Lathis and the Bhuj sand-stones have come to be recognized as potential ground-water reservoirs of great promise. Younger Mesozoic and Tertiary formations in their arenaceous facies are also productive, but these have poor quality of water, often much below all standards of acceptability. Ground-water occurs in the granitic and their volcanic equivalents in the weathered zones and the joints and the fracture planes. In the older sedimentaries some water is found in the top layers when the cementing material is removed or joints penetrate deep enough. Loamy sand and alluvia are good for water accumulation. The ground-water resources of the arid region are recharged at a slow rate by hilly catchments where rainfall is comparatively high and infiltration rates are low. The water depth generally varies between 4 and 15 m. Nearly 35 per cent of the wells are situated in younger alluvium. This provides better formation for tube-wells as these consist of semi-confined aquifers with high coefficient of transmissibility. The total dissolved solids in the arid zone range from 200 to 26,140 p.p.m., of which chloride (as NaCl) varies between 44 and 20,602 p.p.m.; sulphate (as Na_2SO_4) and bicarbonate (HCO_3) range from complete absence to 4785 and 1730 p.p.m. respectively. The percentage of acceptable waters is about 40 per cent. There is a wide range of variation for the anionic and cationic ratios. C_2 type of water is associated with blown sand and younger alluvium; C_3 type is practically evenly distributed in all lithological types; C_4 and C_7 type of waters are more commonly found in older alluvium and volcanics whereas C_6 type of water is found only in older alluvium.

Vegetation is the true indicator of aridity. Therefore, water deficiency should be treated as an index of aridity which may be used as a parameter for systematic analytical study of droughts which are of frequent occurrence in arid regions of the country. Of the several systems of climatic classification, Thornthwaite's scheme appears to be most rational used together with Emberger's pluvia thermic quotients; these reflect a close relationship to the vegetation types in the arid and semi-arid regions. A new climatic index taking into account the parameters of (a) annual average diurnal range of dry bulb temperature and (b) the average annual preciptiation has been evolved in terms of logarithm of the ratio of these two which has several advantages over the former classifications.

The soils of western Rajasthan which belong to the arid and semi-arid climate may be classified in the following groups: (1) Pedocal sierozems of alluvial origin; (2) Pedocal brown soil of alluvial origin; (3) Grey brown (desert) soil; and (4) Desert soil. The predominant soil parent material in the arid zone comprises mainly: (1) vast aeolian sand deposits of recent origin in the west and north-west; (2) the alluvial deposits of Pleistocene and sub-Recent times in the east; (3) the pluvial sheet wash deposits on piedmont apron of 1-3 per cent slope skirting the hills; and (4) the calcareous clays deposited in depressions in the older alluvium and in the abandoned stream channels.

The grasses appear to have advanced from the humid tropical forests progressively into less favourable arid and mountainous environments and to have become taxonomically more advanced in the process. The taxonomic progress is the opposite of ecological progression. Pioneer species of plants into arid and semi-arid environment possess a great reserve of genetic variability. Apomixis is probably an important characteristic of the species of arid lands. The Indian communities are found in the Sahelian zones south of the Sahara, in the Sudan and other parts of north-east Africa, the Near-East and in interesting combinations with non-Indian communities in Iran, Afghanistan and north-west Pakistan. In the Indian arid zone it is more rational to group the plant communities on the basis of land-forms such as sandy plains, sand-dunes, alluvial plains, hills and piedmont slopes, flood plains and so on, and to further categorize them on the basis of structure and floristic composition. Near the coastal dry zone the plant communities have been grouped into three eco-systems: (1) strand, (2) salt marsh and (3) inland mixed scrub forest.

B. UTILIZATION OF RESOURCES

In the arid zone wet spells are of short duration but have great significance in agriculture, hydrology of the region and forage availability in range lands. The longest spells in the period 1901-1950 ranged from 6 days in Jaisalmer to 13 days at Jaipur. Over 90 per cent of the wet spells have 3-day durations. The duration of the wet spells in the arid and semi-arid regions of Rajasthan are related to sunspot characteristics. The spraying of hydroxyethylene decosonal (OED) on the soil surface reduces evaporation by 15 per cent.

The fertility of the arid zone soils is low. This can be maintained by the introduction of crop rotations including leguminous plants; application of manures and fertilizers, and adoption of wind erosion protection measures. Most of the soils have alkaline reaction and contain high calcium content. The micro-flora in such soils differ from other soils and the actinomycetes usually dominate as these organisms can tolerate drought conditions much more than bacteria and fungi. The bacterization of seed with azotobacter and phosphobacterin as well as with the locally isolated microbes which solubilize phosphorus may increase production. Rhizobium inocculation of seeds is another source of increasing the nitrogen supply in the soil. Saline and saline-alkali lands need periodic dressing of gypsum to correct solonetz effect created by saline irrigation waters.

In the arid zone the use of ground water is a necessity to obtain high yields of crops. Usually the quantity of irrigation water given is in proportion to the difference between the limiting rainfall necessary to prevent the formation of saline-alkali soils in the climate and actual rainfall of the locality. But in this region over 66 per cent of the wells have C_2 to C_5 (total soluble salt 180-7000 p.p.m.) type of ground waters. These are used for irrigation on light soils. About 80 per cent of these waters have SAR of the range of 0-10 which indicates that most of the normally used irrigation waters are not likely to produce alkalinity in the soil. The sodium adsorption ratio calculated from the predicted values of sodium as well as from its relationship with electrical conductivity has shown close conformity with the actual SAR values. The yield with the C_4 type of water is significantly reduced than with C_1, C_2 or C_3 waters. This reduction amounts to 50 per cent of the yield with C_1 type of water. Where the rainfall is over 550 mm per annum and the soils are sandy, highly saline waters can be used for crops like wheat. The application of such water increases the salt content of the soil; if the soil is calcareous, the calcium carbonate of the soil becomes soluble at higher salt concentration. The drainage conditions are not ideal when SAR value is greater than 8. But the drainage of very sandy deep soils is not impeded as these have low clay content. On such soils it is possible to use seawater. The plant response to seawater is determined by the level of salinity. The addition of potassium and phosphorus salts in proper ratios creates an ionic balance which reduces the toxic effect of seawater on the metabolic activities of the plant. Dilute amended seawater containing 10,000 p.p.m. total soluble salts could be used to raise normal tobacco plants in pot culture.

The plant-water relationships of sand-dune have indicated that the high rate of transpiration is maintained by the tree species as soil moisture is readily available in deeper profile layers and root system penetrates to that depth. The rate of transpiration of trees decreases when the moisture availability is reduced. *P. spicigera* absorbs water from deeper layers of soil and maintains a high rate of transpiration even during summer months.

The drought effects are dominantly manifested in the latter stages of the crop plant (*Bajra*) as the reversion mechanism during the reproduction phase is not as effective as at the seedling stage of growth. Small changes in the tissue hydrature in the older plant bring about large changes in metabolism. Grain yield and 1000-kernel weight are found to be invariably correlated with the temperatures at the ripening period. An index evaluating drought-resistance has been evolved which is the percentage of the value of growth or yield character under wilting treatment over value of the same character under normal watering. Varieties falling in the same or a close flowering class do not show significant difference in response to drought. The response to drought becomes significant only when appreciable increase in the temperature during the wilting period enhances drought intensity.

Not more than 4 per cent of the untreated seeds at room temperature indicate any imbibition or germination. The imbibition is very low or nil at 3-13°C, and this retards germination of the seeds of *Parkinsonia aculeata* Linn. Hot soil with water at room temperature induces appreciably greater germination. In the *Indigofera* species seed treatment with concentrated sulphuric acid for the period varying between 20 and 40 min. gives very high percentage of germination.

Adaptability trials with 73 species of *Eucalyptus*, 20 species of *Acacia*, and 27 species of other genera have indicated that *Acacia tortilis* (Israel) and *E. camaldulensis* possess great adaptability to this environment and excel in survival and growth than indigenous species. The nursery raised in metallic containers or black polythene bags economize water appreciably. The indigenous species can be transplanted with advantage when they are about 1-year old. High plant establishment is obtained in half-filled pits of 60 cm × 60 cm × 60 cm with a crescent shape — across the local slope. The cost of stabilizing shifting sand-dune with vegetation ranges from Rs 75 to Rs 125. This cost can be recovered from the cut grass forage and fuel trees planted in the reserve in about 5-6 years. The most suitable fast-growing fuel species are *Prosopis juliflora*, *Calligonum polygonoides* and *Acacia tortilis*. The important top feed species are *Prosopis spicigera* and *Zizyphus nummularia*.

The agro-botanical characters of *L. sindicus*, *C. ciliaris*, *C. setigerus*, *P. antidotale* and *D. annulatum* have been studied. These show wide genetic variability and 208 strains have been selected. The strain Nos. 357 and 358 suit light sandy soils and strain No. 362 heavy soil. The highest carrying capacity is possessed by *L. sindicus* of the cultivated pasture. The others in order are *D. annulatum*, *C. ciliaius* and *C. setigerus*. The grasses suitable as soil binders should possess the character of rapid growth, heavy tillering and high carrying capacity. In native pastures the grazing should be regulated dependent upon the utilization of the key species. For this 'proper use factors' have been developed for all the five important perennial species of grasses. The forage production from the range lands is correlated to their hydrological condition. The several factors which influence it are vegetative cover, slope, soil type, rainfall and erosion. To calculate the hydrological condition of range lands different ratings are given to these factors.

In the arid region a dozen of *Cucurbits* have shown remarkable adaptation to survive. Some of them have medicinal value and others can provide seeds which have high content of edible or non-edible industrial oil. The other medicinal plants which have future are *Datura stramonium*, *D. innoria*, *Aloe species*, *Agave*, *Balanites aegyptica*, *Hyoscyamus-mutica*, *Euphorbia resinifera*, *Commiphora mukul*, *Cassia angustipholia*, and *C. acutifolia*.

In the arid areas stubble mulching appreciably increases the yield of *Bajra* crop as the soil blown from the stubble mulching plot is reduced to about one-fourth. Weed control increases the soil moisture availability to the crops and thus increases their yields. Mixture of *Bajra* (*P. typhoides*) + *Guar* (*cluster bean*) in the seed ratio of 50:50 gives the highest returns under the arid environment. The highest response is obtained with fertilizer at levels of 15-20 lb. N. per acre. Although the response is increased by application of phosphate with nitrogen and NPK treatments, the response in *Bajra* crop is not economical. Application of phosphate at 20 lb P_2O_5 level to pulse crops is quite remunerative.

In the Bellary region, in the black cotton soil, the infiltration rate is low. These soils are low in nitrogen and phosphate. The introduction of ley farming appears to improve the structure of the soil and increases the infiltration rate. Optimum spacing of crops conduces to most efficient utilization of the moisture. The response to application of nitrogen and phosphate increases the crop production substantially.

In the arid environment it is necessary to select crops which will suit the moisture status in the growing period during the rainy season. For growing wheat under irrigation, trials have shown that the border strip method is the most suitable one. The optimum length of the border strip is about 200 ft. This has been found particularly suitable in the small grain crops. For distribution of water from small sources clay tiles are very suitable to reduce the water losses in distribution.

The Zebu cattle adapted to the arid regions of India have denser sweat glands and the amount of sweating is appreciably higher when compared with the European cattle of temperate climate. Besides, they have inherently lower basal metabolism and the amount of heat produced in these cattle at high air temperatures is nearly half as much as that produced by cattle of temperate regions. These animals can maintain themselves on native grassland on year-long basis without supplementry feeds when grazed on carrying capacity basis. They largely gain weight during the growing season of the pasture. The average gains in adult animals in "Poor", "Fair" and "Good" range condition class pastures approximate 25·5, 35·5 and 56·7 kg and in growing 1-year-old heifers these average 64·4, 67·9 and 45·4 kg per animal. The gains in body weight of 6-month ram lambs are 10·0 and 11·7 kg respectively in "Poor" and "Fair" range condition pastures. Thus animal production per 100 hectares is nearly double in heifers than in ram lambs irrespective of range condition class. The drinking water of adult cow weighing 272 kg increases from 19·3 litres in January to 41·1 litres per day in June. The requirements of the heifer range from 9·0 to 17·0 litres of water per day in different seasons of the year.

C. PESTS AND THEIR CONTROL

The invasion area of migratory locust extends from north-western Africa to Assam (30 million sq. m.). The general aspect of its ecology is that its existence in the desert is closely dependent on rainfall. The type of vegetation also influences their growth, maturity and rapid increase in population. Temperature is an important factor in locust biology. Under unfavourable conditions locusts scatter and revert to *solitaria* phase. In the critical periods of phase transformation from *solitaria* phase to *gregaria*, 5-eye stripe forms predominate. The knowledge of locust behaviour is a necessary phase for organizing effective control by either suppressing the outbreaks, changing ecological condition conducing to gregarization or control by insecticides. An exhaustive study of natural predators is desirable.

The Indian desert gerbil, *Merriones hurriane* Jerdon, is the dominant mammalian pest of arid zone. The limiting factor to its distribution is soil compactness. The gerbil density is influenced by the occurrence of plant species. Where *Citrullus colocynthis* occurs its density is high. The density decreases in range areas where *C. catharticus* is the dominant grass species. This animal is a prolific breeder and litters throughout the year. Burrows of gerbils provide an optimum microclimate to them. The gerbil and gerboa have acquired burrowing and leaping habits, acute power of vision and sound perception and sandy brown colour by morphological adaptations in their various organs. The gerbil can stay without water for at least sixteen months in captivity, as metabolic water alone suffices for the maintenance of life processes. The gerbil kidney is extremely efficient in excreting a highly concentrated urine which largely preserves body water. A reduction in the total body water level often proves fatal. Short-term water deprivation is often associated with increase in the whole body fat of the gerbil, but prolonged water deprivation depletes the body fat.

D. ECOLOGY OF HUMAN FACTOR

The human geography of the arid region is and has always been dominated by the availability and quality of water and the occurrence of economically exploitable minerals. The human settlements run either along short dry valleys (wadis) or located on pediplain and shallow basins near some deep wells. There are a number of villages on the flood plains of the Luni River. This region is also susceptible to changing economic and social conditions. On this account the Indian desert represents an area of special value for the study of changing bases and processes of human adjustment and readjustment. In arid Rajastan 36·9 per cent of the land is sown every year. Forest area is meagre (1 per cent). The rest is culturable waste or grazing area. The population during the period 1901-61 has increased by 102·8 per cent. Cultivation is the main occupation of 73 per cent earners. Subsistence farming is practised on 10 hectare average holdings. Next to land, livestock constitutes the most important asset of the farmer. There is over-crowding of livestock on the grazing lands, the density of cattle unit per 100 grazing hectare units varying from 225 to 494. Six-tenths of the households are indebted to the extent of Rs 533 per household.

Four groups of nomads consist of trading group, pastoral group, nomads rendering specialized services, and nomads living through alms or acrobatic displays. Nomadism is passing through a critical phase due to development of means of communication, shrinking of grazing resources, extension of area under cultivation, technological changes and so on. They are, therefore, eager to sedentarize. They need facilities for land, housing, water supply, education, medical aid, marketing and credit. *Banjara* group of nomads have already started settling. This process can be expedited. *Gadoliya Lohars*, whose main occupation is blacksmithy, are distributed in Rajasthan, Gujarat, Madhya Pradesh, Punjab and western Uttar Pradesh. They move in lands within circumscribed regions and have strong kinship and social ties. The *Birhor* nomads have their distinct socio-economic life. They are eager to settle in small colonies and have started realizing the advantages of settled life.

The three major areas of agricultural economics are interpretation of the findings of physical-biological scientists, integrating the knowledge by use of economic analytical framework from the physical-biological and the social sciences and carrying out analyses with predominantly economic phenomenon. The specific areas of research which need immediate attention are the study of the input-output coefficients, the study on uncertainty and the study of the institutional arrangements for water and land use rights.

E. MINERAL RESOURCES AND THEIR EXPLOITATION

The presence of exposed marine Tertiary rocks along the fringe of the Jaisalmer desert suggests that this area is quite favourable for oil and gas. The results of the gravity and aeromagnetic survey have indicated that it is the extension of Uch-Mari high trend in India further south-eastward through Kharotar-Bandah. This high trend is flanked by Kishangarh low on the eastern side and Shahgarh low on the western side. The reconnaissance seismic exploration results are encouraging for further exploration. The Rajasthan State has great potentiality for exploitation of a large number of metallic and non-metallic minerals, gypsum and talc resources. The base metal industries now coming up are zinc and copper smelting, mining of flourite for acid and flux production, lignite fuel and use in fertilizer industry in fertilizer plants, augmented cement production where limestone and low-grade gypsum deposits exist, and manufacture of pig iron. Building stones including variety of marbles, white and red sandstones, flaggy limestones as well as slates, phyllites, etc., account for 65-70 per cent of the total value of mineral output. The process for the manufacture of white cement and bleaching earths has been standardized from gypsum, limestone, felspar and fuller's earth. Potassium sulphate is obtained as byproduct in the manufacture of white cement.

The waste bitterns from the manufacture of common salt from the brines of salt can yield 25,000 tons of sodium sulphate. The sodium carbonate can be recovered by carbonating the chilled mother liquor. Similarly, sodium carbonate can be produced by reacting the salt bittern with gypsum which is more economical. The salt industry itself requires modernization by complete utilization of brine and the realignment of salt works, removal and control of algae, mechanization of operations and so on.

F. SOLAR ENERGY, WIND POWER AND FUEL ENERGY

The energy income is least in winter and highest in hot weather period. The total energy available in Rajasthan during the year is equivalent of 319 million kW or 428 million h.p.

With the existing condition of development of techniques and under best circumstances the cost of saline water conversion is about 4-5 times the cost of fresh water. There is immense possibility of improving the economics of production of converted water by diverting the comparatively more concentrated brine at 10°Bé or more to nearby salt works for further processing and recovering other byproducts like heavy water. Comparatively more abundant radiation, cheap labour, and ready availability of the materials of construction are factors conducive to the development of solar still technique for desalination of brackish waters. For large-scale desalination 2500 sq. ft glass-covered, deep basin still and 2500 sq. ft distiller employing polyester film of Mylar are under trial and show promise. A desalination kit based upon silver salt of an indigenous polysterene cation exchanger has been developed. The electrodialysis method in combination with ion exchange column method seems to be highly promising for purification of brackish waters.

Room heating equipment consisting of flat plate solar collector, flat metallic tank for heated water placed at a higher level than solar collector and water circulation system has been developed. The circulation of water through the solar collector is accomplished automatically by thermo-siphon action. The size of room heated in Ladakh area where room ambient temperature is 3°C is 12 ft×9 ft×8 ft. The temperature rise was about 12-15°C. The overall efficiency of the system is about 20 per cent.

A solar cooker consisting of a concentrator of plane glass mirrors and thermically insulated cooking oven has been developed to prepare a dish for 10-12 persons in about an hour. The cooker is neither affected by low ambient temperature nor by wind velocity.

The WP-2 type of water pumping windmill has been developed for regions of low and moderate wind speeds. It gives optimum output in the range 12-18 km p.h. and pumps about 15,000 gallons of water per day through a height of 10 metres in summer months.

Wind electric-generators in the range of 2-5 kW yield the maximum output and are comparatively economical in relation to the wind regime in Rajasthan.

DISCUSSIONS

(a) The wild species of the plant should be studied from the aspect of water deficiency and their adoption to arid environment.

(b) The germination of the cultivated and the wild species of plants require extensive studies as germination and establishment of seedlings offer considerable difficulties under conditions of drought.

(c) The plants with early maturity and high relative rate of growth should be preferred in the arid zone conditions.

(d) The uptake of nutrients under low soil moisture condition is an essential necessity in the arid areas. The techniques for the uptake of the nutrients under such conditions should be developed for cultivated plants.

(e) The establishment of tree species requires special techniques under dry conditions. The regeneration being very small initially, the tree seedlings require special attention.

(f) The regeneration of the grasses in the range lands coupled with livestock studies should be taken up on extended scale to upgrade the deteriorated grasslands in the arid and semi-arid lands. The introduction of pasture species from homo-climatic regions for adaptation under the arid environment of India was specially stressed.

(g) The ecological investigations in arid lands of plant communities and animals should be intensified as the information on these subjects is very fragmentary. The ecology of wild animals which cause imbalance and great stress on vegetation should be studied in a more comprehensive manner than hitherto. It should not merely be restricted to the study of gerbil, but it should be extended to other wild fauna. Investigations on the biology of insect pests and their control should also receive special attention.

(h) The integrated surveys of natural resources should be taken up on a comprehensive basis in both arid and semi-arid zones. In the initial stages reconnaissance surveys should be conducted and thereafter the detailed surveys of natural resources from the aspect of utilization should be taken up in cooperation with State and other agencies. This will provide an inventory of the resources of land, soils, water, vegetation, livestock, etc., and indicate the problems of people in the various regions.

(i) The basic problems of arid lands are: (1) atmosphere-soil-plant-water-energy relationship studies; (2) soil fertility as influenced by microbiological activity, uptake of nutrients from the soil and its rapid synthesis in the plants; (3) saline water and its use in production of crops and selection of species of the legumes with rhizobium flora which will tolerate high temperature and salinity; (4) climatic adaptation of species of plants and domesticated animals; (5) investigations on drought intensity index for plants and animals.

(j) The ecology of human factor should be studied from the aspect of production from the land and the animals. The factor of nomadism should be investigated in all nomadic groups with a view to sedentarizing them.

(k) The geography of desert presents a complex problem which consists of the interrelationship of water to population, the utilization of grazing resources, the water needs for irrigation, domestic and livestock consumption and development of industries to meet the requirements of surplus population.

(l) The hydrological survey should be further intensified. It should include studies on the determination of ground water, water-bearing rock formations and water quality.

(m) The industrial resources of the arid zone consist of gypsum, limestone, base metals, lignite, salt, sandstones and medicinal plants. There are several small-scale industries which can be developed as by-product industries based upon these raw materials. Research should be conducted to set up such industries.

(n) There is a large scope for utilization of solar energy and wind power for desalination of brackish water and generation of electricity.

(o) There is need to conduct investigations on organic compounds to control evaporation of water from soil and water surfaces.

EVENING LECTURES

Father H. Santapau delivered a lecture on vegetation of Saurastra and the need for undertaking extensive botanical surveys from the aspect of selecting useful species of plants for medicinal purpose and for forage.

Mr C. S. Christian in his lecture emphasized the need for recognizing that availability of water puts a limit to the production capacity of the arid and semi-arid lands. Besides, there is need to determine potential of various factors which can raise the efficiency of the available water potential in these areas. These factors are crop and pasture species, nutrition of the plants, control of pests and diseases, wind erosion, control of grazing lands to their optimum carrying capacity, selection of animals which can stand stress of aridity and so on.

FIELD TRIPS

Two field trips were arranged. In the first field trip the participants and observers visited the Unit Research Centre, Pali, where research projects in progress were explained to them. They also studied the geomorphology, geology, and vegetation of the area from Jodhpur to Mt Abu. The range of rainfall in this tract is of the order of 40 in. and, therefore, the vegetation changes from scrub to the moist deciduous. On return journey the delegates visited the Development Block, Sumerpur. They were acquainted with the working of the Development Block from the aspect of development of agriculture, animal husbandry, social education, cooperation and so on.

The next field trip was arranged from Jodhpur to Bikaner. The climate of Bikaner is extremely dry. The average rainfall is about 8 in. per annum. On the way the geomorphology of the dunes, the type of the vegetation and the structure of desert villages were studied. At Bikaner a visit was arranged to the shifting sand stabilization project at Udramsar. Besides, the delegates visited the Veterinary College, studied the experiment work on the range management and the afforestation at Beechwal, in the Unit Research Centre, Bikaner. The delegates visited the game sanctuary at Gajner where wild life was studied in its natural habitation.

STEERING COMMITTEE

At the suggestion of the Director of the symposium, the Steering Committee was nominated by the delegates to draft the resolutions. The members of the Steering Committee were as follows:

1. Dr P. C. Raheja (Convener)
2. Mr C. S. Christian
3. Dr S. P. Raychaudhuri
4. Dr G. B. Maxey
5. Dr S. P. Chatterji
6. Dr M. L. Khanna
7. Dr M. L. Roonwal
8. Dr E. Hovmoller
9. Dr A. B. Bose (Secretary)

The Steering Committee prepared a number of resolutions which were presented to the symposium. With some discussion the draft resolutions were approved with some modifications.

RECOMMENDATIONS OF THE SYMPOSIUM

I. The symposium placed on record its thanks to the UNESCO and Ministry of Education for jointly organizing this meeting of scientists from diverse fields. This symposium has focused attention on specific problems of aridity and arid lands in the context of the Indian situation and will stimulate further research and all-round development of these areas.

II. (a) The symposium was impressed with the development of the Institute to the present stage. The various Divisions of the Institute have been established and work initiated in many fields. This has necessarily been limited to certain areas in the development stages of the Institute. The symposium was of the opinion that the stage has been reached when the Institute could conduct an overall appraisal of arid and semi-arid regions throughout India in order to provide a comprehensive and reconnaissance picture of land, water, vegetation, human, animal and land use resources. With such an overall picture the Institute would be in a better position to determine future investigational programme with an appropriate order of priorities.

(b) With regard to land resources it would be desirable to have this information so that the areas suitable for different broad types of productivity could be known and the scope for increasing production in the near future could be assessed. This would help to locate specific problems on the basis of priorities.

(c) Up to the present time the Institute has not developed a regional programme in water resources. In conjunction with and compatible with reconnaissance surveys in other disciplines making up the integrated approach, reconnaissance hydrology and water resource surveys and compilations of existing data should be initiated to yield in a short time a reasonably accurate picture of the arid and semi-arid regions of India. This regional analysis would provide the basis for overall water planning and control and for assessing potential problems such as those which may result from the importation of water in the arid and semi-arid areas not previously irrigated.

(d) The major vegetation resources of these areas are pastures for animal grazing. In many tracts these have been degraded. It is important for the land resource reconnaissance surveys to indicate the areas with different pasture communities and the stages of degradation which have been reached and the local needs for ecological pasture management studies.

(e) The land recource surveys should also indicate the existing forest areas and those which should be conserved for forests and also indicate land types suited to afforestation.

(f) The existing animal populations contain a large proportion of unproductive animals with low levels of production and lower rates of reproduction or survival. It will be important to make a thorough statistical analysis of the population dynamics so that the most significant gaps for improving their efficiency can be defined. These animal studies are essential in view of the present wastage of land resources involved so that the proportion of unproductive animals should be reduced.

(g) The overall picture provided by land reconnaissance survey should give information on the distribution of hnman populations and of different kinds of land use, and permit these to be studied in relation to actual land resources available. It will thereby help to indicate where adjustments are possible to achieve more complete and efficient use of land, water and vegetation resources.

(h) As the information sought by resource surveys will be of direct significance to State authorities in their administration and development activities, the symposium draws attention to the desirability of having them directly associated with the conduct of resource surveys in order that they become acquainted with the kind of information available. Where it is possible for the State Governments themselves to conduct similar integrated natural resource surveys, they should be urged to conduct them in a manner which conforms to the methods of the Institute to make the results from various surveys comparable.

(i) The symposium felt that the use of aerial photos for study of resources was essential. The method of integrated land survey with the aid of aerial photos adopted by the Central Arid Zone Research Institute should be further developed and personnel trained for the purpose so that the State departments too could do the work.

III. (a) With this background of information about regional resources the Institute will be able to make its programme of resource utilization studies in a more effective manner and concentrate its efforts on methods of production which will give both the best short- and long-term benefits.

(b) The symposium recognized the important function the Institute has to perform and realized that this will be possible only if the staff and facilities are expanded, particularly in the establishment of regional stations in the arid and semi-arid regions of the country, as recommended in the original proposals of the UNESCO Adviser.

IV. The symposium stressed the importance of further developing basic research activities at the Institute in a number of fields, specially the complex fields of eco-physiology including atmosphere, plant, soil, water and energy relationship, plant nutrition, and the related soil and geo-chemical studies. In order that this work can be accomplished adequately in the different ecological environments of India the regional stations referred to in the previous recommendation will be essential.

V. The symposium noted the type of maps produced as a result of integrated resource surveys conducted by the Institute and stressed the importance these would have when made on a more extensive scale for the production of various kinds of thematic maps for national planning and development of resources.

VI. The symposium noted and commended the integrated approach to resource surveys and resource utilization adopted by the Institute. It recommended that the integrated approach be intensified with particular reference to potential for irrigation, possibilities of increasing productivity, rehabilitation and development of pastures, improvement of animal production and the study of social and economic limitations and requirements of the areas being surveyed.

VII. The symposium being aware of the limitations to productivity imposed by water scarcity in arid areas recommended studies of methods of efficiently utilizing distributed water and local ground water for irrigation purposes and studies of the most efficient use of rainfall for crop production, pastures, forestry and stock water in the different land types of the regions.

VIII. The symposium was of the view that since the broad problem of arid zone of India was of human ecology, as is evident from the imbalance between man and his environment, the studies on the human factor and of the interaction between man and land should be intensified in relation to various branches of rural sociology, agricultural economics and action research with reference to the introduction of new technologies.

IX. The symposium considering the major role played in the economy of the arid and semi-arid zones by insect pests and by other animal pests, both of which may cause heavy losses, recommends that considerably more research attention should be paid at the Institute and other research organizations to the study of applied zoology of the arid and semi-arid areas particularly with respect to gathering basic information on ecology of insect pests and animals.

X. In view of the fact that one of the major processes of production for human need is the grazing of native vegetation by animals, the symposium stressed the need of adequate research both for management of vegetation and grazing animals in order to achieve optimum returns. This will involve the development of physiological studies on domestic animals including basic studies on nitrogen metabolism and criteria for selection by animal graziers for physiological adaptation.

XI. As water with excessive salinity for human or stock consumption is a problem in arid and semi-arid areas, the symposium urged that the Division for Physical and Chemical Engneering Liaison be set up in this Institute to carefully watch the development and availability of small-scale desalinization equipment and test such equipment in arid conditions.

XII. The symposium heard with interest of energy production from bio-gas plants and recommends that the examination of the possibilities of use of organic wastes in this process are worthy of consideration keeping in view of the availability of organic matter and plant nutrients of soil fertility and recommended that the Institute should collaborate with the Indian Agricultural Research Institute in studying the adaptation of equipment and process for energy production in the arid areas.

XIII. The symposium recognized the inadequate knowledge currently available about a number of interrelated aspects of soil fertility and animal nutrition related to nitrogen including the possibility of introducing legumes, role of micro-flora in association with legumes or free living and the role of organic matter. It is of the opinion that the basic research work of the Institute should give research attention to (i) the possibility and desirability of building up soil organic matter in arid and semi-arid environments, (ii) study the micro-flora of these regions and (iii) the role of rhizobium and the importance of adapted efficient strains for arid and semi-arid regions and saline and alkali tracts.

XIV. The symposium recommends that the World Forestry Congress should be requested to give greater emphasis on afforestation in arid zones and the UNESCO Advisory Committee on Arid Zone Research should be requested to examine the possibilities of holding an international symposium on this subject.

XV. The symposium felt that the following services were directly related to the efficient utilization of the Institute's resources and should be further developed:

(a) Herbarium and systematic botanical studies
(b) Drafting and cartographic studies
(c) Computer's services
(d) Chemical analysis
(e) Recording and data collection services for hydrology, climatology and hydro-meteorology

XVI. The symposium stressed the importance of biometric and statistical services being closely associated with and familiar with concepts of the research work in various specialist disciplines of the Institute and for this reason recommended that the Institute should develop its own statistics and bio-mathematics unit in order to maintain the close and constant liaison.

XVII. As the Institute is concerned specifically with arid and semi-arid regions, the symposium was of the view that the Institute may have an important role to play in the International Hydrological Decade.

XVIII. The symposium observed that because of the limited resources of arid areas it is important that all resources should be developed. Resources other than agricultural resources would include:

(i) Mineral resources
(ii) Native plant species with pharmaceutical properties
(iii) Wind and solar energy
(iv) Tourism and recreation

XIX. The symposium considered it highly desirable that for the benefit of participants and observers and for other research workers, the papers presented at the symposium should be published and the authors should be provided 50 copies of reprints of their paper for distribution purposes by them. According to the normal practice extra copies required by the authors would be made available at normal cost. While the symposium could not specify the number of volumes required it felt that for distribution to different countries and research workers and for retaining a reserve for future research workers, the total number may exceed 3000 copies.

XX. During the course of the discussions it was pointed out that while there has been considerable exchange of plant species between arid regions of the world, this has been mostly of the species from which it is easiest to collect seeds. There remain many species which produce seed infrequently and their seeds are, therefore, difficult to collect. Furthermore, experience has shown that a minor species in one habitat may become a species of major importance when transferred to a different environment. Emphasis was placed on the importance of facilitating the exchange of additional species particularly those that seed rarely and also paying attention to minor species which because of their place in the ecology of their native habitat might be expected to assume an important role elsewhere. The symposium recommended that UNESCO be requested, through the UNESCO Arid Zone Advisory Committee, to examine the possibilities of establishing collectors in several of the important arid regions of the world and the production of seeds of the collected species in a few selected nurseries established by collaborating countries.

XXI. The symposium being impressed with the excellent staff and equipment available at the Central Arid Zone Research Institute, Jodhpur, recommended to the Ministry of Food and Agriculture to start post-graduate training in these subjects in which the Institute has adequate facilities and for which there is need for more trained personnel by arranging for:

(a) Post-graduate course leading to a Diploma
(b) Post-graduate course in association with universities leading to a higher degree.

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HYDROLOGY AND GEOHYDROLOGY

A PROFILE OF PHYSICO-CHEMICAL CHARACTERISTICS OF GROUND WATERS OF BARMER AND JAISALMER DISTRICTS, RAJASTHAN[1]

by

J. C. CHAUDHURI, T. N. BHARGAV AND A. D. PUROHIT

IT IS a characteristic feature of the well waters drawn from the desert that they are generally highly brackish. The degree of brackishness varies from region to region and also within the same locality. Comprehensive analytical data on the ground water of western districts of Rajasthan are not available. A study of the physio-chemical characteristics of ground water of Rajasthan desert was undertaken at the Defence Laboratory, since November 1960. The present paper covers the entire districts of Barmer and Jaisalmer which together constitute an area of about 37,014 sq km. As a result of the systematic survey and analysis so far made, it has now been possible to present a profile on the physico-chemical characteristics of ground water of the two districts.

The analytical data are considered to be of basic nature since such informations are often sought in connection with different types of research, investigations, technical processes involved in the industries concerned, such as demineralization of water, corrosion in vehicles/industrial plants, industrial utilization, sanitary water supply, scale formation, storage and transport, salt intake by drinking (physiological aspects) and irrigation.

EXPERIMENTAL

Sample collection: 289 samples of ground water were collected from Barmer district during the two years, between November 1960 and November 1962, and 264 samples from Jaisalmer district during the period of one year, between January 1963 and January 1964. Barmer district has an area of about 16,093 sq km and Jaisalmer district about 20,921 sq km. Average rate of sampling was 1·80 and 1·26 per 100 sq km for Barmer and Jaisalmer districts respectively. The distribution of wells are, however, not presented in this paper.

In Barmer district water samples were usually collected throughout the year, except during the monsoon season July to September. In Jaisalmer, however, some samples were also collected during the month of August 1965. It may be mentioned that the year 1965 was relatively a drought year, receiving only 151·9 mm of rain during July and August 1963, as compared to 244 mm in 1962 for the same period.

1. Contribution from the Defence Laboratory, Jodhpur.

Constituents and properties: The maximum and minimum values of the various physico-chemical constituents or properties are presented in Table I. The corresponding values for the tap water supplied at Jodhpur and the seawater drawn from the sea near Bombay and analysed at Defence Laboratory are also given.

The physico-chemical examination of these water samples revealed that the waters of Barmer district are generally more brackish than those of Jaisalmer district, and are richer in chlorides, sulphates and bicarbonates. The hardness of water of the two districts is almost alike. The distribution of calcium and magnesium in the two waters is again similar. The carbonate content in Jaisalmer district is generally less than in Barmer district.

The TDS in Barmer district varied between 200 and 26,140 p.p.m., chloride (as NaCl) varied between 44 and 20,602 p.p.m., sulphate (as Na_2SO_4) and bicarbonate (HCO_3) ranged from complete absence to 4825 and 1730 p.p.m. respectively.

In the case of Jaisalmer district TDS varied between 160 and 17,916 p.p.m., chlorides (as NaCl) between 28 and 10,903 p.p.m., sulphates (Na_2SO_4) from complete absence to 2400 and bicarbonate (HCO_3) from 78 to 927 p.p.m.

The cationic and anionic ratio showed variation over wide range, e.g. Ca^{++}/Mg^{++} varied between 0·03 and 76·8 (for Barmer), and 0·02 and 81·6 (for Jaisalmer); Na^+/K^+ varied between 0·2 and 400 (for Barmer), and 0·4 and 450 (for Jaisalmer); Cl'/SO_4'' varied between 0·06 and 93·4 (for Barmer), and 0·07 and 60 (for Jaisalmer).

It may be observed that 41·2 per cent of ground waters contain TDS within 2000 p.p.m. and 73·7 per cent within 5000 p.p.m. for Barmer. For Jaisalmer, 55·7 per cent of ground waters contain TDS within 2000 p.p.m. and 85·1 per cent within 5000 p.p.m.

Higher the concentration of TDS in ground water, less is its percentage frequency. Beyond 10,000 p.p.m., the percentage frequency of TDS in any group lies below 2·5 per cent either for Barmer or for Jaisalmer district. 38·8 per cent of ground water samples contain chloride as NaCl within 1000 p.p.m., 60·6 per cent within 3000 p.p.m. and 84·8 per cent within 5000 p.p.m. for Barmer district. Jaisalmer district shows that 54·8 per cent of ground water samples contain chloride within 1000 p.p.m., 73·4per cent within 2000 p.p.m. and 94·5 per cent within 5000 p.p.m. In case of Jaisalmer, percentage

TABLE 1: Maximum and minimum values of physico-chemical characteristics of ground waters from Barmer and Jaisalmer districts, Rajasthan

Sl. No.		*Barmer district* Max.	*Barmer district* Min.	*Jaisalmer district* Max.	*Jaisalmer district* Min.	Sea-water (Bombay)	Tap water (Jodhpur)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Depth (metres)	105	2·2	130	3·0	—	—
2	*p*H	8·68	7·12	8·94	7·0	—	—
3	Conductivity in micromhos/cm at 25°C	34,200	51·0	21,700	339	—	18
4	TDS (p.p.m.)	26,140	200	17,916	160	41,408	236
5	Hardness as $CaCO_3$ p.p.m.						
	i) Total	9,946	18·5	4,358	72·9	6,776	91·4
	(i) Temporary	2,196	nil	4,215	9·3	45	64·1
	iii) Permanent	2,896	9·2	4,032	4·3	6,731	27·3
6	Cl' (p.p.m.)	12,361	26	6,542	17	20,068	54·7
7	Cl' (as NaCl)	20,602	44	10,908	28	33,112	91·2
8	SO_4'' (p.p.m.)	3,349	nil	1,600	nil	2,827	16·2
9	SO_4'' (as Na_2SO_4)	4,785	nil	2,400	nil	4,155	26·4
10	HCO_3' (p.p.m.)	1,730	nil	927	78	—	—
11	Ca^{++} (p.p.m.)	804	5·0	617	6·0	400	28·0
12	Mg^{++} (p.p.m.)	467	3·2	616	1·1	1,401	1·63
13	SiO_2 (p.p.m.)	89·6	nil	36·0	nil	—	—
14	Ratio Ca^{++}/Mg^{++}	76·8	0·03	81·6	0·02	1·7	17·1
15	Ratio Na^+/K^+	400	0·2	450	0·4	—	7·9
16	Ratio Cl'/SO_4''	93·4	0·06	60·0	0·07	7·1	3·3

frequency is usually much less than 1·5 per cent (maximum value) in any group higher than 5000 p.p.m. chloride.

With regard to sulphate, 87·9 per cent are found within 1000 p.p.m. and 96·9 per cent within 2000 p.p.m. for Barmer district. In Jaisalmer district, 93·0 per cent of sulphates are found within 1000 p.p.m. and 97·8 per cent within 2000 p.p.m.

Analysis of the calcium values for Barmer district shows that 68·8 per cent of water contains calcium within 100 p.p.m. and 90·9 per cent within 200 p.p.m. The corresponding values for Jaisalmer were 69·5 and 88·1 per cent respectively. Magnesium occurs in 70·3 per cent within 100 p.p.m. and 90·3 per cent within 200 p.p.m. for Barmer district, while Jaisalmer shows 73·7 and 91·9 per cent for corresponding limits. Calcium and magnesium contents are thus similar and comparable for both the districts.

Potassium has been found to occur in 76 per cent for range within 50 p.p.m., 89·3 per cent within 100 p.p.m. and 93·5 per cent within 150 p.p.m. The corresponding values for Jaisalmer are 90, 94 and 98·2 per cent. Potassium content is low in Jaisalmer water.

The bicarbonate (HCO_3) shows peak at 200-300 group range of samples in Barmer and is represented by 28 per cent of samples while the peak for Jaisalmer occurs at 300-400 group range, representing 27·6 per cent of samples. In the range 200-500 p.p.m. of HCO_3, 57·8 per cent of samples are found for Barmer and 66·3 per cent for Jaisalmer.

It was found that 84·4 per cent of samples contain CO_3'' within 40 p.p.m. in Barmer, the corresponding values for Jaisalmer being 99·3 per cent.

The hardness, permanent or total, was similar for both the districts. With regard to permanent hardness 74·8 per cent of samples were within 500 p.p.m. and 88·7 per cent within 1000 p.p.m. for Barmer, the corresponding values being 79·0 and 88·8 per cent for Jaisalmer.

Temporary hardness within 500 p.p.m. was represented by 94·0 and 95·5 per cent for Barmer and Jaisalmer samples respectively.

The total hardness for Barmer was shown by 57·2 per cent samples up to 55 p.p.m. and 64·4 per cent within 1000 p.p.m., the corresponding values for Jaisalmer being 63·3 and 32·5 per cent.

The ground waters have high hardness. From the potability point of view, water containing 121-180 p.p.m. may be considered as hard and beyond 180 p.p.m. as very hard.

Boron in Jaisalmer district has been found to vary from 0·3 to 8·3 p.p.m. Of the 91 samples, 32 contained boron within 1 p.p.m., 37 between 1 and 2 p.p.m., 16 between 2 and 3 p.p.m., 2 between 3 and 4 p.p.m. and 4 samples between 4 and 5 p.p.m. On percentage basis 93·5 per cent of the samples contain boron between 0·3 and 3 p.p.m.

DEPTH

Highest well depths have been observed in Jaisalmer where 0·8 per cent of well water samples in the range of 120-130 m and 1·5 per cent in the range of 110-130 m depth were found. The Barmer well waters were, however, all within 110 m depth, out of which 64·3 per cent of the samples occur within

40 m depth, 29·8 per cent within 40-80 m and 5·9 per cent within 80-110 m. The corresponding values for Jaisalmer are 60·2, 29·9 and 8·4 per cent.

POTABILITY

The U.S. Public Health Service Drinking Water Standards of 1946 gives the following limits of the constituents in connection with the potability of water.

Constituent	*Limit (p.p.m.)*
TDS	500
Cl′	250
SO_4''	250
Mg^{++}	125

Considering the above limits, 4 per cent of ground water samples from Barmer district and 20·8 per cent of the samples from Jaisalmer district may be taken as potable. These limits are, however, not rigid. The data on the chemical analysis of Public Supplies of 100 largest cities of the United States made during 1962 show that even the USA water supply is made much beyond the specification limit, although the percentage of such greatly deviating supplies is very small. As an example, supplies have been made in USA having the concentration, in p.p.m., of silica 72, iron 1·3, sulphate 572, chloride 540, TDS 1580, hardness as $CaCO_3$ 738, conductivity in µmhos at 25°C 1660 and *p*H 10·5. Nordoll has reported that the U.S. Municipal Water Supply SO_4'' content is as high as 726 p.p.m.

Assuming that the following extended limit of constituents may be safely taken as potability limits,

Constituent	*Extended limit (p.p.m.)*
TDS	1600
Cl′	600
SO_4''	800

in scarcity areas of Rajasthan, in respect of TDS, Cl′ and SO_4'', the percentage potability of samples will naturally inrease and it will be 31·5 and 47·8 per cent for Barmer and Jaisalmer respectively.

No sample has, however, shown magnesium content greater than 125 p.p.m. within the extended limit considered above.

CONCLUSION

Ground water is vital to the life and economy of the western parts of Rajasthan. Record of its composition and its changes through years can form useful and valuable data. Such long-term studies may, however, be also undertaken and other agencies connected with the hydrogeological and geo-chemical studies of the arid zone in the country.

ACKNOWLEDGEMENT

Thanks are due to Dr V. Ranganathan, Deputy Chief Scientist, R & D Organization, Ministry of Defence, and Dr H. Nath, Director, Defence Laboratory, Jodhpur, for their keen interest in these studies and for permission to present this paper.

DISCUSSION

R. C. Mondal: Has Sri Chaudhuri taken into consideration various seasonal variations ?

J. C. Chaudhuri: The water samples were collected during January-June, July-September and October-December periods. Due to inaccessibility, the water samples could not be collected immediately before and after monsoon. The data have been analysed without reference to various seasons. For further studies this point has been taken into consideration.

P. G. Adyalkar: What were the geographical limits of the author's observations ?

J. C. Chaudhuri: The administrative boundaries of Barmer and Jaisalmer districts.

B. Ramamoorthy: Have you found the change in composition of ground water with depth ?

J. C. Chaudhuri: We have not found correlation between depth of wells and constituents of water.

PALAEOGEOGRAPHY, SEDIMENTOLOGICAL FRAMEWORK AND GROUND WATER POTENTIALITY OF THE ARID ZONE OF WESTERN INDIA[1]

by

P. G. ADYALKAR[2]

INTRODUCTION

EVER SINCE the holding of the last symposium on the Rajasthan desert by that learned body of the National Institute of Sciences of India in the year 1952, considerable work has been done in both the arid and semi-arid tracts of Western India in the field of geology and ground water. Extensive areas have been mapped in considerable detail and the rich deposits of both metalliferous and non-metalliferous minerals have been brought to light in hitherto unknown or uneconomic areas, earlier known deposits have been proved richer, establishing thereby that Rajasthan in the arid and semi-arid zones of Western India is no longer a dark State; on the contrary, it has come to be recognized as the Second Mineral Belt of India, almost entirely due to the untiring efforts of Indian scientists, both in the public and private sectors. Earlier not much ground water work was done in this region. The available information was restricted to the dug well inventory data in certain isolated pockets. This could not be helped either with limited staff available in those earlier days of pioneering efforts, nor was ground water geology then so deeply entrenched in the country to be recognized in the galaxy of Indian sciences. Large areas have since been covered by systematic well inventory by the budding ground water geologists of the Geological Survey of India. Exploratory Tubewells Organization have also done some inventory within the limits of investigation; but a band of ground water geologists in this Organization of hardly a decade past have been engaged in the collection, compilation and interpretation of deep subsurface data as a result of extensive tubewell exploration in the possible belts of both arid and semi-arid regions of Western India. On the basis of this work it is now possible to project the available data and give a generalized picture of the ground water condition in the arid zone of Western India. This has been attempted in the present paper in addition to presenting a picture of palaeogeographic condition of the past ages in association with the framework of sedimentation. As such information is still in the state of compilation in both the Exploratory Tubewells Organization and the Geological Survey of India, the present paper may very well serve as a forerunner to the series of ground water bulletins to follow in the near future.

The Indian arid zone principally comprises all the area with a rainfall of less than 500 mm; and the western arid zone encompasses vast areas of western Rajasthan, western Gujarat and south-western Punjab (I), together covering an extensive area of over 2,00,000 sq km of Western India. It lies roughly to the west of Rajkot (22°18′: 70°49′; 41-J/15)- Alwar (27°35′: 76°36′; 54-A/10)-Ferozepur (30°57′: 74°37′; 44-J/9) line to the west of the Aravalli axis and south-west of the so-called Delhi-Lyallpur (P) (31°25′: 73°04′; 44-E/3) ridge. It includes Bhatinda and Ferozepur districts and parts of Gurgaon, Hissar, Mahendragarh and Rohtak districts of Punjab (I), Barmer, Bikaner, Churu, Ganganagar, Jodhpur, Jaisalmer, Jalor and Nagaur districts and parts of Alwar, Jhunjhunu, Pali and Sikar districts of Rajasthan and Jamnagar and Kutch and parts of Banaskantha, Junagadh, Mehsana, Rajkot and Surendranagar districts of Gujarat. While it extends for about 1100 km in a north-south extension and about 600 km in an east-west stretch, it occupies 1100 km long north-east-south-west strip with a maximum width of 375 km.

PHYSIOGRAPHY

The eastern limit of the west Indian arid zone is marked by the north-east trending Aravalli Range, once a lofty mountain when the Himalaya was still in the making. There are no other mountain ranges worth the name. Occasionally one comes across gently sloping hills of relict type, carved out of the gently rolling sedimentary rocks or Malani volcanics and their equivalent granitic terrain; in the latter case it often forms high hills of most rugged and uneven topography. Hills in Kutch are also of relict type, often dissected by fault planes of regional and local nature. The general slope of the ground is towards west and south-west with a decreasing gradient away from the Aravalli Range.

The only river of some significance is the Luni. It rises in the Aravalli hill range near Ajmer (26°27′: 74°39′; 45-J/11) and after an initial west-south-westerly course towards Barmer (25°46′: 71°23′; 40-O/5) flows south-westwards until it drains into the north-eastern corner of the western Rann of Kutch. The

1. Contribution from the Exploratory Tubewells Organization, New Delhi.
2. Superintending Geologist of the Organization, but now Director, Geological Survey of India.

principal tributaries of the Luni are the Lilri, Raipur Luni, Guhiya, Bandi, Sukri, Jawai and Jojri, none of which is perennial. Another river of less significance is the Banas, which after originating in the south-western portion of the Aravalli, flows into the Rann of Kutch along with its tributaries. In Kutch there are no rivers of any significance except for a few ephemeral streams. The river system of the arid tract of Punjab (I) had a long chequered history of great interest to both the geographers and the archaeologists alike. The Beas after meetingt he Sutlej now forms the north-western limit of the Indian arid tract. This was not the position in the past. The rivers of the region drained south-westerly. While some of them, particularly the western ones, even then (say, about 2000 B.C.) formed part of the Indus river system, some others possibly drained directly into the Arabian Sea after watering the persent-day arid tract of chronic water-scarcity areas. The river Ghaggar once flowed through the northern part of Ganganagar district and drained into the Arabian Sea and later joined the Indus; but now it is dry except during the rains. In 1897 weir was constructed on the river near Otu (29°30′: 74°53′; 44-K/15), about 13 km west of Sirsa (29°32′: 75°01′; 44-O/2), and with that the flood menace was completely wiped out until very recently when the entire area got flooded with the release of extra spill over water at Otu. The river Ghaggar of prehistory of 1000 B.C. was known by its more prominent tributary of Saraswati; near Suratgarh (29°20′: 73°38′; 44-G/15), it is joined by the river Drishadvati, and beyond Anupgarh (29°11′: 73°12′; 44-G/4) it enters the Pakistanese territory. North of Hanumangarh (29°35′: 74°20′; 44-K/6) is noticed a dry bed of the old Sutlej river before it shifted further northwards to occupy its present course. The section of the old Sutlej river beyond Hanumangarh is called the Naiwal. Almost entire Ganganagar district with Ghaggar and its tributaries and the ancient townships of Rangmahal (29°21′: 73°58′; 44-G/15), Kalibanga (29°28′: 74°08′; 44-K/3) and Pilibanga (29°27′: 74° 06′; 44-K/3) was the cradle of rich prehistoric culture, and once formed part of the extensive and fertile Indo-Gangetic plain of hardly three millennia past.

Due to lack of adequate river and drainage system there are no well-defined channels for the discharge of water in the entire region. However, during monsoon even with meagre rainfall the flowing water has a tendency to accumulate in innumerable fresh-water tanks and reservoirs, which cater the local need of water for at least some months after the monsoon. There are thus no real natural fresh ground water reservoirs *sensu stricto* on the surface. On the contrary, three salt water lakes of Sambhar, Pachbhadra and Didwana are well known in addition to a lot more of less significance. It is interesting to note that all of these are located in the local depressions and the salinity diminishes in them gradually away from the main salt basin. In addition to high chloride content in all of them, while the lake Sambhar abounds only in chlorides (with some sodium sulphate), Pachbhadra and Didwana have in them magnesium sulphate and sodium sulphate respectively as the important constituents, a feature significant of its own type and needs deep meditation and elaborate thinking by the chemists, hydrologists and the stratigraphers alike. Kutch is surrounded towards north, east and south by an extensive almost level marshy land, separating it from the mainland of the subcontinent, and known popularly as the Rann of Kutch. Ranns are also reported from north of Jaisalmer.

CLIMATE AND RAINFALL

The entire west Indian arid zone forms a typical belt of low rainfall, decreasing rapidly from the Aravalli Range towards west and west-north-west. Rainfall is precipitated partly from the south-west monsoon by the diversion of monsoonic winds towards the area of low pressure in West Pakistan, and partly by the diversion of winds through the Gangetic valley. With parallel alignment of the Aravalli the moisture-laden winds meet with no obstruction, accounting thereby for poor rainfall. There is no fixed rainy season in the region; but July and August are the principal rainy months, and there is generally some rain in the months of June and/or September. Winter rains are rare. Number of rainy days also diminish rapidly towards west and west-north-west from 25 to mere 5, the latter towards west of Jaisalmer. The pattern on rainfall is as shown in the table on page 6.

From this it is quite evident that the rainfall in the area is quite erratic with maxima and minima not keeping pace with the average. While the maximum rainfall generally exceeds twice the average, the minimum is generally less than half the average. It has been noticed that there is in general a tendency for negative deviation. The present arid region has generally a cycle of 11-15 years and that at present the region is possibly undergoing a wet cycle. Pramanik (1952) has further critically examined the values of annual precipitation and 5- and 10-consecutive-year means for 29 stations, and come to the conclusion that there is no tendency for rainfall to decrease over the area, which is a very happy and optimistic sign.

Another characteristic feature of arid zone climate is the extremes of temperature with very cold winters and very hot summers. In winter the temperature falls at many places below freezing point and frost occurs, while the summer heat is very intense and scorching. The desertic tract in Western India is the hottest extensive region of India. With dryness of atmosphere, extensive sandy soil and want of vegetative cover, the diurnal change of temperature is sudden, very large and trying. December to February constitute the cold season, and January is the coldest month. During this month the mean maximum temperature ranges from 20°C (Sri Ganganagar)

Rain gauge station	*Rainfall in mm*			*Occasions of large excess in years*	*Occasions of large deficit in years*	*Coefficient of variation*	*No. of years of data*
	Average	*Highest*	*Lowest*				
Hissar	415	1,049	140	8	6	42	89
Suratgarh	230	531	81	8	3	44	44
Bikaner	300	770	28	11	8	48	73
Lathi	146	297	20	7	11	49	20
Ramgarh	164	1,098	127	18	40	112	58
Miajlar	169	701	nil	17	23	91	21
Sankra	207	549	62	8	11	62	19
Jaisalmer	176	579	nil	13	12	65	68
Phalodi	227	653	30	13	12	54	66
Jodhpur	361	1,176	25	11	8	53	76
Sardarshahar	279	1,085	71	3	10	57	44
Nagaur	316	805	64	5	6	45	62
Barmer	285	897	28	10	15	60	67
Jaipur	620	1,405	119	4	4	39	80
Ajmer	483	1,120	150	—	—	45	52
Udaipur	644	1,222	251	5	2	32	74
Bhuj	339	1,065	3	—	—	59	30
Sirohi	565	1,318	145	9	8	47	65
Palanpur	758	1,623	89	11	7	44	77

to 10°C (Barmer). Temperature starts rising by the middle of March and the hot season prevails from April to June. May is generally the hottest month. The mean maximum temperature in May ranges from 39·4°C (Ajmer) to 42·8°C (Jaisalmer) and the mean minimum from 23·9°C (Sri Ganganagar) to 27·8°C (Bikaner); the highest temperature shot up to 50°C (Sri Ganganagar). With dryness of atmosphere, clear skies and sandy soil, there is rapid radiation of heat from earth soon after sunset with the result that the heat of the day rapidly dies down, and the minimum temperature at night is considerably lowered down with cool nights. Occasional dust-storm causes sudden fall in temperature, and some of the thunderstorms of the season culminate in rain, which brings welcome relief from the scorching heat. By October the climate is very good with the withdrawal of monsoon until the cold commences in the month of December.

The relative humidity is minimum during the hot weather months and maximum in monsoon months of July, August and September. Thus it is lowest in April and highest in August. Vapour pressure values, on the contrary, are lowest during the cold season and highest during monsoon months. Low relative humidity during summer months is attributable to the high dry bulb temperature. Wet bulb temperature rarely exceeds 27°C. This means that the Indian arid tract cannot, in general, be considered uncomfortable for hard work during the major part of the year. It is interesting to note that the diurnal variation in relative humidity is nearly the same throughout the year, a feature not generally found in other parts of India.

Winds of higher speed from the south-west or west are more frequent throughout the year in the arid zone; in June they are strongest, and in December lightest. During winter north-westerly and northerly winds are more frequent than those from the conventional directions. Hot and dust-raising winds are experienced in the desertic tract throughout the year. During monsoon rainfall is often associated with easterly winds. After monsoon winds are lighter and highly variable. The maximum velocity of wind in the arid tract is of the order of 135 km per hour, except in short-lived and highly localized gales and severe thunderstorms.

Thunderstorms occur during the period of May to September, particularly in June and July. They are more frequent in the eastern part than in the western. While Jaipur has 46 days of thunder and Ajmer 29, Jodhpur has 23 days and Barmer-Bikaner each has only 10 such days. Contrary to this, the frequency of dust-storm decreases towards east in the area of higher rainfall. Dust-storms are more frequent in the month of June, and a little less in May and continue up to September. While Sri Ganganagar has 27 days of dust-storm in a year and Bikaner 18, Jodhpur has only 8, Jaipur 6 and Ajmer only 3 days of such dust-storm. Unlike dust-storms hail-storms are not common in the arid zone. A few foggy days are reported during winter months, but in general they are far too uncommon.

GEOLOGY

For systematic appraisal of the ground water potential of the west Indian arid zone it is essential to probe into its geological history. The geological succession can be stated as under:

Age (in million years)	*Era*	*Period*	*Name of the formation*	*Lithology*
(1)	(2)	(3)	(4)	(5)
	Quaternary	Recent	Sand and alluvium	Wind-blown sands, *kankar*, sodium salts and gypsum
		Pleistocene	Older alluvium	Fluviatile deposits and alluvia
	1			
Birth of the Himalaya; and breaking up of the Gondwanaland	Tertiary	Mio-Pliocene	Manchhar Series	Sandstones and clays
		Oligo-Miocene	Gaj Series (Dwarka beds) Nari Series	Limestones with interbedded shales and marls and sandy foraminiferal limestones
		Eocene	Kirthar Series	Limestones, richly fossiliferous
			Laki Series	Nummulitic limestone, fuller's earth and bentonite with carbonaceous matter and lignite
	60	Unconformity		
120		Cretaceo-Eocene	Deccan trap	Basaltic lavas with intertrappean beds
		Cretaceous	Abur beds (Umia beds)	Fossiliferous limestones and shales; sandstones, conglomerates and shales with plant beds at the top
	Mesozoic	Upper Jurassic	Parihar sandstones (Upper Katrols)	Quartzites and felspathic and ferruginous sandstones, unfossiliferous
			Bedesar sandstones (Middle Katrols)	Grits and ferruginous sandstones with shale bands
			Unconformity	
			Baisakhi formation (Lower Katrols)	Shales and ferruginous sandstones
			Unconformity	
		Middle Jurassic	Jaisalmer limestone (Middle to Upper Chari)	Fossiliferous limestone with intercalated sandstones
		Lower to Middle Jurassic	Lathi sandstone (Lower Chari to Patcham)	Coarse sandstones, ferruginous with fossil wood
	170		Unconformity	
240	Palaeozoic	Permo-Carboniferous	Bap and Pokaran beds	Boulder beds containing boulders of granite and other rocks
			Unconformity	
	Late pre-Cambrian to Early Palaeozoic	Upper Vindhyan	Vindhyan sandstones	Vindhyan sandstones, limestones and shales
			Unconformity	
		Lower Vindhyan	Malani Series	Acid volcanic flows and tuffs and Jalore and Siwana granites
	500		Unconformity	
610-725	Algonkian or Proterozoic	Delhi System	Ajabgarh Series	Phyllites, calc-slates and calc-gneisses
			(Alwar Series	Quartzites, grits and conglomerates with intrusives of Erinpura granite from the core of the Aravalli Range
	1000		Unconformity	
	Archaean (Middle pre-Cambrian)	Raialo Series		Limestones, calcite or dolomitic, with basalt sandstones, quartzites and conglomerates
			Unconformity	
		Aravalli System		Phyllites, slates, limestones and schists
			Unconformity	
	(Lower pre-Cambrian)	Banded gneissic complex		Granites and gneisses forming the oldest basement
	1500			

Rocks of the Aravalli System occupying a great thickness occur in southern Alwar and continue right up to the south-western plains of Gujarat with occasional irregular interruptions. In Mewar and Ajmer area they cover extensive tracts with interruptions of the rocks of gneissic complex. The basal horizon is covered by arkose, grits and quartzites with conglomerate bands resting directly on the Bundelkhand gneisses or the banded geneissic complex; these are followed by the phyllites, mica-schists and composite gneisses, the latter formed by the injection of granitic material into the schists; lenticles of cherty limestone band are also strewn in Bundi and eastern Mewar. Unmetamorphosed shales of brown and olive colour in eastern Mewar, and slates and impure limestones in western Mewar, together with the Ranthambhor quartzites occurring towards the east of the Aravalli Range constitute the youngest member of the system. While in southern Alwar they occupy varieties of schists and limestones occurring in the depressions, in the Pali region they are characterized by greenish grey and dull purple slates with steeper dips and occurring as buttes and ridges parallel to the Aravalli Range. According to Heron (1936, p. 24) the rocks of the Aravalli System were deposited on the slightly uneven platform of the eroded basement complex fo banded gneissic type, and deposited by mature streams in a rather uniformly dry and arid climatic condition.

Resting unconformably on the softer and weathered Aravallis, or directly on the older basement complex of banded gneissic type, are a thick series of sediments forming one of the finest marbles in India adding to the grandeur and beauty of the famous Taj. These are about 600 m in thickness comprising limestones with basal conglomerates, sandstones and quartzites. The typical Raialo marble of Mewar is medium-grained, saccharoidal and of dolomitic composition; but the famous Makrana marble of Jodhpur is of calcite type, possibly injected by the thin veinlets of pegmatites and epidiorites. The Raialo basin of sedimentation forms the central part of the great and more extensive geosyncline in which were later deposited the rocks of the Delhi System, and in respect of time interval belongs to the Great Eparchaean interval of Indian geology (Pascoe, 1950, pp. 345, 384).

With further unconformable relations are found the rocks of the Delhi System extending from Delhi in the north-east to Idar (23°51′: 73°01′: 46-E/1) in the south-west with best development in the main Rajasthan synclinorium of Ajmer and western Mewar. The rocks comprise quartzite, arkose, grits and conglomerates of the older Alwar Series followed by a set of younger rocks comprising phyllites, biotite-schists, calc-schists, biotite limestones and younger phyllites. The older rocks of the Alwar Series occasionally rest directly on the banded gneissic complex. In Alwar area Kushalgarh limestones and hornstone breccia also appear in the Lower Delhis, while they are absent further south. The rocks of the Delhi System are presumably deposited in the Aravalli geosynclinal basin after the folding and erosion of the Raialos and further deepening of the basin. Torrential stream deposits in the form of conglomerates were laid down on the fringes, followed by vast quantities of medium and coarse sands and impure calcareous sediments, unlike their equivalents in the Cuddapahs and elsewhere. The Delhis are invaded extensively by large bodies of granites and pegmatites of the Erinpura suite, resulting in the metamorphism of the Delhis and the pre-Delhi sediments with maximum intensity in the core, and decreasing outwards (Heron, 1935). From the age determination so far carried out it may be mentioned that the Aravallis are not the oldest mountains of India. On the contrary, it is younger than the great Satpura and several others, although it once formed the great mountain range in the northern Gondwanaland, extending from the southern Tethys to the Laccadives and Madagascar in the south-west, the granite outcrop of Nagar-Parkar (25°16′: 71°42′; 40-O/11) north of the Rann of Kutch being the visible western outpost of the great range.

Malani Series forms a group of acid igneous rocks in the form of volcanic flows and tuffs together with their plutonic and hypabyssal equivalents in the form of Jalore and Siwana granites. Malani rhyolites are of acidic type and embrace felsites, devitrified lavas and glassy rhyolites intercalated with acid tuffs and pyroclastic materials. Flow structure is very clearly and significantly seen. The Siwana granite contains quartz in abundance, pink or white felspar and hornblende, but no mica. The Jalor granite contains all these minerals and biotite with or without muscovite, and biotite is the predominating ferromagnesian mineral. Heron (1932, p. 469) has recognized two varieties of granite, the pink and the grey ones; and from its characteristic nature he considered the pink variety as intrusive into the grey one. The difference in colour is due to the predominance of pink orthoclase felspar, less plagioclase and absence of ferromagnesian minerals other than biotite. From their outcrops in the Pali region and elsewhere Taylor *et al.* (1955) have inferred that they have invaded the Aravalli slates and the Delhis in a batholithic manner with volcanic activity following the plutonic emplacement. They are thus intrusive into the Delhis and are later than the Erinpura granites; and on it are deposited the Vindhyan sediments of trans-Aravalli region with marked unconformity. They are, therefore, post-Delhi in age, and assigned a Lower Vindhyan horizon.

At the end of the volcanic activity there was a period of quiescence in Late Vindhyan times with the establishment of two (or possibly one continuous in the earlier times) arcuate sedimentation basins in which were laid the deposits forming the Vindhyan System of the trans-Aravalli region. Thes etwo basins converge near Jodhpur (26°18′: 73°02′; 45-F/3). The lower sandstone member of red to fawn colour with a basal conglomerate band often rests unconformably on the steeply dipping Aravalli slates. They are coarse-textured with occasional gritty bands and profusely current-bedded with abundance of ripple marks of varied nature. The sandstone member is succeeded upwards by limestones, often cherty in nature due to leaching away of the calcareous material. The limestones are generally poorly bedded, hard, fine-grained, non-crystalline and of dark grey colour; and chert occurs in them in discontinuous stringers, lenses and irregular patches. East of Bilara (26°10′: 73°42′; 45-F/12) dark grey bituminous limestone crops out, which emits fetid odour when freshly chipped, and on distillation yields small quantity of oil and dirty smelling inflammable gas. In contrast with the sandstone member bedding attitude is not clearly discernible, but they have conformable relations and both have a general northerly strike with a gentle easterly dip of hardly 5-10°. The thickness of the formation in this region is reported to be only 90 m as against 4575 m in the cis-Aravalli region, although the report from the borehole on the outskirts of Bikaner (28°01′: 73°18′; 44-H/8) has registered a thickness of 535 m. The lofty Aravalli mountain had already come into existence before the deposition of the Vindhyans. With the association of the rich gypsum beds in Nagaur area it is inferred that the deposition of the Upper Vindhyans must have taken place under continental and arid and semi-arid conditions unlike that in the cis-Aravalli region where it is marine. From the overlying Gondwanas in the region they have been assigned an age between Late pre-Cambrian and Early Palaeozoic.

In the vicinity of Bap (27°23′: 72°22′; 45-A/7) is an irregular exposure of boulder bed, extending for over 40 km in a north-east-south-west direction, and in all probability equivalent to the Talchirs, representing thereby evidences of Permo-Carboniferous glaciation in the trans-Aravalli region. The Bap bed typically consists of sub-rounded to rounded pebbles, boulders and cobbles of Malanis, calcareous suite of Vindhyans and the Aravallis with abundant evidences of striations, and embedded in a matrix of marl. A boulder bed of smaller magnitude is also reported to the east of Pokaran (26°55′: 71°55′; 40-N/13). It is over this land of Bap-Pokaran that the thick sheets of ice had once accumulated, and over which descended the glaciers in their journey towards the Salt Range (P) in the north-west.

Towards west Pokaran beds pass upwards with apparent unconformity into ill-exposed thick series of generally dark red shaly sandstones and clays, which have been designated as the Lathi Series, named after its outcrop near Lathi (27°03′: 71°31′; 40-M/12). These sandstones cover an extensive area of over 2000 sq km, and strike in a north-east-south-west direction with a gentle dip of 2-5° towards west-north-west. The sandstones are poorly sorted, medium to coarse-grained with intercalations of clays and carbonaceous shales, and with clear evidence of current bedding; they have a ferruginous tendency towards west, felspathic towards east and south-east and calcareous towards north. In certain sections they very much exceed 500 m in aggregate thickness. They are often associated with a rich assemblage of drifted silicified wood of varying sizes, which according to Blanford is dicotyledonous, suggesting a Triassic to Lower Jurassic or even younger age. Sandstones exposed near Barmer have been correlated with the Lathis from their association of fresh-water fauna and dicotyledonous flora.

Jaisalmer Series comprising generally thick bands of compact, chrome-yellow limestones, interstratified with gray, brown and blackish sandstones containing some conglomerates are exposed close to the township of Jaisalmer, where they form conspicuous scarps. The rock formations of the series overlap the Lathis. The series is typically marked by a rich assemblage of bivalve fauna, which according to Sahni and Bhatnagar (1958) have a tendency to embrace at least Middle to Upper Chari and the Kantkot Stage of Katrol Series of Kutch.

Further north-west of Jaisalmer Series are exposed a younger group of rocks extending from Sri Mohangarh (27°18′: 71°14′; 40-M/3) in the north-east to 16 km west of Jaisalmer (26°54′: 70°55′; 40-J/13) in the south-west; these have of late come to be known as ' Baisakhi Series ' after Baisakhi (27°02′: 70°54′; 40-I/16). The basal horizon comprises conglomerate with sub-rounded to rounded pebbles and boulders of Jaisalmer limestones and sandstones. This is succeeded by soft felspathic, gypsiferous grey sandstones passing into variegated shales, dark siltstones and yellow and pink micaceous sandstones. On the basis of the exploratory data obtained at Bhadasar, the thickness of the Baisakhis has been estimated at 235 m. The Baisakhis are also rich in fossil fauna, and bear unconformable relation to the limestones of Jaisalmer Series.

With further unconformable relations overlapping the Baisakhis are a group of coarse sandstones and grits, called ' Bedesar sandstones ', forming a set of parallel ridges, striking N30°E to N40°E, and thereby being almost parallel to the outcrop of the Baisakhis with an apparent width of 3-8 km. The sandstones are medium to coarse-grained, gritty, ferruginous, hard and compact. The Bedesar sandstones with occasional shale bands are fossiliferous containing ammonites and terebratulidae; the fossils have a tendency to form clay iron band nodules. The ammonites have been correlated with the Umia beds of Kutch, and possibly include at least the upper part of the Katrol Series.

Sandstones belonging to the Parihar group conformably overlie the Bedesar formation. Parihars are constituted of coarse to very coarse-grained, friable, felspathic sandstones with grains well rounded, and topped by a set of very compact fine-grained and quartzitic type of sandstones, the latter rising in the form of Parihar hills in and around Pariwar (27°16′: 70°44′; 40-I/11). These formations extend from 3 km north-west of Bhadasar (27°06′: 70°47′; 40-I/16) from their imperfect conformable contact with the Bedesars to right up to Sanu (27°14′: 70°39′; 40-I/12), about 20 km further north-west; thus occupying a thickness of over 150 m with a gentle dip of 5-13° towards north-west to north-north-west. Lithologically Parihar Series is said to very closely resemble the Umia beds of Kutch, but no fossils of any kind have so far been reported.

Above this series comes another, the Abur beds of R. D. Oldham, extending from east of Sam in the south to Habur (27°10′: 70°33′; 40-I/12) in the north, and comprising sandstones, shales and fossiliferous limestones, the last weathering into a dark red colour. In the limestone is noticed a thin fossiliferous band, the 'Aburstone', characteristic of its own type, in which all the fossils with the possible exception of mollusca have been converted into a yellow mass contrasting with the matrix and comparable very closely with the Cretaceous fossil limestone of Tiruchirapalli district of Madras. This band is extensively used for the construction of temple thresholds. The fauna has yet to be fully worked out, but according to Dr Spath it comprises rich assemblage of ammonites with Lower Aptian tendency.

The Eocene formation in Rajasthan, occurring in a crescent-shaped patch unconformably overlapping the Aburs in the west, Parihars in the north-west and Bedesars in the north, is characterized by the presence of white limestone-rich foraminifera, sandy limestones, fuller's earth with occasional clay bands and gypseous pockets. This formation extends from Bandah (21°11′: 70°21′; 40/I-8) through Ramgarh (27°23′: 70°30′ 40-I/7) to Khinyan (27°19′: 70°52′; 40-I/15) and it is possibly in continuation with the Bikaner Eocene patch further east-north-east, the continuous stretch being concealed by the extensive stretches and sand-dunes prevalent in the area. Eocene formation also occurs on either side of the Jaisalmer-Barmer road between Botia (25°58′: 71°21′; 40-O/5) and Barmer, where these are associated with richly fossiliferous bentonites and fuller's earth deposits of Barmer district.

Peninsular India, which was practically devoid of all marine sediments, was in the grip of stupendous marine activities during the Jurassic, Upper Cretaceous and Miocene times, of which the best development has taken place in Kutch and Kathiawar regions of Gujarat. The sedimentation has taken place in a shallow basin extending from Kathiawar, Kutch and Rajasthan right up to the Salt Range (P).; and the thickness of about 2000 m must be due to gradual sinking in the geosynclinal sedimentation basin. In Kutch the Jurassics rest on the pre-Cambrian basement, bordered on the south by the Deccan traps and the Tertiaries and on the north by the Rann. They occupy three anticlinal ridges trending east-west and due to parallel faulting the whole sequence is repeated. While the northern range, 160 km long, is broken up in 4 islands of Patcham, Karrir, Bela and Chorar in the Rann, the middle range, 165 km long, extends from Lakhpat (23°50′: 68°47′; 41-A/15) east-south-eastwards and the southern ridge south of Bhuj (23°16′: 69°40′; 41-E/11), 65 km long, occupies Charwar and Katrol hills. In Dhrangadhra area of Kathiawar also the same succession is repeated. The Jurassic System in the region is divided into four Series, Patcham, Chari, Katrol and Umia from below upwards; and range in age from Bathonian to Neocomian and later, with Aptian and post-Aptian tendency. The topmost horizon of Umia Series has lately been designated as Bhuj Stage comprising fresh-water estuarine deposits of about 500 m in aggregate thickness, and possibly accounts for the fresh-water reservoir in depth in the region.

Surrounding the hard rock area on the north and west are extensive stretches of multitude of sand-dunes overlapping one another, and often obliterating all evidences of local basement or subsequent geology. In the alluvial tract of recent age one often notices an endless chain of sand-dunes extending right up to the horizon.

PALAEOGEOGRAPHY AND FRAMEWORK OF SEDIMENTATION

After studying the geology of western Rajasthan, western Gujarat and southern or south-western Punjab it is interesting to weave the pattern of past geological events to construct the palaeogeography of the Western Indian arid zone. There are not many outcrops of banded gneissic complex in the region, except those of very isolated and localized nature forming the relict of the original shield area.

The west Indian arid zone was, therefore, the westernmost fringe of the Deccan mainland forming the shield area of the Indian sub-continent during the pre-Cambrian times, covered by the banded gneissic complex, which in Bundelkhand area is merged with the Bundelkhand gneisses in its easterly extension. From the paucity of outcrops in the arid zone and scarcity of adequate data on the oldest gneissic basement it is difficult to decipher or delineate accurately the western boundary of the Indian shield area, but from the present outcrops it must have definitely extended at least 60-75 km west of the Aravalli axis. Those were the times when the first sediments were in the making. Naturally the weathering agents were active for the first time in their most violent form; and not much later that once uniform Deccan shield area, including its western fringe, was the scene of somewhat uneven topography, with normal agents of sedimentation active in their normal form. Sedimentation had started right in earnest and as usual initiated with the basal conglomerate band. There were several shallow depressions of local and isolated nature which were the first sedimentation basins. The first set of sediments were very coarse giving rise to arkose, grits and quartzites, suggesting that they were not carried very far from their source rocks. With the first set of sediments once laid the basins became more and more flat and extensive, and with that the provenance differed; the next set of sediments were, therefore, more fine comprising the materials giving rise to phyllites and mica-schists with possibly subsidence keeping pace with the sedimentation. At some places the crust gave way resulting in the injection of the molten granitic material and thereby forming the composite gneisses. The sedimentation culminated with the formation of pure and impure limestone bands strewn haphazardly in western Mewar and southern Alwar. It is, therefore, apt to say according to Heron (1936) that sedimentation had taken place on a somewhat uneven basement under uniformly dry and arid condition. With the silting of the Aravalli basin the entire area was subjected to erosional activity; and on the weathered surface of the Aravallis, and partly on the original uneven basement of the gneissic complex, came into existence the new set of basins of sediments which coincided with the later geosyncline to be in the making to accommodate the rocks of the Delhi System at a later date, and thus very much coinciding with the main axis of the Aravalli. The order of sedimentation was again similar with conglomerate at the base, and sandstones and quartzites following and later giving rise to thick series of pure and impure limestones under more or less similar climatic condition as evident from the thick calcareous beds. The sedimentation of the Raialo group of rocks took place during the great Eparchaean interval and with its deposition came to an end the great epoch of Middle pre-Cambrian; but with such deposition the great geosynclinal basin was in the making to record its events in the later pre-Cambrian or Delhi times.

The rocks of the Middle pre-Cambrian aggregating into a huge thickness were then folded, and later subjected to normal erosional activity. With changes in crustal deformation as a result of folding the original basin of deposition was opened up; and in place of the original nucleus of a narrow basin came into existence a great geosyncline, possibly unheard of in the region in earlier times. It extended from Garhwal in the north-east to right up to north Gujarat, and in width from some 20 km to about 200 km, being widest in the Alwar region and with best development in the narrow arm in the Ajmer region, where it is possibly the thickest. Here again the sequence of deposition was similar. Large number of torrential streams were active depositing conglomerate beds on the fringes followed first by coarse sediments giving rise to quartzites, arkose and grits, and later by finer set of sediments giving rise to phyllites, biotite- and calc-schists and limestones and younger phyllites in the central part of the basin; in Alwar area the finer sequence is preceded by the sediments giving rise to Kushalgarh limestones and hornstone breccia. The Delhis were also a scene of stupendous igneous activity in the form of granites and pegmatites of the Erinpura suite, resulting in the metamorphism of the Delhis and the earlier sediments with intensity increasing towards the centre of the geosynclinal basin; and with it came into existence the lofty mountain of Aravalli in place of the earlier geosyncline, extending from the southern boundary of the Tethys to right up to Laccadives, and possibly also up to Madagascar, and of which Nagar Parkar occupied the western outpost.

Lower Vindhyan sediments are not represented in the west Indian arid zone. Instead, the time unit of Lower Vindhyan, after the formation of the sediments of the Delhi System, and coming into existence of the lofty Aravalli Range, was occupied by the Malani igneous activity of great significance. It was the period of emplacement of granitic rocks in an extensive area of western Rajasthan, in the form of Jalor and Siwana granites from the places of their occurrence in the type areas, and the pink and grey granites from the colour and mineral composition of the granitic rocks. This great suite of rocks had invaded the Delhis and the Aravalli slates in a batholithic manner resulting in their metamorphism. The igneous activity was by no means confined to the only plutonic and hypabyssal zones. It also erupted in the form of volcanoes and covered all the available valleys and depressions then known in the extensive regions of erstwhile Jodhpur and Jaisalmer princely states. The western region of Rajasthan and part of northern Gujarat were thus once more extensively covered by the igneous suite of rocks, matching considerably with the original territory of the oldest gneissic basement complex.

After the stupendous volcanic activity of Malani times there was a period of quiescence with no crustal movements whatsoever. On the igneous basement of the western arid zone there came into existence two arcuate basins, one located west of Pali (25°49′: 73°18′; 45-G/5) and the other was much more extensive with Jodhpur lying in the south-central part of the basin. While the southern basin was concave towards north, the northern one had its concavity towards south; and in all probability they together possibly formed only one extensive basin, extending northwards up to Dulmera (28°24′: 73°39′; 44-H/11) and possibly further east and north of it. As in earlier periods, the sedimentation took place with basal conglomerate band followed by coarse-textured sandstones and grits. The sedimentation was once more keeping pace with the sinking basin, and when the basin attained adequate depth in its eastern sector it started deposition of the limestones, often rich in siliceous material, with sand grains of cherty material associated with it. With the sandstones are also associated in the succession the gypsum deposits in depth, both in Nagaur and Bikaner areas, suggesting that the sequence of deposition had once more taken place under dry, arid and trying climatic conditions. Limestone is also bituminous near Bilara suggesting that the Vindhyan limestone was possibly one of the host rocks in which petroleum was initially formed and later drifted elsewhere. Sediments were mostly derived from the lofty Aravalli Range, but the adjoining granitic and rhyolitic terrain had also its deep imprint on the Upper Vindhyan sediments of the trans-Aravalli region. It was in this basin that life had its beginning, although there is no clear and conclusive evidence to substantiate it for lack of adequate data.

After silting of the extensive Vindhyan basins under continental facies in western Rajasthan, the sediments were compacted and gradually uplifted up to the Middle Carboniferous in keeping with the folding of the Aravallis during the period. In Late Carboniferous, or Permo-Carboniferous time, this was followed by a period in which there was general cooling of temperature in the entire Gondwanaland with accumulation of thick sheets of ice under conditions matching with those responsible for the formation of Talchir boulder beds in the cis-Aravalli region. It is from this highland with ice-sheets that glaciers descended towards the Salt Range (P), and in its transit deposited sediments, the relict of which is seen near Bap and Pokaran, where pebbles, boulders and cobbles comprising Malanis, calcareous suite of Vindhyans and the Aravallis were embedded in a matrix of marl.

The Bap-Pokaran beds were undoubtedly much more extensive than what they appear today. At the end of the glacial period the ice-sheets began to melt, and in the scar left by the extensive glacial action there accumulated large body of water in the form of lakes and fresh-water lagoons in the mainland of Lathi as also in Fatehgarh (26°30′: 71°12′; 40-N/3), Botia and Barmer areas. It is here that the fresh-water sedimentation took place initially under lacustrine condition followed later by fluviatile tendencies; thus the sedimentation once more began with the basal conglomerate band followed by a set of poorly sorted coarse sediments with occasional clayey and carbonaceous partings. The sediments have a ferruginous tendency towards west, felspathic towards east and south-east and calcareous towards north, suggesting again the existence of arid and dry climatic condition. Fresh-water continenta land fluviatile origin of sediments is further confirmed by the predominance of zircons and rutile over tourmaline in the ZRT plotting, and also by the presence of dicotyledonous wood and/or fresh-water mollusca ni certain selected sectors.

Before the Lathi basin was fully silted up the Middle Jurassic sea was active enough to overlap the fresh-water basin along its western fringe depositing typical chrome-yellow, fossiliferous limestone bands with intercalations of occasional sandstones, and thus marking the eustatic movement of the sea. The shoreline was fluctuating until the conditions were stabilized at the beginning of Upper Jurassic to give rise to shallower sea in which were deposited clayey and arenaceous sediments. With further break in depositional sequence are a set of coarse sediments in still shallower seas, profusely populated with ammonites and terebratulidae often occurring as clay iron bands; the new set of sediments to be deposited were still coarser, though unfossiliferous. With the end of Jurassic the sea was very much silted up; but with the beginning of Cretaceous it had further deepened in a subsidence basin giving rise to richly fossiliferous rocks with a characteristic 'Aburstone'. Thus the sedimentation pattern was closely linked with the crustal movements taking place during the Late Jurassic and Cretaceous epochs.

In Kutch and Kathiawar also more or less similar but all marine sediments were deposited on possibly the gneissic basement complex, except towards the latter half of Cretaceous when part of Kutch had emerged as land as a result of crustal movements, and continental fresh-water deposits were laid in the basins in the form of Bhuj Series. At the close of the Cretaceous the southern fringe of the earlier sediments in Kutch and western fringe of Kathiawar sediments were covered by volcanic rocks of basaltic nature, which was already engulfing the extensive part of Deccan shield area further southwards.

Before constructing the palaeogeography of the Tertiary epoch it is essential to examine the general disposition of salinity in the entire western Rajasthan. While the great salt lakes of Sambhar (26°54′: 75°10′; 45-N/1), Kuchaman (27°09′: 74°52′; 45-I/16), Didwana (27°24′: 74°35′; 45-I/11) and Pachbhadra (25°56′: 72°08′; 45-C/1) are well known to the scientists working in that part of Rajasthan, there are many more less well known local saline tracts similar to those of Tal Chhapar (27°50′: 74°30′; 45 I/5), Sujangarh (27°41′: 74°28′; 45-I/6), Lunkaransar (28°29′: 73°45′; 44-H/11), Kaparda (26°16′: 73°29′; 45-F/7), etc., of varying magnitude and extent. While in Bikaner, Churu and Nagaur districts it is difficult to locate fresh-water wells in the horizons other than those belonging to the Vindhyan or the Delhi System, it is equally true of southern and eastern parts of Barmer district, and to some extent of Jodhpur and Pali districts as well. To account for so much of salinity in so extensive an area it is but apt to extend the Eocene sea. Eocene transgression was thus more of the nature of inundation when all the presently low-lying areas as also the salt lake basins were submerged directly, or by an arm of the Eocene sea, the latter by the most convenient route of low-lying areas. The author has considered all the possible explanations so far recorded to account for the salinity of western Rajasthan lakes, and is strongly of the opinion that no other principle can possibly explain the uniform presence of over 75 per cent of sodium chloride in all the noted salt lakes of western Rajasthan matching very well with seawater. This also explains satisfactorily the remarkable absence of fresh-water lakes, except those with accumulated surface or near surface perched or ground water.

Unconformably overlapping the Abur beds in the west, Parihar in the north-west and the Bedesar sandstones in the north in western Rajasthan are a group of limestones of undoubted Eocene age with rich assemblage of foraminifera in continuation with the Bikaner and Barmer-Kapurdi (25°54′: 71°23′; 40-O/5) Eocenes, the latter characterized by a rich assemblage of bentonites and fuller's earth. The Eocene sea was thus much more extensive than what has hitherto been stated, and extended further eastwards to explain the cause of relict salinity on the one hand and presence of salt lakes on the other, the latter possibly by extending the arm of the Eocene sea. Thus while the Bikaner sea extended to Sambhar salt lake via Sri Dungargarh (28°04′: 74°01′; 44-L/4), Tal Chhapar, Sujangarh, Didwana and Kuchawan, the Barmer-Kapurdi sea extended to Kaparda salt playa and beyond by the route following mostly the present upstream course of the river Luni. It is interesting to note that the salt lake of Sambhar is located at a lower level than that of Kuchawan, and that the Delhis did not act as a barrier as often surmised. The area was subsequently upheaved more towards north and north-east at the close of the Eocene to emerge as a highland, while the once extensive sea was then confined to the salt water lakes and pans to account for their existence in the depressions. In Kutch and Kathiawar the area along the fringes of the trap country were the scene of first Eocene and then Mio-Pliocene deposits.

After the close of the Tertiary when the land had attained almost the present form, the area had fallen once again into a droughty region because of the trend of the once lofty mountain of Aravalli towards east, and the rising Himalayas towards north. The aridity gradually increased, dotting the whole land with series of overlapping sand-dunes of possibly Recent and Sub-Recent times concealing all evidences of basement and subsequent geology.

WATER-BEARING PROPERTIES AND POTENTIALITIES OF THE ROCK FORMATIONS

The main source of ground water in the west Indian arid zone is meteoric water. The occurrence and quality of ground water is, therefore, mainly dependent on the mode of formation, compaction of the sediments constituting them and their relation to the overlying beds. On the basis of the study so far conducted by the officers of the Exploratory Tubewells Organization as also by G. C. Taylor of the U.S. Geological Survey and by A. K. Roy, B. D. Pathak, D. N. Sett, B. N. Sen and A. L. Kidwai of the Geological Survey of India, a generalized picture of water-bearing properties and potentialities of the rock formations is presented in this section.

The rocks of the Aravalli System occur generally as arkose, grits and quartzites followed by phyllites and mica-schists, and further by shales, slates and limestones. In the Pali region they have been studied in detail. There the Aravallis comprise slates trending N15°E to N50°E with a dip of 45° to almost vertical. Ground water occurs along bedding planes and through fracture and cleavage planes, and is confined to a depth range of 75 m b.g.l. The capacity of the wells ranges from about 0·15 to 1·15 litres per second. The chlorides range from 25 to 7150 p.p.m., bicarbonates from 309 to 1214 p.p.m. and the sulphates from 0 to 2360 p.p.m. rendering the water fair to saline and usable to unusable. The quality of water in Alwar district is superior to this, although the wells may not differ much in capacity.

Taking the aerial extent into consideration the occurrence of Raialo marble is not of much significance in western Rajasthan. With the marble being mostly of calcitic type, the ground water should normally occur in cavities and solution channels in depth; but there are no specific data on the actual quality and quantity of water available in the formation.

The Delhis comprise quartzites, grits and conglomerates with the intrusives of Erinpura granite, and younger series of phyllites, calc-slates and calc-gneisses. The rocks of the Alwar Series are compact and poor water-carriers, except in the alluvial fill of the intermontane valleys, where, depending upon the nature and thickness of the alluvium, the productivity may be poor to very good. On the average, wells in the alluvial fill yield at least 5 l.p.s., if the alluvium extends for at least 15 m below static water level, with good granularity and absence of aquiclude to prevent any large-scale recharge to the aquifer zones in depth. Due to intricate folding pattern of the Alwar rocks, there are many fault-planes along which water trickles and gives rise to tanks and reservoirs; but there is no dependable storage in the formation itself. Ajabgarhs, on the contrary, are fairly good as water-carriers and the wells in them may in general yield about 1-3 l.p.s., and in exceptional cases up to 6 l.p.s. Granites are fairly good water-carriers in their weathered zone, but poorly so when the hard rock is reached.

Ground water in the Jalore and Siwana granites occurs through surficial mantles of disintegrated rocks, as also through joints, sheets and minor partings. Normally zone of weathering extends for about 30 m. and the joints to a maximum depth of about 60 m The nature and extent of ground water, therefore, depend on the concentration of joints and the weathered mantle. The capacity of the wells in the Pali region ranges from 0·06 to 0·15 l.p.s.; and somewhat poor and disappointing. On the score of quality the water is generally saline with higher content of chloride, and thus at times practically unusable for any purpose.

The water in the Malani volcanics is confined to the joints and other secondary partings. The water-table varies widely from 3 to 30 m. in different parts of the region. The yields from these formations are of the order of 0·1-0·4 l.p.s. According to Kidwai, water in the rhyolites is relatively better in quality than that occurring in the granites, but generally rich in bicarbonates.

The Vindhyans in the region comprise older sandstones followed by younger limestone member. Sandstones of the system occupy extensive areas in

Jodhpur, Nagaur and Bikaner districts. The wells are generally deep, but their capacity often ranges from 1·5 to 3 l.p.s. and rarely up to 6-8 l.p.s. when the formation is very well jointed. The limestone member behaves differently. While generally the capacity of the limestone ranges from 0·09 to 0·32 l.p.s., there are instances when highly cavitous limestone yields even over 10 l.p.s. The quality of water is generally superior to that from the Aravallis or the Delhis. The boulder beds of Pokaran and Bap are purely of local nature, and systematic studies undertaken so far in them do not throw any light on the capacity of the wells.

There is a concentration of dug wells in the Lathi formation of Jaisalmer district accounting thereby for its more dependable source of unconfined or shallow confined ground water. The Lathis yield relatively more fresh water. The water level ranges from 30 to 105 m b.g.l. Though the yield capacities of the dug wells and the shallow confined or unconfined zones thereof are much limited, the deeper aquifers from their present trend can be dependable, and successfully tapped in tubewells with discharges exceeding 37 l.p.s. at a drawdown of 6 m. on the average, even on 24 hours' continuous pumping, with but a few exceptions.

The water-table in the Jaisalmer limestone ranges in depth from 69 to 107 m b.g.l. The limestone members of the Series bear water through their joints, while the sandstone members support only a few dug wells through their porous nature. This formation comprising only marine facies did not prove successful for tubewell construction. The quality of water in dug wells as well as in some of the deeper zones tested indicated the presence of very saline water suggesting thereby the influence of connate water. The dug wells range in their capacities from 0·15 to 0·80 l.p.s. per well.

The dug wells in Baisakhis and Bedesars are very few and far apart, and the water is generally saline and lies at a depth of about 26-125 m b.g.l. Due to lack of adequate granular zones below static water level these formations, too, have very poor capacities and do not support any possibility of tubewell construction.

Being coarse-grained sandstones, the felspathic group of Parihar sandstone supports good amount of water with recently dug wells which do not dry up even in summer. The static water level is about 106 m b.g.l. However, the quality is very poor. The deeper zones of this formation can support the possibility of heavy duty tubewells as at Sanu; but the quality of water is poor and highly saline.

Except for *Bherris* with shallow fresh perched water, Abur beds do not generally support any wells.

In Kutch, rocks of Patcham and Chari Series comprise calcareous shales and limestones, and in Chari Series they occur as calcareous oolites, all of them being marine in origin. The quality of water is, therefore, saline and the capacity of the impervious formation is generally very poor. Katrol Series comprises hard, blocky sandstones at the top underlain by soft brownish variegated gypseous clay slates, the outcrops showing quaquaversal dips with a domical structure. The rocks are, therefore, impervious yielding only meagre supply of salty water. Umia Series of the island comprises Umia beds followed by Ukra beds and Bhuj beds in succession, which were deposited mainly under fluviatile and estuarine conditions and partly under marine condition. The marine formation of the series yields only saline water and hence there is no development of ground water in the fossiliferous sediments of the series. The rocks of the Bhuj Series comprise current bedded sandstones with interbanded shales and siltstones, and Upper Bhuj Series is more permeable than the Lower Bhuj. Ground water in the Bhuj sandstones occurs under both confined and unconfined conditions with shaly bands, clay and siltstones serving as aquicludes. The static water level in the dug wells ranges from 2 to 30·5 m b.g.l. and that in the dug-cum-bore wells and tubewells tapping confined aquifers from 3·4 to 31·4 m b.g.l. In Lower and Upper Bhuj Series of Kutch ground water to the tune of over 9,000 and 26,000 million litres respectively has been developed for purposes of irrigation. The quality of water is generally good. While there is no definite record about the capacity of the individual dug wells, the tubewells located well within the Bhuj sandstones yield about 13-55 l.p.s.

Deccan trap occurs mainly in the form of lava flows along the fringes of the Jurassic formation in both Kutch and Kathiawar. Ground water occurs in them along joints, fractures and secondary partings, which are generally limited in depth up to 50 m. Intertrappean beds in the region are limited in thickness. The static water level in the dug wells ranges from 4 to 12 m. with yield capacities of 0·05-0·20 l.p.s. The dykes of basalt, when they occur in the area serve as effective barriers resulting in the impounding of water against natural dam.

Apart from the quarry water, the regional water-table in the Eocene formation of western Rajasthan is about 35 m b.g.l. The wells generally contain saline water and their yield capacities are very much limited. The Tertiaries in Kutch and Kathiawar comprise either compact fine-grained marine formations or coarse-grained conglomerates with fine-grained matrix. The yield capacities range from 0·06 to 0·24 l.p.s. with generally slightly or moderately saline water.

Alluvial formations comprising generally dune sands of Recent origin occur invariably above the zone of saturation. However, the infiltrated rain-water is just sufficient to support some of the perennial grasses.

CONCLUSIONS AND RECOMMENDATIONS

Entire tract with an annual precipitation of less than 500 mm falling in western Rajasthan, western Gujarat and south-western Punjab (I) forms the west Indian arid zone of the country. With such meagre, erratic and undependable rainfall and frequency of famine condition almost once in eight years, water has assumed a great significance for the very existence of human and stock population as also for irrigation, particularly when it is not available from any extraneous source.

The past geological history suggests that the dry conditions prevailed in the area from time to time starting right from the deposition of the Aravalli sediments and continued at least periodically through the Raialo times, Delhi times, Vindhyan times and later through Jaisalmer, Abur and Eocene times; at the end of the Tertiary epoch dry and arid conditions were once again established and continued till present times.

On the older gneissic basement complex were deposited the rocks of the Aravalli System forming the first sediments. On the weathered sediments of the Aravallis came into existence the geosynclinal basin in which were deposited the calcareous sediments of the Raialos, and later with break in sequence the thick sediments of the Delhi System. The weathered platform of the Delhi rocks was later a scene of violent volcanic activity in all its phases, and on it were deposited the Vindhyan rocks in two separate basins. In Permo-Carboniferous period this was followed by glaciation with lowering of temperature, when glaciers moved towards the Salt Range depositing Bap and Pokaran beds. In the scar left by the glacial action were deposited the Lathi sediments first in a lacustrine and then in a fluviatile basin. No sooner were the Lathis deposited, they were followed by a marine transgression in Jaisalmer times. There was then a period of regression until Eocene times when the relict sea was once more advancing, submerging all the available lowland, including the Sheo (26°11′: 71°15′; 40-N/4) embayment and the salt lake basins of Didwana-Kachawan-Sambhar on the one hand and Pachbhadra-Kaparda on the other, the relict of which is seen in the form of extensive dissemination of salinity in the entire western Rajasthan, almost always increasing in depth, particularly in the alluvial tracts. This was followed by quieter times with the recession of Eocene sea and emergence of the once submerged lowland into a highland. In Kutch and northern Kathiawar the transgression started a little earlier practically with the beginning of the Jurassic times and continued through the Jurassic. At the beginning of the Cretaceous part of the central portion emerged as land in which were deposited the thick series of fresh-water sediments followed by a volcanic activity of stupendous nature. With the recession of sea the marine activity continued during Eocene and Mio-Pliocene times.

During the protohistoric (3000 B.C. to 500 B.C.) and early historic (500 B.C. to A.D. 400) periods western Rajasthan in Ganganagar district was the cradle of rich river valley culture of ancient Saraswati until it drifted westwards and disappeared with the change of river course. At last with the establishment of the present dry and desertic condition almost the entire area was strewn with series of sand-dunes.

Storage of surface water is naturally a luxury in the dry desertic tract of western Rajasthan; and by impounding water of smaller or bigger streams one comes across large number of tanks and reservoirs. Jawai dam is one of recent date formed by impounding water of the river Jawai, the tributary of Luni. Further scope exists in damming the water of similar rivulets for local use in several isolated pockets, particularly when the precipitation exceeds 200 mm.

When the tanks and surface storage reservoirs go dry, deep dug wells serve as the only source of water in the region. Rocks of the Aravalli System provide fair to saline water of usable to unsuable quality to the maximum extent of 1·1 l.p.s. per well. Alwars are poor water-carriers, but Ajabgarhs provide water to the tune of 1-3 l.p.s., and the alluvia in the inter-montane valleys to the tune of at least 5 l.p.s. if it extends for at least 15 m below static water level. In the weathered mantle of Jalore granite ground water to the extent of 0·15 l.p.s. may be obtainable; rhyolites, on the contrary, yield water up to 0·4 l.p.s. in the weathered mantle with relatively better quality. In the rocks of the Vindhyan System, while the ground water in the calcareous member depends upon its cavitous nature, the wells in the sandstone yield 1·5-3 l.p.s. Shallow wells in the Lathis and the Bhuj sandstones are generally quite productive, but the later formations are generally characterized by their typical brackish to saline water content. The wells in Deccan trap yield up to 0·2 l.p.s.

Both the Lathis and the Bhuj sandstones have been explored in detail by deep drilling during the last decade; and come to be established as potential ground water reservoirs in Rajasthan and Kutch (including partly Kathiawar) respectively. The wells in the Lathi Series have produced 18-37 l.p.s. at a drawdown of 6 m. In Kutch the tubewells have yielded 13-55 l.p.s. at similar drawdown.

The scope, therefore, remains to cautiously develop the known and the proved ground water pockets Lathi and Bhuj in entirety to determine the of magnitude of the reservoirs in them. This by means is the complete picture of ground no water.

The potentiality of all the hard rock formations must be examined in extensive areas by first testing the existing dug wells; the data so far available are only of a very isolated and limited nature. Once the potentiality of the hard rock formations is known individually and collectively and in isolated and extensive areas, it will be possible to formulate any scheme for diversion of water from elsewhere to supplement any future developmental activity from surface or deep subsurface water.

The data on the soft rock formations are also not complete. The establishment of salinity in them, with the exception of Lathis and Bhuj beds, is a generalized fact. Drilling of isolated boreholes in a single horizon does not give a clear and complete picture to generalize evidences. Exploration on a broad scale has, therefore, to be taken up to know once for all the potentiality of the soft rock horizons. In doing this one has to arrive at an optimum limit in respect of both quality and quantity. It is essential to record here that water up to 2500 p.p.m. of chloride content and 4000 p.p.m. of TDS has been accepted in some of the Middle East and Middle West countries; and on this score it should not be difficult to accept water up to 1500 p.p.m. of chloride content and 3000 p.p.m. of TDS in respect of quality. When the very existence of human life is questionable there is no alternative to accept any quantity of water; but it is not unreasonable to consider tubewells with discharges of 6 l.p.s. as productive and acceptable, where acute scarcity and famine conditions prevail.

In alluvial tracts where salinity increases with depth, there is no other alternative than to use surface storage tanks and diversion canals to supplement the available source. Artificial recharge of shallower granular zones may also be worth attempting to serve as subsurface storage tanks. Perched water often provides adequate quantity of water in certain areas for limited population of the region.

There are also two important energies plentifully available all the year round in west Indian arid zone, namely high velocity wind and solar heat. High wind velocity can be harnessed for running windmills, if the static water levels in wells do not exceed about 30 m. Solar heat can also be cheaply and plentifully utilized for popularizing solar demineralizers after adequate experimentation for water supply to individual families and villages for purposes of drinking water.

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DISCUSSION

A. K. Sen: What are the evidences of the existence of shallow depressions of local and isolated nature which are referred to as the first sedimentation basins ?

P. G. Adyalkar: The Aravallis, so far as it is reported, are the first sediments. Naturally they must have been deposited on the gneissic basement complex. Further, we get the beds of conglomerate, grits and arkose which are very coarse formations suggesting sedimentation in shallow basins.

A. K. Sen: Has the author found any evidence that the Pachbhadra, Lunkaransar and Tal Chhapar may be the deserted beds of rivers ?

P. G. Adyalkar: Salinity in such saline tracts increases with depth which cannot be explained by river origin alone. Further, the Aravallis did not act as a barrier as often surmised, as the water poured in Kuchaman lake will have its access to Lake Sambhar unhampered; and hence they are not in the intermontane valleys. Lunkaransar lake, for example, is definitely the saline water lake of Recent times as we have got a fresh-water horizon in depth. This is the result of the past palaeogeographical features, and not by mere concentration in the past river courses.

C. T. Abichandani: Is it not possible that the fluvial action which followed the transgression of sea flushed out all marine salts from the Sambhar Lake and origin of salts in this Lake may have some other source ?

P. G. Adyalkar: The aridity is not a unique feature of recent date in western Rajasthan. It has repeatedly come and gone in past geological epochs. Studying the lithology of the sedimentary formations and correlating the occurrence of limestone, gypsum and salt playas it can be definitely stated that arid conditions also prevailed during Aravallis, Raialos, Delhis, Vindhyans, Middle Jurassic, Late Cretaceous, Eocene and Recent times. Further, even if the pluvial periods have occurred, of which the author has no idea, the salt simply accumulates in the lacustrine depressions, and will still account for the marine transgressional origin.

K. Narayanan: Are the Bap and Pokaran boulder beds of the same age ?

P. G. Adyalkar: Yes. Both belong to Permo-Carboniferous period.

S. P. Raychaudhuri: The soils of the Sambhar lake are rich in montmorillonite which contains Mg. The formation of montmorillonite may be due to the contact of sea water ?

P. G. Adyalkar: This requires further investigation.

HYDROGEOLOGICAL INVESTIGATIONS CARRIED OUT IN THE REGION OF MALANI SUITE OF IGNEOUS ROCKS, WESTERN RAJASTHAN[1]

by

P. C. CHATTERJI[2]

INTRODUCTION

THE importance of water for arid and semi-arid regions is well depicted by an old saying of the Turkmenians: "Water, not earth, gives life." For centuries, since ancient times, these people fought for water that gave them life.

Availability of water in such a region is of paramount importance for its overall development and prosperity. Where the potentials of surface water resources are not adequate, one has to bank upon the ground water resources. The available quality and quantity of ground water are directly related to the lithology and hence the need to study the hydrogeology of such regions for proper planning of development.

Very little systematic study of the ground water problem was undertaken up to 1949. People of this tract banked upon water diviners and ground water witching. Even in the former princely States such techniques were usually employed for assisting the people. Though water witching is still commonly resorted to by the villagers, the Central and Provincial Governments have now taken to a geological approach for the study of ground water.

The region under study covers the entire districts of Jalore and Sirohi along with major portions of Barmer, Pali, Jaisalmer and Jodhpur districts and minor portions of Bikaner and Nagaur districts of western Rajasthan as shown in Map 1. This region could be taken as a representative area having all of the lithological formations belonging to the Malani suite of igneous rocks.

In this paper a review of the hydrogeological studies carried out by the various Organizations, with special reference to the work of this Institute, have been given.

GEOLOGY

Out of the succession of rock formations of Rajasthan, as given by Heron (1925), the following sequence of rock formations, as given in Table 1, is encountered in the region covered by the SOI topographical sheet 45C.

The region of Malani suite of igneous rocks (Map 1) is bound by the sedimentary formations of the Upper Vindhyans and the Jurassics in the north and north-west and by the Erinpura granite, the Delhis and the Aravallis in the south-east.

TABLE 1: Geolithology of Central Luni Basin

Era		*Geolithological formation*
Quaternary		Recent deposits; Younger alluvium
	Pleistocene	Older alluvium and grit
	Unconformity	
Palaeozoic or L. Vindhyans		Malani volcanics; Siwana and Jalore granite; Erinpura granite
	Unconformity	
Archaean		Aravalli System composed of impure limestone, phyllites, quartzites and conglomerates

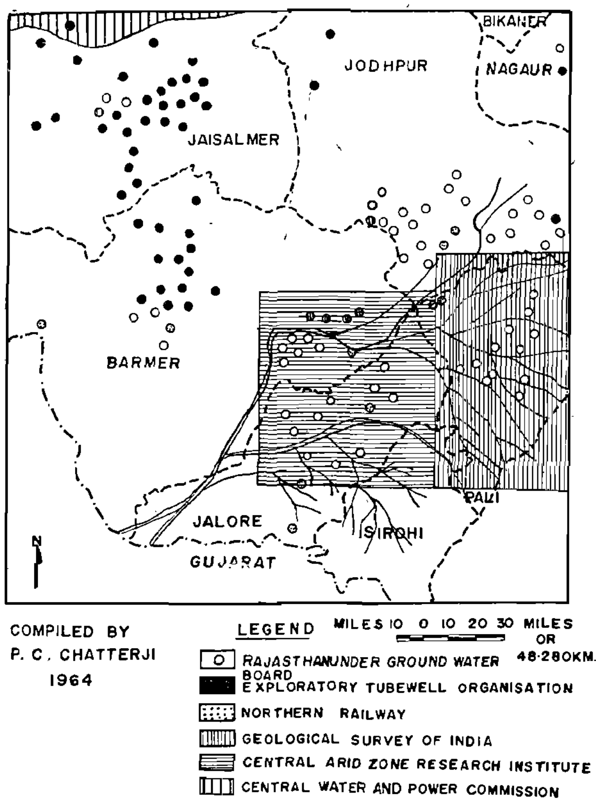
It is evident from the presence of pendents of Aravallis in the bosses of Malani suite of igneous rocks that the igneous crystalline and volcanic rocks were intruded into the Aravallis. The region stood above sea-level after its formation and was subjected to pronounced weathering and erosion which gave rise to the grit and alluvium (Chatterji, 1963).

The Malani suite of igneous rocks comprises Jalore (hornblende, aegirine and biotite) and Siwana (hornblende and aegirine) granites with their effusive phases as Malani volcanic tuffs and porphyries. The Malani rhyolite includes felsites, devitrified lavas and glassy rhyolites intercalated with acid tuffs and pyroclastic breccias. These formations occupy a tract of the country 150 miles long (E-W) and 120 miles broad (N-S) (Krishnan, 1952; Murthy *et al.*, 1961).

PREVIOUS WORK

1. Geological: Geologists have been undertaking studies in the field of structural, stratigraphical, petrological, mineralogical and general geology for western Rajasthan since the latter half of the 19th century (Blanford, 1876, 1877; Ghosh, 1932; Gupta, 1934; Holland and Christie, 1909; Heron,

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Geologist at the Institute.



Map 1 — Study sites of various organizations in the region of Malani suite of igneous rocks (W. Rajasthan)

1925, 1933, 1935; La Touche, 1902, 1911; Murthy *et al.*, 1961; Murthy, 1963; Oldham, 1886, 1891; Pascoe, 1950; Rode, 1958; Rode and Sharma, 1958; Sharma, 1953; Siddiquie, 1963). These investigations are of considerable value in the study of the regional ground water in relation to the geological setting.

2. Hydrogeology: Some information regarding ground water was available as early as 1909, e.g. the river Luni is most capricious and erratic, on one bank it may be a blessing while on the other it becomes a curse. In Balotra the ground water is generally sweet, but lower down it becomes more saline up to the Rann of Kutch. Drinking water is available from ground water resources only from the month of November to the month of June. It was Tipper (1921) who systematically worked in 1921 on the possibility of increased and improved water supply in the Jodhpur area in connection with the proposed change from narrow to broad gauge from Luni Junction in the east to Khokhrapar in the west. Out of 10 stations examined he recommended sinking of new wells in some, and deepening of the existing ones in the others. But this study did not solve the problem. Finally the position had again to be examined by the Jodhpur Railway Administration in 1939. They suggested various steps to increase the supply from different wells either by increasing the well diameter or by driving down tubes through the bottom.

Edgar (1931) discounted the possibility of deriving a large quantity of water from Jodhpur sandstones. Fergusson (1939) worked on the ground water for irrigation in Jodhpur region. He observed a fall of 25 ft, in the water-table, in a period of 1930-39, and attributes it to over-utilization of ground water, but did not rule out the possibility of utilizing ground water for irrigation. Shelton observed that there were a number of subterranean streams which could be utilized for urban and rural water supply and agriculture. The Stampe Committee (1938) examined the details and came to the conclusion that there was no possibility of any tube-well scheme for irrigation in the Jodhpur region. This conclusion has also been supported by Heron (1939) and Auden (1950).

Auden (1950) has divided the older geological formations of western Rajasthan into eight groups of which he considers the sandstones of Vindhyan, Jaisalmer and Barmer variety and the numullitic limestones as likely to be water potential. He has also prepared a tentative map showing ground water basins of this region and also the depth of the water-table. These works are not based on any detailed hydrogeological investigations but are based on the intimate knowledge and experience of the local geology. Mehta (1949) has studied the water supply of Jaisalmer where the water-table has been reported to vary from 200 to 300 ft, but sometimes only 25 ft in the alluvium.

Taylor (1952) indicates that over 75 per cent area of western Rajasthan is occupied by semi-consolidated and consolidated bedrock formations of Eocene and older geological ages, and except for Bikaner region, the formations have poor capacity to hold and transmit water. The ground water is moderately to highly mineralized and its suitability for irrigation and other beneficial uses is limited.

Ground water investigations in some details were taken up in 1954 for Pali region and have been reported by Roy and Seth (1954) and Taylor *et al.* (1955). In these studies the physical nature of the rock types, the average chemical composition of ground water and the discharge potential of the lithological formations have been studied, but water potential zones have not been delineated.

3. Geophysical: Geophysical methods have also been utilized for the study of ground water in this region. Electrical sounding method was employed by Ermisch (1949), and Anandalwar and Mathew (1949) in the region extending from Shergarh to Phalsand to delineate the boundary between sweet and brackish waters, but the results were not satisfactory. Gravitational survey of western Rajasthan has provided a large mass of water-table data, and on that basis Survey of India has prepared a water-table contour map of Rajasthan.

4. Exploration: Mechanical exploration and exploitation of ground water by drilling has been

TABLE 2: Percentage of open wells and tube-wells drilled in western Rajasthan

District	*Rajasthan Underground Water Board*				*Exploratory Tubewells Organisation*			*Northern Railway*
	Abandoned well	*Open well*	*Tube-well*	*Total*	*Abandoned well*	*Open well*	*Total*	*Tube-well*
Jaisalmer	—	—	2·2	2·2	12·3	—	12·3	24·6
Jalore	2·2	7·8	10·0	20·0	—	12·3	—	—
Pali	1·1	10·1	3·3	14·4	3·5	—	3·5	—
Nagaur	4·5	1·1	5·6	11·2	2·6	—	2·6	—
Jhunjhunu	—	—	1·1	1·1	24·6	—	34·2	9·6
Bikaner	2·2	—	4·5	6·7	8·9	—	8·9	—
Sikar	2·2	—	1·1	3·3	3·5	—	3·5	—
Barmer	4·5	4·5	—	9·0	12·3	50·0	14·0	1·7
Jodhpur	6·7	22·1	3·3	32·1	2·6	37·5	2·6	—
Churu	—	—	—	—	6·1	—	6·1	—
Total	23·4	45·5	31·1	100·0	76·4	100·0	100·0	23·6

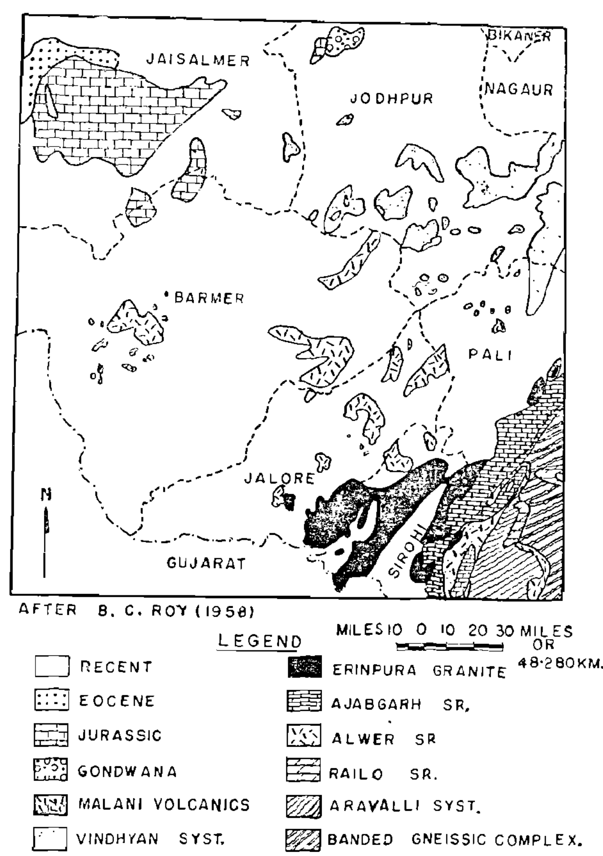
Sources: Based on the map of Rajasthan Underground Water Board, Memorandum No. 13 of ETO, 1963, and personal communication from Executive Engineer, Water Supply Division, Northern Railway.

taken up by the Rajasthan Underground Water Board, Exploratory Tubewells Organization (Adyalkar and Ramesan, 1963) and Water Supply Division, Northern Railway. Details of their activities are shown in Table 2.

From the data in Table 2 it is apparent that very few tube-wells have been successful. Various Organizations have mostly deepened the existing wells to increase the yield. This failure is due to the fact that the drilling operations have been carried out mostly in virgin areas without any or adequate knowledge of the hydrological behaviour of the formations explored. Map 2 shows the various operational areas.

STATEMENT OF PROBLEM UNDER STUDY BY THE INSTITUTE

From the review of the previous work on record in this region, it is apparent that systematic study of ground water in relation to subsurface geology in association with other factors and utilization of ground water in the region has not been undertaken on any extensive scale. For the development of arid and semi-arid regions availability of ground water is one of the principal factors, and unless the hydrogeological nature of the rock formations, the nature of the ground water and their present utilization are properly and adequately known, it is difficult to plan for fresh exploration and proper utilization of the ground water resources, whatever available within the region. Study of present ground water exploitation areas gives clue to locate fresh ground water zones which should be further studied with the help of geophysical surveys followed by drilling before exploitation is done.



Map 2 — Geological map of the region of Malani suite of igneous rocks (W. Rajasthan)

Hydrogeology of a region needs study from the following points of view:

1. Geology and structure of the region with special reference to subsurface geology;
2. Physical nature and water-bearing properties of the lithological units;
3. Types of ground water bodies, variation in salt concentration and static water level in them;
4. Water analysis and classification, depending upon local use and adaptability for certain other purposes;
5. Chemical quality of ground water in relation to lithology of the aquifer;
6. Probable chemical changes that take place in the precipitated water during the course of infiltration;
7. Present ground water exploitation zones with available quality of ground water for irrigation and scope of development;
8. Study of ground water in relation to human and livestock population and utilization.

Systematic study of the hydrogeological nature of the rock formations in the Central Luni Basin region has, as mentioned above, been initiated by the Geology Section of this Institute in 1961. Broadly the results obtained so far are summarized as under.

1. Geology and structure: According to Chatterji (1963) only 2 per cent of the area of the region is covered with hill ranges and rock outcrops and the rest is covered with the Quaternary deposits. The hill ranges and rock outcrops belong to the Lower Vindhyan and the Malani volcanics and the Siwana and Jalore granites. The Quaternaries are composed of older alluvium and blown sand.

The blown sand accumulation has been more favoured on the western hill slopes and along the principal ephemeral water channels due to the prevailing westerly winds. Generally these are stabilized dunes. The younger alluvium generally exists as a continuous band along the main water channel and is composed of stream laid silt, sand and gravel. These deposits are generally thick. The older alluvium occurs generally as thick deposits which are discontinuous and derived in part from erosion and stream transportation.

Structurally the region is very simple. There are intermontane valleys and basins developed due to igneous and volcanic rocks which are now filled up with the Quaternary deposits (Chatterji, 1961).

2. Physical nature and water-bearing properties: The lithological formations of this region could be grouped into two, i.e. primary and secondary. The primary rocks are composed of volcanics and granites which are massive, compact and are not good hosts for water accumulation, except in joints, beddings and weathered mantles. In the granites, there are three predominant types of joints, which are of "Q", "L" and "S" types. Of these "Q" joints are more water-bearing (Chatterji, 1964). The weathered mantles are favourable zones for ground water accumulation, but the quality of water deteriorates due to the presence of secondary salts (Chatterji, 1964a). The deposition of secondary salts also deteriorates the water-holding capacity of rock formations up to 60 per cent. On the whole ground water from the granites is superior in quality to that from the volcanics.

The secondary formations are composed of blown sand and younger and older alluvia. The blown sands are composed of medium to fine-grained sand which are sometimes calcareous. These sands have good water-holding capacity, especially when the dunes are situated near the hill slopes. In such regions, due to the availability of more fresh water recharges, the quality of ground water is also good. The younger alluvium is made up of clay, silt and sand and has good water-holding capacity, especially near the principal ephemeral channels but the quality of ground water is poor. The older alluvium is principally composed of gritty material cemented with carbonates of calcium, magnesium, sodium, potassium, iron, etc. with little silt and clay which have developed due to the physico-chemical reactions of the weathering agencies on the primary rocks of the region. The water-holding capacity of this rock type is moderate to poor, which is due to the deposition of secondary salts.

3. Ground water bodies and variation of salt: In this region only the phreatic water, and in particular perched water bodies, can be economically utilized by the people with modest means by employing manual and bullock power. These bodies can be classified according to their geomorphic settings, i.e. plain tract, river tract, interdune, intermontane, foothills and rising water-table tract. These are 9, 11, 4, 6, 6, 9 and 3 respectively in number (Chatterji, 1964b). The source of recharge for all these types of bodies is the same, i.e. rainwater, but they differ from one another in respect of total soluble salt concentration, discharge capacity, static water level, etc. This variation is due to their different geomorphic setting. The average total soluble salt concentration is the least in the case of aquifers from intermontane and foothill zones, intermediate from the interdune and river tract areas, whereas it is highest from the plain tract. The average discharge capacity per well is higher for the aquifer from intermontane and river tracts, whereas for others it is practically of the same order. The static water level is the least for river tract and high for the plain tract and interdune tract. The ground waters of all these tracts, except those from intermontane and interdune areas, are predominantly alkaline in nature. The correlation study between the concentration of total soluble salt and static water level reveals that these characters are independent of each other, except for interdune zone where the salt concentration increases with the depth (Chatterji, 1964b; Chatterji and Jain, 1964).

4. Water analysis and classifcation: Recently Mondal and Jain have worked on the ground water samples of this region and have suggested the use of various regression equations developed for proper classification of waters. By the use of these equations employing electrical conductivity, total soluble salts, calcium, magnesium, calcium+magnesium, sodium, sulphate, bicarbonate, chloride and sodium adsorption ratio can be calculated.

Ground water from different lithological formations differ in several variables, such as concentration of total soluble salts, cations, anions, *p*H, sodium adsorption ratio, etc. Differentiation of these ground waters on the basis of the single variable does not make it possible to evaluate their relative qualities as found by employing several variables. The use of discriminant function, as has been advocated by Jain and Chatterji (1964), solves this problem.

Normally ground water containing up to 3200 p.p.m. total soluble salts concentration, i.e. up to Class 4, has been accepted as fit for irrigation. But in this region ground water containing up to 10,000 p.p.m. total soluble salts is being used for irrigation of crops and ground water containing up to 12,000 p.p.m. total soluble salt concentration is being utilized for stock and hence three new classes, i.e. Class 5 to Class 7, have been introduced in the standard classification of waters (Chatterji and Mondal, 1964).

5. Chemical quality of ground water: The average sodium, bicarbonate and chloride concentration has been recorded as the least, and carbonate as the highest in the case of blown sand. The average calcium, magnesium, carbonate and sulphate are the highest in the younger alluvium, whereas other cations and anions are of medium order. In the older alluvium the average carbonate content is less and sodium and chloride the highest and the rest of the ions are of moderate order. The Malani volcanics have low magnesium, potassium and carbonates and the rest of the ions are of moderate order. The average calcium, magnesium, potassium, sulphate and carbonates are low, chloride moderate and bicarbonate and sodium high in Siwana granite, whereas in Jalore granite carbonate, potassium and magnesium are low and the concentrations of the rest of the ions are moderate.

From the irrigation point of view 8·7, 28·7, 27·5, 26·6, 6·2 and 3·1 per cent ground water samples of this region have Class 2 (C_2), Class 3 (C_3), Class 4 (C_4), Class 5 (C_5), Class 6 (C_6) and Class 7 (C_7) types of water. C_2 type is more commonly associated with blown sand and younger alluvium, C_3 type of ground water is practically evenly distributed in all lithological formations. C_4, C_5 and C_6 types are more commonly associated with older alluvium and volcanics whereas C_6 type of water is found only in older alluvium (Chatterji, 1963a).

6. Metamorphism in ground water: Ground water can be classed into four groups on the basis of dominant anions, i.e. the anion which is equal to or exceeds 25 per cent of the total 50 per cent anions. The groups are (i) bicarbonate, (ii) sulphate, (iii) chloride and (iv) mixed water. The chemical quality of ground water is very little with the precipitation, but is more related with the lithology of the aquifer. The metamorphism of the ground water can be traced for most of the types of aquifers. It is extremely well marked in the blown sand and alluvia. In this process, as the total soluble salt increases, the ground water changes from primary bicarbonate water through an intermediate stage, where no anion will be dominant, i.e. the transitional type of water to final stage where total soluble salts are very high and the chloride ion predominates. If the causes of these changes in a particular area can be determined, and if the external factors could be restored, further degradation of the quality of ground water could probably be avoided or reduced (Chatterji, 1964a).

7. Ground water exploitation zones and scope for development: To study a region for ground water exploration and exploitation, it is very essential to study the present ground water exploitation zones, which could easily be demarcated with the help of village cadastral map or vertical aerial photographs. The zones should be classified as over-exploited, sparsely exploited, under-exploited and unexploited depending upon the draft that a well can stand. This would give an idea of the stress on the ground water resources in various parts of the region and to adopt measures for proper exploitation and utilization. Moreover, study of the present zones along with water-table would offer clues to discover fresh zones of ground water. After demarcating the various zones, sodium and salinity hazards within the zone should be studied for proper planning of agricultural development (Chatterji and Mondal, 1964).

8. Ground water and population: The development of irrigated lands and growth of population in a region of scarce surface water resources are generally related to the ground water resources. It is very essential to study the requirements of water for irrigation, population, etc., and to adopt measures to remove the bottlenecks in exploitation of ground water to meet the requirements. The difficulties generally faced by the cultivators in further exploitation of ground water, despite the fact that the State Government is giving loans for digging new wells, are as follows:

(a) In 26 per cent of the cases farmers do not have sufficient human and cattle power, or the ground water is available at greater depths, where cattle power is ineffective.

(b) In 50 per cent of the cases the farmers do not have adequate land for irrigation, though only 34·00 per cent of the total irrigable area is under cultivation. This is due to the fact that 50 per cent of the total irrigable land has to be kept fallow due to the saline nature of ground water and soil.

(c) In 24 per cent of the cases the land is undulating or duny, due to which ground water cannot be lifted with manual and cattle-operated irrigation devices.

Exceptions to the generalized statements given above must and do occur; such exceptions can generally be attributed to some unusual factor influencing the aquifer on the region.

SUMMARY AND CONCLUSIONS

A review of the hydrogeological studies carried out in the region of Malani suite of igneous rocks has been given in this paper and the future lines of study have been indicated. The results of comprehensive investigations conducted on hydrogeology of the region are given as under.

(1) Only 2 per cent area of the region is covered by rock outcrops and the rest of the region is covered by Quaternary formations which have been deposited or developed in the intermontane valleys and basins of igneous and volcanic rocks.

(2) The granite and volcanics (primary rocks of the region) are not good hosts for ground water accumulation except in joint planes, fractures and the weathered mantle. The Quaternary formations consist of blown sand, younger alluvium and older alluvium and are good hosts for ground water accumulation. Water-holding capacity of these lithological formations has deteriorated due to development of secondary salts. Ground water from weathered granite is by far the best which is followed by water available in order of descending salt concentration, weathered volcanics, older alluvium, younger alluvium and blown sand.

(3) In this region only phreatic water bodies, and in particular only perched water bodies, are being exploited. These bodies, through having the same origin and lithological formation, differ in their static water level, discharge potential and concentration of total soluble salt. These variations are related to their geomorphic setting.

(4) Regression equations have been worked out for quick and proper classification of ground waters and discriminant functions have been used for correlating the chemical quality of water with lithology. Instead of adopting any standard classification for assessing the quality of ground water for irrigation, consideration should have been given to the local practices of utilizing ground water.

(5) Considering the chemical quality of water for irrigation, ground water from blown sand, younger alluvium and volcanics is satisfactory.

(6) During the process of percolation through the zone of aeration and infiltration the primary rainwater which has bicarbonate changes to chloride water through sulphate water, as the concentration of total soluble salt increases.

(7) For proper planning of the ground water exploitations, present ground water exploitation zones have been classified as over-exploited, sparsely exploited, under-exploited and unexploited. More emphasis has been given to the ground water requirements for the population and irrigation. Along with these, the bottlenecks in the development of ground water exploitation have been stressed.

(8) This region has fairly good ground water resources and their exploitation for irrigation is limited due to deep-seated water, high cost of mechanization and power, undulating relief of the terrain, high cost of digging wells and failure of tube-wells, and slow recharge rate of the aquifers.

(9) The exploitation activities should be restricted and measures to improve recharge of the aquifers to be adopted in the over and sparsely exploited zones. The exploitation activities should be enhanced in the under-exploited region keeping in view the maximum draft they can stand. In the unexploited regions fresh exploitation for ground water should be undertaken with the help of hydrogeological studies aided by geophysical techniques and core drilling.

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DISCUSSION

P. G. Adyalkar: Can the water-holding capacity of Jalore granites and Malanis be expressed in terms of l.p.s. on the basis of the work of the author?

P. C. Chatterji: The water-holding capacity has not been worked out in terms of litres per second so far. Efforts will be made to work it out.

B. Ramamoorthy: Have you considered quick methods of analysis of Ca and Mg by versinate and computing SAR from this and conductivity?

P. C. Chatterji: The recent work by Mondal and Jain indicates the possibility of determining Na, Ca, Mg, Ca+Mg, SO_4, Cl, etc., from electrical conductivity by the use of regression equations. They have compared the results with the actual laboratory results. Quick determination of radicals expedites the hydrogeological investigation. Moreover, its applicability for a region should be first determined.

K. V. Raghavarao: Is it a new fascination for wording in the ground water hydrology like "metamorphism" by the author for chemical zoning when this word is not universally in use?

P. C. Chatterji: The chemical zoning indicates the distribution of various types of ground waters, whereas the metamorphism indicates the descent or chemical changes in the precipitated water which occurs during the course of infiltration through the zone of aeration. This expression is widely accepted and has been used by various hydrogeologists in other countries.

EFFICIENT USE OF WATER RESOURCES IN INDIAN ARID ZONE[1]

by

V. V. DHRUVANARAYAN, SHRI NIWAS & K. N. K. MURTHY[2]

INTRODUCTION

IN THE Indian arid zone the chief source of replenishing the water resources is rainfall which is also very low. According to Ramanathan (1952) the average rainfall of western Rajasthan, which constitutes the major part of north-western Indian desert, is only 280 mm, 90 per cent of which falls during the hot months of June to September when the evaporation losses are very high. A large proportion of the rainfall, therefore, goes back to atmosphere through evaporation and transpiration resulting in inadequate replenishment of water resources and improper utilization of land. These poorly replenished water resources may, however, be classified into two main categories of (a) surface water resources and (b) underground water resources. Of course, the ground water is not independent of surface water as the recharge of ground water is accomplished through surface stream flow. Therefore, the development of any one or both the types of water resources constitutes the most important factor in attaining the optimum utilization of cultivated and grazing lands in this region. The paper gives the broad outlines of water resources of Indian arid zone and indicates the possible measures which may be taken up for their development and efficient utilization.

SURFACE WATER RESOURCES

The streams in this region are mostly ephemeral and they flow when torrential storms occur. The Luni is the only organized river system in western Rajasthan. It rises from the Aravallis near Ajmer; and is lost in the Rann of Kutch. It is entirely a rain-fed river and remains dry in non-monsoon period. A study of different hydrological phases showed that the ground water resources of the Luni basin are recharged at a slow rate by hilly catchments in Udaipur and Ajmer regions, where the rainfall is comparatively high and infiltration rates are low. In the Luni, the water is sweet up to Balotra, but lower down it becomes saline up to the Rann of Kutch. The main tributaries of the Luni are the Lilri, Mithri, Sukri, Guhiya, Bandi, Jojri, Jawai, Bandinadi, Sukrinadi and Saginadi. As the flow in most of these streams is of very short duration to develop a stable channel section, occasional high flows change the cross-section radically. Sometimes, an almost stable channel section which had been used for years is abandoned after a heavy flood carrying high amount of silt load and a new channel is developed in a different location.

No regular river-gauging has been done so far to establish the amount of surface water available at various localities. Dhir and Krishnamurthy (1952) computed the surface water potential of the Luni basin using Strange's table and considering the nature of catchment as bad. They concluded that there is nearly 0·42 m a. ft of available surface water potential in the basin. Dhruvanarayan (1963) reported after computing the surface water of the Luni basin on the basis of monsoon rainfall of the region and using Strange's constants as $5{\cdot}714\times 10^8$ cu m. The runoff index also varies because of varying rainfall pattern in the same types of catchments in different areas as indicated from the computed values of runoff index for the Luni and the Sukrinadi catchments falling in SOI toposheet No. 45C for the year 1960. The data are given in Table 1.

TABLE 1: Probable runoff index for the year 1960 based on Strange's coefficients.

Sl. No.	*Name of catchment*	*Area*	*Rainfall*	*Runoff index based on daily rainfall*
1	Luni river	4107 sq km	156·19 mm	16·81 mm
2	Sukrinadi	4937 sq km	335·28 mm	47·49 mm

It is observed that the runoff index of the Sukrinadi catchment is higher than that of Luni catchment because of favourable rainfall pattern, when calculating the runoff on the basis of Strange's table for daily rainfall.

In the Luni basin 31 main storage tanks are functioning at present. The total utilizable capacity of these tanks is nearly 366·1079 million cu m and cultivable commanded area 6003·58 sq km. Out of these, six reservoirs, viz. Jaswant Sagar, Sardar Samand, Jawai, Hemawas, Ora and Bankali, are the major ones irrigating more than 4000 hectares each. Small surface water tanks are, however, found in

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Hydrologist, Assistant Hydrologist and Assistant Hydrologist, respectively.

most of the villages in the region. For example, in Jalore Block, these surface tanks exist in villages Panwa, Odwara, Debhawas, Mespura, Mithri, Deoki, Desu and Sedira, holding water for nearly 8-9 months. In Saila Block, village ponds do not hold water for long periods due to high percolation and evaporation losses as observed in ponds of villages Pegupura, Birana, Baetu, Bautra and Megalwa, where the water was found to last for only 2-4 months in the year.

GROUND WATER RESOURCES

Essentially all the water that is stored in the rocks of western Rajasthan originates as rain. So far, there is no evidence of the presence of continuous aquifer in this region. They exist only in patches with varying hydrological properties. Auden (1950) stated that the Malani rhyolites are almost barren of water and three types of Pre-Cambrian granites also are barren of water except in small quantities along joints. The depth of water-table varies with varying yielding capacity of wells. The hydrological data of sampled wells of important localities of six districts of western Rajasthan have been given in Table 2 to show the differences in water-yielding capacity of wells.

TABLE 2: Hydrological data of wells of important localities of western Rajasthan

Sl. No.	*Name of village*	*Name of district*	*Depth of water-table m,*	*Dis-charge per hour Litres*	*Remarks*
1	Siwana	Barmer	15·55	36,000	Open well
2	Dewara	Barmer	12·58	31,500	Open well
3	Gadra Road	Barmer	104·80	2,700	Tube-well
4	Bituja	Barmer	9·75	27,000	Open well
5	Bunda	Jaisalmer	95·25	9,000	Tube-well
6	Fatehgarh	Jaisalmer	95·50	90,450	Tube-well
7	Dabla	Jaisalmer	74·37	90,450	Tube-well
8	Burragarh	Jaisalmer	69·40	86,400	Tube-well
9	Sirohi	Sirohi	11·75	6,750	Open well
10	Kalandri	Sirohi	12·55	2,250	Open well
11	Swarupganj	Sirohi	12·00	22,500	Open well
12	Pindwara	Sirohi	21·00	6,750	Open well
13	Rohira	Sirohi	18·00	28,125	Open well
14	Nagaur	Nagaur	33·00	40,500	Tube-well
15	Bhinmal	Jalore	7·00	36,000	Open well
16	Jalore	Jalore	6·50	9,000	Tube-well
17	Sojat	Pali	9·00	9,000	Open well

So far only one isolated sizeable pocket of good ground water has been delineated in Rajasthan near Chandhan as reported by Mahavir Prasad (1962). This promising zone is confined to Lathi Series where the discharge is 200 kilo litres per hour at a steady drawdown of 5·5 m. The average static water level is 36 m below ground level. The water has been found suitable for all purposes including domestic, livestock and irrigation. Taylor *et al.* (1955) concluded that the older alluvium of Pali region gives the water yield ranging from 4000 to 30,000 gallons per day. About Bikaner tract, Taylor (1952) stated that the principal water-bearing beds in the Bikaner formation are fine sandstones and soft conglomerates which are intercalated with limestones and shales, but the water yield is quite good ranging from 1500 to 16,000 gallons per hour. Large differences exist in depths of water-table between the places which are not far off, as is evident from the hydrological observations recorded for over 100 wells by the Basic Resource Survey Division in Jalore Block, where it varies mostly between 4 and 15 m. In Saila Block also the water-table is as shallow as 3 m below ground level in village Narsana, while in Rautra it is as deep as 31 m b.g.l. Similar variations have also been observed in the water yield of wells situated at small distance apart. In Saila Block the maximum discharge rate of about 58,400 litres per day has been recorded near Megalwa and a minimum discharge of only 11,000 litres in a day near Dewara. In Jalore Block the draft per well is higher in younger alluvium as compared to that of many wells in winter season.

The quality of water also is variable in these tracts. Taylor *et al.* (1955) working in Pali region reported that the average chemical quality of ground water of older alluvium is slightly superior than that in younger alluvium. But recent studies have shown that the water in the wells situated in the younger alluvium is generally sweet, while in older alluvium it varies from moderately saline to saline. In Jalore Block nearly 35 per cent wells are situated in younger alluvium and they contain sweet water with electrical conductivity below 2000 micromhos/cm at 25°C. Similarly, in Saila Block the electrical conductivity of well water of Paharpura situated in younger alluvium was recorded as low as 376 micromhos/cm, while it exceeded 17,850 micromhos/cm for well water of Kalapura situated in the older alluvium.

The extent of exploitation of ground water also varies in these regions. Some wells are over-exploited while, on the other hand, many wells are left unexploited. In Jalore Block water columns in the wells near foothills are quite high and are even up to 12 m, but the water is not being utilized as the water lies at depths up to 36 m below ground level. In Saila Block in village Narsana, sweet water has been found at 40 m depth, and approximate yield of 50,000 litres per day has been recorded. The villagers are not using this water as it is beyond their means to lift it. The supply of economic pumping sets will go a long way in exploiting the available water resource of such areas.

MEASURES FOR DEVELOPMENT OF WATER RESOURCES AND THEIR EFFICIENT USE

At present the number of watering-points in this area are inadequate for the large concentration of human population and grazing animals. This results in degradation of vegetation near watering-points leading to soil erosion, while considerable fodder resources in the interior are left unutilized due to lack of water. The under-grazing lands result in consuming almost the whole of water available from rainfall through evapo-transpiration, and no water is yielded as runoff or ground water from catchments which could be used for animals for drinking. Christian (1959) reported that migration of animals from Jaisalmer and other dry districts is more due to lack of water rather than to lack of fodder. By increasing the number of watering-points it is possible to have adequate water for animals and in consequence it will result in the more effective utilization of grazing in rangelands. An increased number of watering-points may be created either by locating the ground water aquifers or by surface storage. The size of surface storage tank should be such that the area exposed for evaporation is minimum. Taylor *et al.* (1955), while investigating the water resources of Pali region, reported that the inhabitants of western Rajasthan feel that two good storms of nearly 10 cm in 24 hr, first in June and the other in September, are adequate to replenish tank storages. The estimation of runoff by Strange's coefficient for the last 20 years for different places of the Luni river basin indicated that it is possible to establish medium-size storage tanks in the average and good catchments of semi-arid tract. Such storage sites have been located in Jalore Block in areas where the ground water is very deep or highly saline for use. Small dug-out type of ponds may also be set up in most cases in these areas. However, where the soils are highly permeable, these dug-out ponds may be provided with low-cost lining such as puddled earth or soil-cement. The small covered underground reservoir known as *Tanka* has also great potentiality in these areas. Mahendra Prakash and Gopinath (1962) have stated that *Tanka* has great scope in western Rajasthan and it takes care of losses both by evaporation and percolation. The observations recorded on a rectangular type *Tanka* (25 ft $\times$ 16 ft) situated in a grassland near Ustaran (Jodhpur) go to prove its good performances by minimizing the storage losses to a great extent.

For increasing the production of forage in rangelands which belong to land capability classes IV, V, VI and VII, the different soil and water conservation practices including water-spreading, bunding and furrowing have great scope in arid regions. In areas, where the upper portions of catchments are hilly and rocky, the runoff causes soil loss. By putting suitable structures across the gullies and the water spread out in the land it is possible to reduce this erosion. Such water-spreading serves several objectives such as ensuring greater forage production from superior quality grasses of perennial species and recharging the ground water-table in addition to checking the soil erosion by water and wind. The water-spreading work done in a grassland area near Samdari could almost check the erosion caused by torrential runoff of 3 m deep gully within 4 years, and at the same time increase the forage yield up to 60 per cent of the original. Kanitkar (1952) recommended that contour bunds of 1 or 2 ft height may be quite sufficient for Rajputana desert areas. A rangeland near Jadan (Pali) which had been bunded at 2 ft vertical interval showed average soil moisture as high as 3·78 per cent during the driest part of the year as compared to only 1·54 per cent in the land with no contour-bunding. Such retention of moisture is conducive to greater forage production. Contour furrowing is of great use involving the maximum utilization of water resources at a low cost. A grassland area near Jethana (Ajmer) which was contour furrowed at 20 ft spacing showed average soil moisture up to 5·26 per cent; without furrows it had only 1·93 per cent of average soil moisture at 0·15 m depth. The contour furrowing in other grassland areas also indicated significant increase in forage production. This increase in forage more than compensated for the expense involved in this operation in 3-4 years. Thus, for efficient utilization of grazing resources in western Rajasthan measures including executing the moisture conservation practices and providing more watering-points are essential.

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HYDROGEOLOGY OF THE RIVERINE PLAIN OF S.E. AUSTRALIA[1]

by

S. PELS[2]

INTRODUCTION

THE geological subdivision of alluvial sediments on the Riverine Plain in New South Wales has a distinct bearing on ground water aspects, both on its distribution and quality.

The Riverine Plain has an area of 26,000 sq miles and its present climate ranges from semi-arid in the east to arid in the west.

Most irrigated areas in New South Wales are situated on the plain. Water is diverted from the main rivers, which are regulated by storages in the eastern highlands.

The major portion of the plain is older alluvium, but the minor occurrence of younger alluvium was found to have a dominant bearing on ground water distribution in the region. Younger alluvium is restricted to a system of ancient and relict rivers which were termed 'ancestral rivers'.

Recent tectonic movement has diverted the ancestral river system and this provided a unique opportunity to study the processes which were responsible for its formation.

The partial superposition of the ancestral and present-day river systems has resulted in the present rivers having many anomalous characteristics. The most striking of these anomalies is the presence of a flood plain and source bordering sand-dunes in some sectors and their complete absence in others.

Visiting scientists of the Jodhpur Central Arid Zone Research Institute have commented that similar anomalies apply to some parts of the river systems in Western India and that ground water availability and quality varied with younger and older alluvial sediments.

The delineation of these two groups of alluvia is, therefore, of practical importance and it is in this light that a description of investigations in Australia and a comparison with results obtained in this part of India may be of mutual benefit.

OLDER ALLUVIUM

Study of the general geological map of the southern portion of the Riverine Plain in New South Wales shows that the older alluvium forms an aggradational landform displaying a pattern of prior stream relics representing the final widespread phase of deposition. At the close of this phase, the plain may, therefore, be visualized as having been devoid of other rivers of transit, as occur today, and only displaying this prior stream pattern which largely dissipated on the plain. There is evidence to suggest that this final phase occurred in the Pleistocene and the cross-section shows a typical prior stream relic. Patterns of soil distribution are governed by the prior stream pattern with sandy soils in the stream beds, medium-textured soils on the levees and heavy soils on the flood plains.

Because of the stream bed's relatively high topographic position, prior streams play a minor role in ground water intake during floods. Their intake is restricted to the low rainfall which prevails in the region. An exception to this general rule applies where prior streams are intersected by younger alluvium.

Along the western boundary of the plain a zone of transition from *alluvial* sediments to older mallee (uplifted lacustrine) sediments occurs which is characterized by dry lakes, lunettes and mallee outliers.

The prior stream pattern of the older alluvium is thought to represent deposition under relatively arid condition and the numerous source-bordering sand-dunes on the leeward side of the prior streams were derived from the stream beds during the seasonal fluctuations within this period of aridity. Lunettes associated with the lakes of the western transition zone were probably formed during the final stages of older alluvium deposition and are thought to have been in existence before the period of younger alluvium deposition which forms the main theme of this paper.

YOUNGER ALLUVIUM

Following the deposition of older alluvium, described above, a phase of large-scale incision occurred and resulted in a system of deep and wide channels being cut across the plain. Those channels which were subsequently filled with coarse sediments were termed 'ancestral rivers'. The study of cross-section indicates a typical ancestral river. This phase of ancestral

1. Contribution from Regional Research Officer.
2. Water Conservation and Irrigation Commission of N.S.W., Deniliquin, Australia.

river activity was interrupted by tectonic movement which also vertically displaced relict prior streams. Diversion patterns around the fault line indicate that the younger alluvium of the ancestral river system was capable of further subdivision.

The evidence now indicates that there were three major phases of ancestral river activity, each consisting of a degradational and aggradational subphase. The entire sequence consists of one pre-tectonic non-diverted phase and two post-tectonic diverted phases.

It was shown that the first phase was not diverted and observations downstream from the fault line have shown that the non-diverted river went through both degradational and aggradational subphases.

The diversion, therefore, could not have been a simple one and subsequent phases of entrenchment and aggradation occurred, assuming that degradation took place under pluvial conditions and aggradation under arid conditions.

Tectonically induced topographic changes in the landscape, together with a partial combination of the present and ancestral river system, are responsible for the differing character of the Murray river down its course.

It now consists of three different sectors: (1) the eastern sector where the three phases are superimposed; (2) the central sector where the three phases are largely separated; and (3) the western sector where the three phases are again superimposed.

The terraces represent remnants of the upper surfaces of the infilled ancestral rivers and now form the 'flood plain' of the present rivers, where they are superimposed on them. In the central sector, however, the present rivers commonly have deserted the younger alluvium and have incised independently through older alluvium with a complete absence of terraces. It is here that the younger alluvium can be located well away from the rivers. These deserted flood plains are found in the landscape as depressed linear belts of slightly undulating country, up to one and a half miles wide and commonly have source-bordering sand-dunes on their leeward side. In the absence of drainage by incised present rivers, these areas of younger alluvium are an asset, as a ground water source in dry country, but commonly become waterlogged problem areas in irrigated districts.

PRACTICAL IMPLICATIONS

Apart from explaining the many geomorphological features of the landscape which were previously regarded as anomalous, the delineation of younger alluvium within the older sediments has proved to have many practical applications. These include:

1. Location of fresh ground water supplies: Results of pump tests have shown that the younger alluvium contains water with much lower salinities, and characteristically, transmissibility values are higher, thus allowing higher pumping rates from these sediments.

Pump test data below demonstrate this —

Aquifers in	*Coefficient of transmissibility sq ft per sec.*	*Coefficient of storage %*	E.C. $\times 10^6$ 25°C	*Remarks*
Older alluvium	0·071	0·082	38,000	Average from all sites tested (26)
Younger alluvium	0·299	0·512	4,700	Average from all sites tested

2. Replenishment of ground water: This takes place in two ways, i.e.
   (a) During normal river flow: Where the present river is situated on the younger alluvium the underlying coarse sediments are continually being charged. Where the present river leaves the younger alluvium and travels independently through older alluvium, the ground water and surface flow separate and ground water follows the younger sediments.
   b) During floods: Although normal flows follow the present newly incised rivers, as soon as the flow exceeds the channel capacity of the present rivers, flood flows follow the path of ancestral rivers (younger alluvium).

It is in times of high floods, therefore, that ground water replenishment takes place throughout the younger alluvium. This includes the deserted flood plains.

Original ground water levels on the plain verify this. In the south-west corner of the plain where ancestral rivers are closely spaced, depths to ground water of 25-30 ft were recorded as compared with depths in excess of 120 ft in the north-east.

3. Hydrologic hazards: Where irrigated, the younger alluvium is much more liable to excessive water intake and waterlogging than is the older alluvium. The accurate delineation of these sediments is, therefore, important in order that they may be irrigated differently from the adjacent sediments. Location of channels and drains is of particular importance in this respect.

4. Agronomic considerations: Here again delineation is important as the younger sediments are more fertile and often lighter textured so that farm subdivision according to sediments is required for optimum land use.

5. Drainage of waterlogged areas: Where areas are waterlogged, the more effective tube-well drainage

sites are on the younger alluvium, which consists of semi-confined aquifers with high coefficients of transmissibility. The lower salinities of the ground water also facilitate disposal of pump effluent either for irrigation use or into the present river system with the least salt accession to its flow.

6. Ground water storage: The younger alluvium of the ancestral rivers in New South Wales is a storage system with natural annual replenishment, running from high rainfall country, through semi-arid areas into arid regions.

Apart from the Murray river system, other inland regions may have similar systems. Features resembling ancestral rivers have been mapped in Western Queensland and in Western Australia. Other rivers in New South Wales are also known to have been diverted and to have deserted their former 'flood plains'. Examples are known along the Lachlan river where younger alluvium occurs 15-20 miles away from and parallel to the present river for a distance of 55 miles. An estimated 250,000 acre ft of ground water occurs in these sediments which form a regularly replenished ground water reservoir, free from evaporation losses, in an arid region. There are a number of other situations in New South Wales where the configuration of younger alluvium is now being mapped and investigated for ground water exploitation.

DISCUSSION

K. V. Raghavarao: Mr Pels stated that the estimate of ground water in the younger alluvium is of the order of 250,000 acre ft. Could he kindly enlighten us with the methodology on which this estimate is based ?

S. Pels: The estimate of ground water reservoirs is based simply on the known volume of the aquifer and its estimated porosity.

G. B. Maxey: This method of investigating ground water aquifers in the arid tract is admirable. This may be followed in the Indian arid zone.

S. Pels: Are the observations made in the arid tract of Australia; that the younger alluvium along the prior and present river courses contains good reservoirs of ground water of good quality, confirmed by the findings in the Indian arid zone ?

B. Ghose: Yes. The sweet water is found in good quantity in the younger alluvium derived from along the Luni and the Jawai river catchments.

ECOLOGICAL AND BOTANICAL SURVEYS

ECOLOGICAL STUDIES OF SAURASHTRA COAST AND NEIGHBOURING ISLANDS: III. OKHAMANDAL POINT TO DIU COASTAL AREAS[1]

by

T. ANANDA RAO & K. R. AGGRAWAL

INTRODUCTION

COASTAL terrestrial ecology in India has scarcely entered the broad phase of detailed ecological studies and descriptive phytogeography. However, attention had been paid on the mangrove vegetation (1957) and algae (1959) occurring in some parts of sea coast in the States of Bengal, Orissa, Andhra Pradesh, Madras, Kerala, Mysore, Maharashtra and Gujarat. The few ecological investigations on coastal plant communities are from the coasts of Tinnevelly (Fyson, 1919), Dwarka (Borgesen, 1929), Bombay (Satyanarayan, 1958), Konkan (Jain, 1962), Cape Comorin (Lawrence, 1963); recently attention has also been given to islands off the coast (Rao *et al.*, 1963, 1964). In the present paper is given an account of plant communities and habitats in the coastal areas of Saurashtra from Okha point to Diu Island.

GENERAL DESCRIPTION OF THE AREA

Saurashtra in Gujarat State, lying on the west coast of India between 20°40′ and 23°25′N latitude and 69°05′ and 70°20′E longitude, is a square peninsula projecting out into the Arabian Sea. Its physical features indicate that it may once have been an island, or a group of islands, of volcanic origin. Between Saurashtra and the mainland of Gujarat there is a belt of salt land interspersed with occasional marshes and pools suggesting that at one time a channel joined the Rann with the Gulf of Cambay, and that the entire northern region of Saurashtra from the Gulf of Kutch to Cambay was once washed by the sea. The silt from the Indus, the Sabarmati and other rivers has gradually filled up the shallow sea and joined north-western Saurashtra with the mainland. Except for this alluvial tract, Saurashtra is everywhere an undulating plain, or is broken into hills which are higher in the south and west than in the north and east. The highest tableland is in the centre of the peninsula from which rivers run in all directions. The surface rocks are limestones in the south and sandstones in the north. The higher hills are of granite and the lower of trap and basalt.

Saurashtra is bounded by the Arabian Sea in the south and south-west, by the Gulf of Kutch in the north-west and by the Gulf of Cambay and mainland Gujarat in the east. Lying between the deserts of Sind and the wet lands of the Western Gujarat State, Saurashtra represents in the nature of both. It has the barrenness of one and richness of the other. There is a variety of scenery, with arid sandy tracts in the west, desert vegetation in the east and thick forests in the Gir, where perennial streams flow through picturesque glades. The Rann is a desolate waste, but to the south-west the coast is covered throughout the year with shady groves and green fields.

Saurashtra can be divided physically into three regions, the coastal lands, the inland plain and the hills.

The coastal lands with which we are mainly concerned may again be divided into four different parts on the basis of the conditions of soil, slope, drainage and climate (Janaki, 1955).

(a) *The Gulf of Kutch to Okhamandal*: This is throughout a line of low reefs and muddy foreshore fringed with mangroves, low ugly stretches, often transformed by the mirages into shifting scenes of rock and castle, and shady groves and still lakes.

(b) *Okhamandal to Diu*: It is a region about 160 miles long. This region is generally arid and fringed with a line of wind-blown sand humps.

(c) *Diu to Gopnath*: This part, about 80 miles long, presents a succession of cliffs of moderate height sometimes hollowed by the sea into caverns. Seen from the sea this region has a pleasing appearance with rolling plains, palm groves, broad estuaries and glimpses of distant hills.

(d) *Gopnath to Amli*: It is a low muddy foreshore, about 70 miles long, lined with mangroves, partly rocky and sandy.

The coastline on the whole is broken by mouths of rivers and creeks and sometimes the sea gains access to salt marshes and mangrove bushes.

Ecological studies of the Okhamandal to Diu coastal area between latitudes 22°29′ and 20°43′N and about 160 miles long (256 km) form the subject of this paper. Adjacent portions averaging 4-5 miles (6·4-8 km) in width of the semi-arid coastal plain are also included. Okha, Dwarka, Porbandar, Mangrol,

1. Contribution from the Ecology Section, Botanical Survey of India, Calcutta 14.

Veraval (Somnath) and Diu are the more important places in this region.

CLIMATE

The climate of this coastal region (Okhamandal to Diu) is arid to semi-arid. In the extreme north, i.e. at Okha, Dwarka and their environs, it is recognized as arid or desert type, but as the rainfall increases southwards it changes into the semi-arid type. The mean annual rainfall of 13·93 in. at Dwarka increases to about 20 in. at Porbandar and Veraval, with a further increase to about 40 in. at Diu. The vegetation of coastal situation is determined primarily by environmental factors such as tides, wave action, sea-winds, saline water and the nature of the substratum; the change in vegetation due to the effect of the increased rainfall near Porbandar, Veraval and Diu is not appreciable at least in the coastal area; and almost similar vegetation is present throughout this region. Except for a few fitful showers the rain comes in June to October during the months of the south-west monsoon. The main features of climate, temperature, humidity and rainfall for the two meteorological observatories at Dwarka and Veraval for which climatological data are available are presented in Table 1. The severity of the weather on account of high temperatures, high humidity and low rainfall is compensated to a considerable extent by the sea-breezes which make the climate moderate during the day and pleasant during the night.

TABLE 1: Climatological data of Dwarka and Veraval

Month	*Temperature °F*		*Relative humidity*		*Rainfall*	
	Daily max.	*Daily min.*	*8.30 hr.*	*17.30 hr.*	*Mean monthly total in.*	*No. of rainy days*
Dwarka: Lat. 22°22′N, long. 69°05′E, height above MSL 37 ft						
January	77·9	59·5	70	44	0·10	0·3
February	78·5	63·2	74	57	0·24	0·5
March	82·3	70·6	79	64	0·11	0·2
April	85·1	76·4	86	74	0·03	0·1
May	88·0	80·6	86	77	0·02	0·1
June	89·3	82·4	85	75	2·01	2·3
July	86·7	80·7	86	80	6·95	6·0
August	84·7	78·6	89	78	2·58	3·8
September	85·2	77·7	88	77	1·47	2·0
October	87·3	75·5	82	73	0·25	0·3
November	87·1	68·7	70	49	0·08	0·1
December	81·2	61·9	67	38	0·09	0·2
Annual total or mean	84·4	73·0	80	65	13·93	15·9
Veraval: Lat. 20°55′N, long. 70°22′E, height above MSL 26 ft						
January	82·0	59·8	53	60	0·04	0·1
February	81·8	61·1	59	66	0·07	0·2
March	85·6	66·1	66	72	0·05	0·1
April	86·2	72·4	77	81	0·00	0·0
May	86·1	78·7	85	84	0·28	0·3
June	86·5	81·5	85	86	4·66	3·9
July	84·0	79·8	88	89	7·78	9·2
August	82·5	78·2	89	87	3·61	5·9
September	83·7	76·8	87	86	2·49	3·9
October	89·1	73·3	69	76	0·62	0·8
November	89·2	68·1	55	68	0·17	0·2
December	84·7	62·7	52	63	0·07	0·2
Annual total or mean	85·1	71·5	72	76	19·84	24·8

GEOLOGY AND SOILS

In the coastal areas of Saurashtra the following geological formations are found:

1. Recent and subrecent: Alluvium, blown sand, miliolites, tidal flats, raised beaches.
2. Tertiary: (i) Pliocene or (post-Pliocene) — Dwarka beds
   (ii) Miocene — Gaj beds

The rocks which have been correlated with the *Gaj Series* (of Sind) of Lower Miocene age occupy a portion of the coastal tract in western Saurashtra, and are best exposed near Okha. These nearly horizontal beds are several hundred feet in thickness. The constituents are highly fossiliferous and consist of clays, sandstones and conglomerates.

These Miocene rocks of Saurashtra have been overlain by gypsiferous clays and sandy foraminiferal limestones which are called *Dwarka beds.* Some of these are composed entirely of organic fragments, shells and corals. In the south-eastern part the Tertiary rocks are rare except in the Piram Island in the Gulf of Cambay, where a remarkable assemblage of mammalian remains (Mid. Siwalik) are found.

A foraminiferal limestone known as *Miliolite limestone* (Porbandar stone) and newer alluvium occur mostly in the western coastal areas of Saurashtra.

The foreshore of the area is generally exposed rock consisting mainly of marine limestone and hollowed by the sea into caverns. This rocky area is interrupted by water laid sands, which cover the underlying rock at certain places but are invariably followed by wind-blown sand, which often gives rise to sand humps. Much of the sand is of marine origin, composed of shells of marine microfauna and mollusca; it contains a high proportion of $CaCO_3$ and small proportions of quartz, felspar and heavy mineral particles. These sands are poor in organic matter. The thin cover of light brown sandy soil at Dwarka and its environs on the seashore is mixed with gravel pieces from the underlying calcareous conglomerate rock. The soil in the salt pans, creeks and mud formations is coarse sandy mud or black mud mixed with broken shells as a result of the presence of organic matter, the loose rock pieces having a coating of soft black organic matter.

METHODS

The vascular flora was studied in different seasons during the years 1962-64. Kassas' method (1957) of using Braun Blanquet's (1932) method of description is adopted while describing plant communities grouped into three ecosystems: (1) strand, (2) salt marsh, and (3) semi-arid coastal plains. In this way the natural vegetation is analysed into several plant communities grouped into the above three ecosystems. Each community type is recognized by its plant cover and habitat. The plant cover is identified by its dominant species and the habitat by its edaphic features. For each community type five stands have been recognized. The species present in the stand are listed with indices of cover — abundance and sociability as described by Braun Blanquet (loc. cit.). Braun Blanquet's description is used throughout, but not his concept of 'association' nor his method of classification. Each stand is a uniform sample site with uniform distribution of the dominant species and uniform habitat.

To study soil features in relation to plant communities, soil samples were analysed for mechanical composition, *p*H, organic matter content, total dissolved solids, sodium chloride and calcium carbonate by the methods referred to by Rao *et al.* (1964) except that *p*H determinations were made by the Cambridge direct reading *p*H indicator on 1: 5 soil: water suspensions. The mechanical composition of only the samples with less than 50 per cent $CaCO_3$ was determined after removing the same by treatment with dilute HCl.

VEGETATION AND SOIL

The vegetation based upon the ecosystem is studied under the following heads: I. Strand, II. Salt marsh, III. Semi-arid coastal plain.

I. *Strand vegetation*: The strand habitat is the portion of the land immediately adjacent and parallel to the seashore under the direct influence of salt spray. Strand communities can be studied under two subheads: (A) Sandy strand, and (B) Rocky sandy strand.

(A) Sandy strand: The sandy strand habitat either at the top of the beach ridges or on rocks with a thick mantle of sand above tide level has many interesting plant communities. These communities are composed of either halophytes or psammophytes. Only plants adapted to such rigorous conditions can be found here. Since the habitat is more or less uniform over vast distances, the same species with a wide range of distribution can be seen almost everywhere on tropical beaches. *Ipomoea pes-caprae* is one of the most widely distributed of seashore seed plants and forms the dominant community on the sandy shores. Besides plants of worldwide distribution, a few local additions to this strand flora in different regions could also be seen.

Under the sandy strand ecosystem nine subdivisions or community types have been recognized: Community of (i) *Hydrophylax maritima*, (ii) *Ipomoea pes-caprae*, (iii) *Asparagus dumosus*, (iv) *Halopyrum mucronatum*, (v) *Cyperus conglomeratus*, (vi) *Cyperus aristatus*, (vii) *Sporobolus tremulus*, (vii) *Leptadenia pyrotechnica*, (ix) *Cynodon dactylon*.

(i) Community of *Hydrophylax maritima*: The community type dominated by *Hydrophylax maritima* occupies the sandy seashores within the littoral zone near Veraval/Mongrol coast. This type does not form extensive patches but is found scattered in colonies occasionally mixed with *Cyperus conglomeratus*, *C. aristatus* and *Sporobolus tremulus*. Slightly away from the sea beaches in the inland sandy areas, the presence of *Dactyloctenium aegyptium* and *Psilostachys sericea* mixed with *Hydrophylax maritima* can also be seen.

(ii) Community of *Ipomoea pes-caprae*: This excellent sand-binder is found all along the coast, but its most extensive development was noticed at Somnath, Dwarka/Okha and Porbandar coasts. Either it forms a pure stand or is sometimes found associated with other strand plants like *Cyperus conglomeratus*, *C. aristatus* and *Sporobolus tremulus*. Occasionally inland, where sea-sand has been transported and deposited, it forms extensive patches. On such sea-sand spots it is found with *Psilostachys sericea*, *Melanocenchris abyssinica* and *Dactyloctenium aegyptium*.

(iii) Community of *Asparagus dumosus*: This community type is found growing on sandy bars. It does not form a thick vegetal cover but only scattered patches. This plant is often grazed, but attains a shrubby habit if protected. The present survey has indicated its occurrence on Dwarka/Okha coast and also in Beyt Island near Okha. It is often found growing with *Cyperus conglomeratus* and occasionally with *Cyperus aristatus*, *Sporobolus tremulus* and *Melanocenchris abyssinica*.

(iv) Community of *Halopyrum mucronatum*: This community type forms large clumps and attains a good height if undisturbed. In the coastal areas it is a conspicuous component of the strand flora. Its occurrence in clumps of pure colonies or in larger groups was noted from Dwarka/Porbandar and Diu coastal sandy areas. Sometimes *Cyperus conglomeratus* and *Sporobolus tremulus* are present at the peripheral portion of the clumps. *Leptadenia reticulata*, a common climber in the adjacent plain areas, is also present in 20 per cent of the stands.

(v) Community of *Cyperus conglomeratus*: This plant is found associated with more or less all the community types of strand vegetation found throughout the coast. It forms tufts with long running rhizomes. It is often found forming gregarious patches with *Cyperus aristatus* and *Sporobolus tremulus*.

(vi) Community of *Cyperus aristatus*: This community type is a close associate of *Cyperus conglomeratus* on sandy bars. Towards the interior it is often found in association with *Cynodon dactylon* and *Melanocenchris abyssinica*. Sometimes its growth is very gregarious and it may form pure stands almost to the exclusion of other common associates.

(vii) Community of *Sporobolus tremulus*: This community type exhibits dense patches on dry sandy spots. It is found growing with *Dactyloctenium aegyptium* and *Cynodon dactylon*. In wet situations it represents 60 per cent of the stands. Its coverage and sociability increase with a change from wet to dry sandy condition towards the interior.

(viii) Community of *Leptadenia pyrotechnica*: This community type was found growing in abundance on the sand-dunes near Mandvi coast, often on thin mantle of sand along with *Cynodon dactylon* and *Melanocenchris abyssinica*. However, pure stands form gregarious bushes on the sand-dunes and tolerate burial by sand to a considerable extent. Wind-blown sand round the bushes produces huge mounds or hillocks.

(ix) Community of *Cynodon dactylon*: This ubiquitous grass is found throughout the coast adjoining the strand vegetation. It can tolerate varied habitats and forms extensive patches under wet conditions. Often its dominance is limited by the development of other community types.

The sandy strand habitat is composed of water-laid loose sands which have given rise to sand humps and sand hills. A major proportion of these sands at Okha, Dwarka and Veraval is of marine origin, composed of the shells of the marine microfauna, mollusca and coral fragments and is very rich in $CaCO_3$. Other quartz derived sands are also highly calcareous and contain small proportions of felspar and heavy mineral particles.

A reference to Table 2 will show that the texture of soils, which have been analysed for mechanical composition, is sand to loamy sand. *p*H values of all the soils from this ecosystem exhibit moderate alkalinity. Organic matter contents depending on the intensity and nature of the vegetation range between 0·02 and 0·64 per cent. Values of total dissolved 'solids and sodium chloride' contents point to the effect of salt spray but not to direct inundation with sea water.

(B) Rocky-sandy strand: The rocky-sandy habitat adjacent to the seashore is characterized either by the presence of sand in the rock crevices or by the presence of a thin mantle of soil over the underlying rock. The soil cover over the underlying rock at Dwarka has been formed by the weathering of the latter *in-situ*; actually it is mixed up with the conglomerate rock there, but at other places water-laid or wind-blown sands are present in thin layers over the underlying rock, and have become mixed up with the soil from the weathering of rock. The rocky-sandy ecosystem is represented by the following types of communities. Community of: (i) *Capparis cartilaginea*, (ii) *Fagonia cretica*, (iii) *Indigofera cordifolia*, (iv) *Kickxia ramosissima*, (v) *Lepidagathis trinervis*, (vi) *Sericostoma pauciflorum*, (vii) *Enicostema verticillatum*, (viii) mixed species.

(i) Community of *Capparis cartilaginea*: This is the significant community in the rocky-sandy localities. Under protection it grows in stature and dominates the habitat. The associated plants are mostly local species distributed between the ground areas supporting larger bushes. They are chiefly represented by *Kickxia ramosissima, Heliotropium tuberculosum, Echinops echinatus, Statice stocksii* and *Sclerocarpus africanus*. These plants are present to the extent of 60 per cent or more. The other significant associates are *Sericostoma pauciflorum, Lepidagathis trinervis, Indigofera cordifolia, Convolvulus glomeratus, Pulicaria angustifolia, Alysicarpus monilifer, Capparis decidua, Cleome gynandra* and *Polygala erioptera*. *Fagonia cretica, Celosia argentea, Trianthema* spp., *Pulicaria foliolosa* and *Blumea amplectans* are other species which are often recorded in this community type.

(ii) Community of *Fagonia cretica*: This widespread community extends all along the coast. Its chief associates are *Sericostoma pauciflorum, Heliotropium tuberculosum, Kickxia ramosissima, Trianthema* spp. and *Capparis decidua*. Another frequent associate is the woody *Statice stocksii*, which is present to the extent of 80 per cent in Dwarka/Okha coastal area. The remaining associates of this community type are the local plants already recorded under the community of *Capparis cartilaginea*.

(iii) Community of *Indigofera cordifolia*: This community type could be seen frequently stretching to considerable distances in pure stands. It is present up to 80 per cent under the protective shade of *Capparis cartilaginea*. *Enicostema verticillatum, Fagonia cretica, Sida ovata* and some local plants are the chief associates.

(iv) Community of *Kickxia ramosissima*: This community type is often found distributed all over the habitat, forming extensive patches in pure stands. A flat rocky habitat with a very thin layer of sand is ideal for this community, and its frequency decreases towards pure sandy situations. *Pulicaria foliolosa, Statice stocksii, Blumea obliqua, Alysicarpus monilifer* and *Pavonia patens* are other members of this community.

(v) Community of *Lepidagathis trinervis*: This woody stunted plant is found growing more in isolation than in extensive patches. Other associates are represented by *Sericostoma pauciflorum, Indigofera cordifolia, Pulicaria foliolosa, Echinops echinatus* and *Capparis decidua*.

(vi) Community of *Sericostoma pauciflorum*: This community type is found on the inland margins of pure sandy-rocky situations, forming conspicuous hemispherical mounds all along the coast. This

TABLE 2: Analysis of soil samples collected within the sandy strand habitat (0-10 cm depth)

Location and vegetation cover	*Soil colour*	*Mechanical composition*				*Soil texture*	*pH*	*Organic matter* %	*TSS* %	*NaCl* %	$CaCO_3$ %
		Clay %	*Silt* %	*Fine sand* %	*Coarse sand* %						
Sand bar, Okha *Asparagus dumosus*	dull white with some brown particles	1·9	15·6	40·2	42·3	loamy sand	8·3	0·08	0·039	0·028	45·67
Sandy hump, near light house, Okha *Cyperus conglomeratus*	dull white	——Not determined——				—	8·4	0·02	0·042	0·029	79·00
Sandy hump, near Burmah Shell, Okha *Cyperus aristatus*	do			do		—	8·4	0·21	0·060	0·036	92·90
Sandy shore, Okha *Halopyrum mucronatum*	do			do		—	8·4	0·61	0·155	0·118	72·95
Sand bar, Rupan, Dwarka *Cyperus aristatus*	dull white with brown particles			do		—	8·3	0·25	0·064	0·025	76·67
Dhuyu shore off Dwarka *Cyperus conglomeratus*	dull white			do		—	8·3	0·03	0·109	0·087	75·47
Sand bank, Porbandar *Asparagus dumosus*	dull white with brown particles			do		—	8·4	0·25	0·038	0·010	70·53
Sandy hump, Porbandar *Cyperus conglomeratus*	dull white			do		—	8·2	0·64	0·140	0·044	70·07
Sandy shore, Veraval *Hydrophylax maritima*	dull white with brown particles			do		—	8·2	0·58	0·085	0·048	65·65
Sandy shore, Somnath temple *Ipomoea pes-caprae*	mixed white, light brown and black particles	—	11·7	20·5	67·8	sand	8·3	0·25	0·038	0·013	31·73
Sandy shore, Tribeni Sangam, Somnath *Melanocenchris abyssinica*	white with black particles	—	8·6	16·3	75·1	sand	8·2	0·17	0·090	0·042	23·00
Sandy shore, Mandvi *Cynodon dactylon*	white	1·1	2·3	93·7	2·9	fine sand	8·0	0·43	0·108	0·068	28·52
Sandy hump, Mandvi *Melanocenchris abyssinica*	dull white	——Not determined——				—	8·2	0·32	0·160	0·022	55·73
Sandy, hump, Mandvi *Sporobolus tremulus*	do	7·0	0·7	92·0	0·3	fine sand	8·2	0·21	0·085	0·022	40·00
Dune field, Mandvi *Leptadenia pyrotechnica*	do	——Not determined——					8·2	0·11	0·050	0·014	55·63
Dune field, Mandvi *Leptadenia pyrotechnica*	do	3·7	20·9	71·0	4·4	loamy sand	8·1	0·18	0·165	0·018	49·36
Base of mobile dune, Mandvi *Sporobolus tremulus*	dull white with brown particles	3·6	2·5	78·8	15·1	fine sand	8·0	0·29	0·060	0·008	26·63
Base of consolidated dune, Mandvi *Leptadenia pyrotechnica*	dull white with blackish tinge	2·2	4·9	91·9	1·0	find sand	7·9	0·63	0·175	0·008	22·18

community exhibits a scattered disposition on the habitat and is sometimes found mixed up with *Statice stocksii* and *Lepidagathis trinervis*.

(vii) Community of *Enicostema verticillatum*: This community type occurs in moist sandy-rocky habitat. It occurs in patches, sometimes extending inland. It forms a significant component of the rocky-sandy habitat along with *Sericostoma pauciflorum, Statice stocksii* and other local plants.

(viii) Community of mixed species: The habitat occupied by this community is situated slightly away from the sandy-rocky situation all along the coast. No community type dominates the habitat at any time. However, some of the plants of this habitat are found to extend to seaward habitats. By virtue of its intermediate position between the sandy-rocky and the coastal plain habitats, its floristic composition includes species of both eco-systems.

Analysis of soil samples from the rocky-sandy habitat is presented in Table 3.

The soil is loamy sand. The *p*H values of the soil or rock samples from this habitat indicate mild to moderate alkalinity. Organic matter contents range between 0·22 and 0·81 per cent. The contents of total dissolved solids and sodium chloride like those of sandy strand soils indicate the effects of salt spray only. All the soil and rock samples are highly calcareous.

II. *Salt marsh vegetation*: The salt marsh plants are the inhabitants of the littoral or sublittoral belt. The river deltas, the creeks and the backwater shallow areas inundated by tidal waters on sea coasts usually contain a light to dense growth of a few salt marsh species. Muddy seashores, quiet bays and shallow inlets are the habitats for mangrove vegetation. The varied components of the salt marsh flora can be studied under the following community types: Community of (i) *Avicennia alba*, (ii) *Suaeda nudiflora*, (iii) *Aeluropus lagopoides*, (iv) *Fimbristylis cymosa*, (v) *Scirpus maritimus*, (vi) *Urochondra setulosa*, (vii) *Atriplex stocksii*.

(i) Community of *Avicennia alba*: Mangrove vegetation is composed chiefly of this community. Its presence is noted not near the coastline but in the interior sheltered muddy areas. Due to intense biotic activity, this community is fast disappearing and its characteristic thicket-forming feature is seldom observed. With the change in the level of water and dryness, the occurrence of sedges like *Fimbristylis cymosa* and *Scirpus maritimus* may be noticed. Further away and especially on dry ridges *Tamarix troupii* could be occasionally seen.

(ii) Community of *Suaeda nudiflora*: This plant community forms an impressive mat all along the fringes of inland creeks and shallow muddy areas. It often forms extensive pure stands but is sometimes found mixed with *Aeluropus lagopoides* and *Urochondra setulosa*. A slight change in the water level of the area towards inland forms a congenial habitat for the growth of *Atriplex stocksii* and *Tamarix troupii*.

(iii) Community of *Aeluropus lagopoides*: This community type is characteristic of saline areas, where the stand forms extensive green meadows and tolerates some inundation with sea-water. This plant is sometimes found in association with *Fimbristylis cymosa, Urochondra setulosa* and *Suaeda nudiflora*.

(iv) Community of *Fimbristylis cymosa*: This community becomes dominant towards the interior, frequently with *Aeluropus lagopoides* but sometimes it is found growing with *Scirpus maritimus* and *Urochondra setulosa*.

(v) Community of *Scirpus maritimus*: This type is found in pure stands, or occasionally mixed with *Fimbristylis cymosa* closely followed by *Aeluropus lagopoides*.

(vi) Community of *Urochondra setulosa*: *Urochondra setulosa*, an inland salt marsh plant, is a good sand-binder, sometimes found growing in association with *Aleuropus lagopoides* and *Fimbristylis cymosa*. Its occurrence and sociability increases towards dry rocky-sandy areas.

Soils from the salt pans are sandy loam, loam or silt loam with mild alkalinity. Their organic matter contents are much higher than the soils from the strand habitat. Dissolved solids and sodium chloride contents are very high as the result of direct influence of sea-water. All the soils are highly calcareous. Soil from salt marsh behind the Okha sand bar is very highly calcareous with $CaCO_3$ content of 82·65 per cent (Table 4).

Slacks are depressions or low-lying moist lands, which may go dry during the dry season. They fringe the shore line and provide interesting plants and habitat. Normally they are not connected directly with the sea despite their proximity, and they support a characteristic vegetation of their own, independent of the salt marshes. Of several slacks examined at different localities, in almost all of them there is an admixture of local plants with a few characteristic plants of this habitat. Slacks at Dwarka are composed of plants which have the presence value of 60 per cent or more. They are represented by *Portulaca tuberosa, P. quadrifida* and *Heylandia latebrosa*. Next come species like *Alternanthera sessilis, Bacopa monnieri, Eclipta prostrata, Phyllanthus asperulatus, Eragrostis ciliaris, Bracharia ramosa, Sporobolus marginatus* and *Digitaria sanguinalis* recording a presence value of 40 per cent or more. Other components with a presence value of 20 per cent or more are represented by *Cyperus rotundus, Cymbopogon caesius, Chenopodium murale, Euphorbia bombaiensis, Euphorbia hypericifolia* and *Vitex negundo*.

The flora of Okha coast slacks composed chiefly of *Taverniera cuneifolia, Phyla nodiflora* and *Heylandia latebrosa* constitutes 60 per cent or more of the total plant cover. Other plants of this habitat are: *Polycarpaea corymbosa, Corchorus depressus, Bacopa*

TABLE 3: Analysis of soil samples collected within the rocky-sandy strand habitat

Location and vegetation cover	*Depth of sampling cm*	*Soil colour*	*Mechanical composition*				*Soil texture*	*pH*	*Organic matter %*	*TSS %*	*NaCl %*	*$CaCO_3$ %*	*Remarks*
			Clay %	*Silt %*	*Fine sand %*	*Coarse sand %*							
Rocky-sandy strand, near Baroda Maharaja's palace, Dwarka *Capparis cartilaginea*	0-12·5	light brown	4·6	19·3	26·4	49·7	lomy sand	7·8	0·81	0·043	0·015	25·38	Soil is mixed with calcareous sandstone
Rocky-sandy strand, near Govt R.H., Dwarka *Fagonia cretica*	0-8	dull white to light brown	——Not determined——				—	7·8	0·46	0·075	0·028	69·59	Soil is from the friable calcareous sandstone
Rocky-sandy strand, near light house, Dwarka *Indigofera cordifolia*	0-10	light brown	do				—	7·8	0·39	0·061	0·024	69·35	do
Rocky-sandy strand, near Rupan, Dwaraka *Sericostema pauciflorum*	0-10	do	1·9	18·6	30·8	48·7	loamy sand	8·1	0·43	0·086	0·044	40·28	The sand is from calcareous friable aggregates
Rocky-sandy strand, Rupan Bander, Dwarka *Lepidagathis trinervis*	0-15	do	3·1	17·3	28·7	50·9	do	8·2	0·72	0·059	0·029	42·25	do
Rocky-sandy strand, Dhuyu off Dwarka *Enicostema verticillatum*	—	light black	——Not determined——				—	8·3	—	—	—	62·71	Hard rock, a little sand in crevices
Rocky-sandy strand, Kyu, Okha *Lepidagathis trinervis*	—	black	do				—	7·9	—	—	—	47·80	Very hard rock, a little sand in crevices
Rocky-sandy strand, Porbandar *Sericostoma pauciflorum*	—	light pink	do				—	8·1	—	—	—	58·81	Medium hard stone with sand in crevices
Rocky-sandy strand, Porbandar *Enicostema verticillatum*	—	dull white	do				—	8·1	0·22	0·120	0·059	59·68	Soil from friable calcareous aggregates

TABLE 4: Analysis of soil samples collected within salt pans (0-10 cm depth)

Location and vegetation cover	Soil colour	Mechanical composition: Clay %	Silt %	Fine sand %	Coarse sand %	Soil texture	pH	Organic matter %	TSS %	NaCl %	$CaCO_3$ %
Salt pan behind Okha sand bar *Urochondra setulosa*	greyish	——Not determined——				—	7·8	2·55	2·285	1·710	82·65
Salt pan, Okha-Dwarka Rly. line *Aeluropus lagopoides*	grey	14·9	51·4	33·3	0·4	silt loam	7·6	1·90	3·656	3·073	12·11
Salt pan, Dwarka-Veraval Road *Avicennia alba*	light grey	——Not determined——				—	7·8	2·91	3·987	3·339	53·75
Salt pan, Gomati creek, Dwarka *Avicennia alba*	do	10·4	38·9	49 8	0·9	loam	7·7	1·86	2·589	2·172	15·97
Salt pan near Mandvi *Fimbristylis cymosa*	blackish	10·3	66·3	20·9	2·5	silt loam	7·8	1·93	3·020	2·039	14·42
Salt pan, Gogla *Suaeda nudiflora*	light grey	3·0	37·5	58·6	0·9	sandy loam	7·8	2·49	2·035	1·640	21·80

monnieri, *Justicia simplex*, *Eclipta prostrata*, *Portulaca quadrifida* and *Cyperus rotundus*. Further plants which constitute 20 per cent of the vegetal cover are represented by *Bergia odorata*, *Tephrosia tenuis*, *Dipteracanthus patulus*, *Digera muricata*, *Rostellularia procumbens*, *Euphorbia bombaiensis*, *Alternanthera sessilis*, *Leucas urticaefolia*, *Crotalaria medicaginea*, *Eragrostis pilosa*, *Setaria verticillata*, *Sporobolus marginatus* and *Andropogon monticola*. However, near Veraval coast, 60 per cent of the plant cover is composed of *Polycarpaea corymbosa* and *Bacopa monnieri*. Other plants of this area are: *Corchorus depressus*, *Phyla nodiflora*, *Digera muricata*, *Alternanthera sessilis*, *Eclipta prostrata*, *Heylandia latebrosa*, *Bergia capensis*, *Ammannia beccifera*, *Ammannia multiflora*, *Andropogon monticola* and *Setaria verticillata*.

At no stage could dominance of a single community be seen. At best, certain communities may form 40-60 per cent of the vegetal cover.

Analysis of soils from slacks and mud formations is given in Table 5.

The soils are loamy sand, sandy loam or sandy clay loam with mild to moderate alkalinity. Organic matter contents of the surface soils (0·26-4·69 per cent) varying within wide limits depending upon the age of these slacks and mud formations and also on the density and nature of vegetation. This content of dissolved solids and sodium chloride suggests that the soils are not under the direct influence of sea-water. All the soils are highly calcareous (16·52-77·80 per cent $CaCO_3$).

III. *Semi-Arid coastal plain:* This region lies behind the strand habitat or salt marsh, slacks and mud formations in some localized patches with an average width of 4-5 miles. The thickness of the sand layer over the underlying calcareous conglomerate rock or calcareous sandstone rock varies from a few inches to a few feet. This plain is at a comparatively elevated level and is free from inundation with sea-water. The vegetal cover is a mixture of inland open communities forming scrub forests. The pattern of distribution is not zonal and the existing flora is a clear example of biotic interference. A range of plant communities could, however, be recognized on the basis of edaphic factors. Another feature of this belt is the presence of a number of strand climbers frequently found encircling the shrubby communities. Their presence value up to 60 per cent is recorded in certain communities in this region. This ecosystem is represented by the following six community types: Community of (i) *Euphorbia nivulia*, (ii) *Zizyphus nummularia*, (iii) *Calotropis procera*, (iv) *Butea monosperma*, (v) *Solanum arundo*, (vi) *Hyphaene indica*.

(i) Community of *Euphorbia nivulia*: The clumps of this community are significant along the coastal plain lying between Okha and Porbandar. The three plants of more than 80 per cent occurrence are *Zizyphus nummularia*, *Barleria prionitis* and *Cassia auriculata*. They are often found near the main clumps of *Euphorbia nivulia* community. Other associates of 60 per cent presence value are *Capparis decidua*, *Commiphora roxburghii*, *Mimosa hamata* and *Vernonia anthelmintica*. The above plants are often found intermingled with the *Euphorbia* clumps. Sometimes one may find plants such as *Calotropis procera*, *Senra incana*, *Indigofera trifoliata*, *Amaranthus gangeticus*, *Pupalia lappacea*, *Eragrostis ciliaris* and *Flaveria australasica* distributed between the clumps of *Euphorbia*. The disturbed areas are

TABLE 5: Analysis of soil samples collected within slacks and mud formations

Location and vegetation cover	*Depth of sampling cm*	*Soil colour*	*Mechanical composition*				*Soil texture*	*pH*	*Organic matter %*	*TSS %*	*NaCl %*	$CaCO_3$ %
			Clay %	*Silt %*	*Fine sand %*	*Coarse sand %*						
Wet slack behind Okha sand bar *Taverniera cuneifolia, Heylandia latebrosa* and *Phyla nodiflora*	0-10	dull white with pinkish tinge	Not determined			—	—	8·3	0·63	0·038	0·007	76·64
Dry slack, Dwarka *Portulaca tuberosa, Portulaca quadrifida* and *Heylandia latebrosa*	0-10	light brown	5·8	18·0	19·9	56·3	loamy sand	8·2	0·47	0·114	0·066	45·31
Swamp near Veraval, soil from within *Bacopa monnieri, Eclipta prostrata* and *Cyperus rotundus*	0-10	blackish	22·1	11·6	36·9	29·4	sandy clay loam	7·8	0·53	0·071	0·018	27·09
Swamp near Veraval, soil from periphery *Bacopa monnieri, Eclipta prostrata* and *Cyperus rotundus*	0-10	dull white	9·8	5·6	51·8	32·8	loamy sand	7·9	0·26	0·174	0·062	28·11
Wet slack behind Dhuyu sand bar off Dwarka *Portulaca quadrifida, Heylandia latebrosa* and *Phyla nodiflora*	0-10	dull white with pinkish tinge	Not determined			—	—	8·3	0·30	0·047	0·013	77·80
Profile 1:												
Dry muddy flat Okha-Dwarka Rly. line about 3 km from Dwarka *Eragrostis ciliaris, Cymbopogon caesus* and *Chenopodium murale*	0-10	grey	8·4	38·3	52·2	1·1	sandy loam	7·8	4·69	0·058	0·030	18·29
	10-30	light grey	6·3	35·4	56·5	1·8	sandy loam	7·9	2·13	0·032	0·012	16·52
	30+	brown	Hard kankar nodules									
Profile 2:												
Dry slack in-between Mandvi sand-dunes *Polycarpaea corymbosa, Bacopa monnieri, Corchorus depressus* and *Phyla nodiflora*	0-10	very light grey	5·5	7·0	86·4	1·1	loamy sand	8·0	1·76	0·100	0·290	40·97
	10-30	dull white	9·8	27·3	61·3	1·6	sandy loam	8·1	0·64	0·085	0·015	47·95
	30-60	do	Not determined				—	8·2	0·25	0·065	0·012	54·69
	60-90+	do	do				—	8·2	0·15	0·050	0·008	56·58

TABLE 6: Analysis of soil samples collected within semi-arid coastal plains

Location and vegetation cover	*Depth of sampling cm*	*Soil colour*	*Mechanical composition*				*Soil texture*	*pH*	*Organic matter %*	*TSS %*	*NaCl %*	$CaCO_3$ %
			Clay %	*Silt %*	*Fine sand %*	*Coarse sand %*						
Profile 3:												
Sandy plains, Dwarka-Khambhalia Rd. 2 km from Dwarka	0-12	light brown	4·5	15·8	68·8	10·9	fine loamy sand	7·9	2·29	0·064	0·021	12·80
Euphorbia nivulia	12+	white and light brown mixed	Conglomerate rock				—	8·1	—	—	—	61·72
Profile 4:												
Sandy plain near Tribeni Sangam, Somnath	0-10	black sand with dull white particles	3·0	2·2	17·8	77·0	fine sand	8·1	1·96	0·110	0·022	32·63
Solanum arundo, Boerhavia verticillata and *Zizyphus nummularia*	10-30	do	2·1	1·5	18·9	77·5	do	8·2	1·02	0·075	0·015	34·50
	30-60	do	2·4	1·5	26·7	69·4	do	8·2	0·31	0·050	0·008	37·81
	60-90+	do	1·9	1·0	36·1	61·0	do	8·2	0·11	0·045	0·008	39·13
Profile 5:												
Left side of Delvada-Gogla Road near Mandvi village	0-10	blackish grey	2·3	2·1	95·6	—	fine sand	7·6	1·10	0·115	0·018	35·84
Hyphaene indica	10-30		0·4	22·1	72·5	5·0	fine loamy sand	7·8	0·73	0·100	0·015	36·63
	30-64	very light grey	4·6	21·7	69·1	4·6	do	7·8	0·70	0·085	0·008	30·70
	64+	Hard calcareous sandstone rocks										

composed of *Eragrostis ciliaris*, *Achyranthus aspera*, *Tribulus terrestris* and *Aerva javanica*.

(ii) Community of *Zizyphus nummularia*: This type forms a pure stand only in certain localities far from the strand belt. Its main associates are: *Cassia auriculata*, *Boerhavia verticillata* and *Pupalia lappacea* with other associates as found in the *Euphorbia nivulia* community.

(iii) Community of *Calotropis procera*: This type inhabits dry sandy localities, and attains a good stature. Its chief associates are: *Capparis decidua*, *Euphorbia nivulia* and other local plants which can endure this habitat.

(iv) Community of *Butea monosperma*: This type may be noted at several localities from Porbandar to Delvada coastal plain belt. Though not thick, it is found scattered all along the plain. Increasing in density inland, towards the sea, other plants like *Hyphaene indica*, *Capparis decidua*, *Boerhavia diffusa* and *Eragrostis ciliaris* often appear with this community.

(v) Community of *Solanum arundo*: This exotic shrubby community is recorded along the Delvada, Somnath and Mangrol coastal plains. This community is spreading fast in the coastal plains of Veraval-Somnath area. Its chief associates are local plants like *Vernonia cinerea*, *Capparis decidua*, *Blepharis sindica*, *Boerhavia verticillata*, *Zizyphus nummularia* and others of minor significance.

(vi) Community of *Hyphaene indica*: The community of this tall branching palm is significant along the coastal plain of Kodinar, Delvada, Gogla and Porbandar. Sometimes it is so dense as to exclude other plants growing in its shade. *Euphorbia nivulia*, *Butea monosperma* and *Cassia auriculata* are its chief associates.

Analysis of soil samples from three profiles within the semi-arid coastal plains are presented in Table 6.

All the soils are immature. The thin cover of loamy sand under *Euphorbia nivulia* thickets gives a moderate alkaline reaction. It contains 2·29 per cent of organic matter and is calcareous (12·80 per cent $CaCO_3$). Roots of *Euphorbia nivulia* plants in fact penetrate into the underlying conglomerate rock with 61-72 per cent $CaCO_3$. Sand of the profile under *Solanum arundo* and its associates is, however, quite deep. Individual particles of this sand lie apart without any aggregation. It is moderately alkaline, the *p*H of the surface layer being a little lower than the underlying layers. Organic matter content of 1·96 per cent in the surface layer falls to 0·11 per cent at a depth of 60-90 cm. All the sand samples from this profile are highly calcareous. The surface soil in the profile under *Hyphaene indica* is fine sand but changes to loamy sand at lower depths. The soil here is well compacted and consists of hard aggregates mainly due to the binding action of $CaCO_3$. Hard calcareous rock is met at a depth of approximately 60 cm. The *p*H indicates mild alkalinity. Organic matter content decreases with depth, although the decrease is not so significant. All the soils of the profile are highly calcareous. The contents of total dissolved solids and sodium chloride are fairly low in samples from all three profiles. Their concentration is highest in the surface layers and falls with increasing depth.

CONCLUSIONS

Studies on vegetation usually include two major aspects, namely, the flora and the plant communities. Our knowledge of the Indian coastal plant comnities to date is mainly based on systematics. No comprehensive ecological account of the coastal terrestrial communities has yet been published. The coastal vegetation is now analysed into several plant communities grouped in three ecosystems. In other countries certain attempts have been made on the classification of coastal communities. Hemming (1961) has described the vegetation of the Northern Eritrean coast, primarily on a geomorphological basis with pedological subdivisions. A purely vegetational basis is adopted in a few cases where the edaphic factor could not conveniently be further divided. Vesey-Fitzgerald (1955, 1957) has described the vegetation of the Red Sea coast to the north and south of Jedda in Saudi Arabia in a range of plant communities, each associated with important variations of soil and drainage pattern. While comparing Kassas (1957) account of the ecology of the Red Sea coastal land with the coastal area of Northern Eritrea, Hemming (1961) emphasizes the similarity and resemblance of several communities, taking into consideration the purely botanical basis of the former and the geomorphological approach as outlined in his own work. Furthermore, he considers that the purely botanical approach is not helpful in delimiting and defining certain categories of coastal areas. In the present study of the vegetation between rocky-sandy and the coastal plain habitats, the vegetation of slacks cannot be classified under community types because no community type is found to dominate at any time. The 'raised beach' described by Kassas (1957) clearly corresponds with the elevated habitat of mixed species mentioned elsewhere in the present survey. Thus the trend to classify the tropical coastal vegetation either on geomorphological basis with edaphic subdivisions or on a vegetational basis is mainly one of convenience with reference to strand and salt marsh ecosystems. However, with increasing distance from the shore certain areas would appear to be less easy to define on a purely botanical basis.

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A STUDY IN THE PROBLEMS OF RAJASTHAN DESERT

by

*B. N. Mulay and M. C. Joshi**

INTRODUCTION

Certain parts of Rajasthan are covered by enormous amounts of wind-blown sand dunes of various types. The rugged hills of the vast Aravalli system, saline and aquatic areas comprise yet other habitats in the area. In such situations, therefore, vegetation is of potential importance for its several beneficial influences on climate and soil, and also for its protective and productive functions.

The purpose and aim of the present paper is to enumerate the problems of Rajasthan desert, give a general account of the various types of habitats and to suggest plants for afforestation programme.

ENVIRONMENTAL FACTORS OPERATING IN THE AREA AND INFLUENCING THE VEGETATION

(A) *Physiographic Factor*: Physiographically the following main ecosystems can be recognized in Rajasthan:

(1) *Rocky areas*: Includes all rugged hilly projections, folds of hillocks, scattered isolated outcrops of rocks and loose gravel formations.
(2) *Aquatic and marshy areas*: Includes lakes, 'Bundhs', river banks, ponds, puddles, ditches, tanks and low-lying areas.
(3) *Saline areas*: Includes salt lakes, salt basins, saline water river and their environs.
(4) *Sandy plains and dune areas*: Includes vast stretches of loose sandy plains, embryo, barchanoid, fusing barchanoid, longitudinal, scattered hummocky and stabilized dunes.

The debatable Rajasthan desert has a geological history of its own which affords a noteworthy example of the evolution of desert topography within comparatively recent geological times. According to Wadia (1944) and Krishnan (1952), the area was occupied by sea during the Jurassic, Cretaceous and Eocene and that it must have been uplifted in the Tertiary. The desert conditions must have been thus brought about during or after Pleistocene.

The tertiary deposits of *Mesua ferrea* vel-eff and other Guttiferae have been reported by Lakhanpal and Bose (1951) from Kapurdi, Rajasthan. The plant is a tropical tree which thrives well in moist, warm and equitable climate with a high rainfall. It has been pointed out by them that it tends to show moist humid climate in Rajasthan during the tertiary period.

Recently Wadia (1954) has put forth the hypothesis that the deserts of Asia were caused as reaction to the Ice Age of the northern world.

(B) *Climatic Factor*: The extreme climate of the Rajasthan desert is characterized by high solar radiation, seasonally and diurnally fluctuating temperatures and precarious and erratic low annual rainfall that acutely varies from year to year. The low humidity of the atmosphere for the greater part of the year except the rainy season, powerful hot and cold winds, sand-storms, duststorms, occasional hailstorms, dew, mist, fog, frost, evaporation for exceeding precipitation and high insolation, all tend to modify the ecosystems.

Infering from the meteorological conditions, as stated by Pramanik, Hariharan and Ghose (1952), there seems to be neither an accentuation of the Rajasthan desert nor extension on any large scale of arid conditions over the adjoining areas during the last seventy or eighty years. According to Meigs (1952), who has summarized the climates of the arid and semi-arid zones of the world, the Rajasthan desert (taking Jaipur as a station) closely approaches the African and Australian climates in certain respects. He has designated the area as semi-arid hot desert. At the same time Ferguson's (1944) observations (Sarup and Bhandari, 1958) on evaporation readings of some parts in Jodhpur are interesting since the value obtained here is much higher than the value known for Australian desert. Subramanyam (1956), Shanbagh (1957, '58) and Bharucha and Shanbagh, (1957) the Rajasthan desert falls under Dd and Ed types of climate which indicates semi-arid with a little or no water surplus respectively. The observations are based upon the readings evaluated for Ajmer, Jaipur and Jodhpur stations.

(C) *Edaphic Factor*: Based upon the physiography the nature of the soil substratum varies from place to place in Rajasthan. The Rajasthan desert soil is derived partly from material formed by physical disintegration of the local rocks and partly from blown sand.

Tamhane (1952) has divided the soils of Rajasthan into two main groups taking Aravallis as a demarcation line for the Eastern and the Western Rajasthan.

*Deceased.

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According to Krishnaswamy and Gupta (1952), the salt content of the desert soils (aeolin origin) is not so high as to be toxic to plant growth. It is present in that desirable moderation to impact a certain amount of impermeability to the soil to keep the moisture in the region of the plant roots for a longer time. At the same time the chemical analysis of these desert sands also revealed the presence of a fair amount of nitrates varying from one to seven parts per million.

Generally the soils of Rajasthan desert are immature, mostly sterile with a poor fertility status, low in water-holding capacity, in exchangeable bases, in organic matter with high value and often with significant amount of calcium carbonate. The subsoil water is present at variable depths in different parts of Rajasthan. The water for irrigation is, hence, collected during the monsoon in artificially constructed basins or 'Bundhs' etc., and also by digging deep wells.

(D) *Biotic Factor*: The animals exert tremendous influence on plant life and sometimes are responsible for aggravating desert conditions.

The excessive and indiscriminate cutting, lopping, coppicing, stripping, and amputating the branches of the sparsely growing trees have caused considerable damage to the developing vegetation. The usual practice of destroying trees, without maintaining any balance between need and supply, may pose a serious problem in the near future. The lack of scientific cultivation, the preparatory tillage by ploughing on slopes without bunding, the defective weeding method and lack of rotation of crops, the faulty reaping of crops, the neglect of farm lands during the dry season, of fallows and pastures, neglect of tree planting and of enclosures, all help in creating and maintaining the desert conditions.

The impact on vegetation of the indiscriminate grazing and trampling by domestic animals like cattle, large flocks of goat and sheep, camels, donkeys and other burrowing animals is immense, and results in:

(1) removal of photosynthetic organs,
(2) decrease in plant cover and wind protection,
(3) reduction of shrubs into undershrubs.

The pathogens, micro-organisms, insect pests, locusts (*Schistocerca gregaris* Forsk.), grasshoppers, caterpillars, ants, termites, beetles, birds, etc., are all to be reckoned as among the agents of destruction. All these agencies combined together hasten the process of sheet erosion in sand dune regions and gulley erosion in the rocky areas contributing to the furtherance of desert conditions.

VEGETATION

In spite of the hazardous climate, unproductive soils and intense biotic pressure, vegetation of some sort manages to cover a lot of land surface of Rajasthan. The life forms are a xerophytic scrub flora which is seen in discontinuous patches of plant communities consisting of an open assemblage of ephemerals, grasses, perennial herbs, undershrubs, shrubs and dwarf trees and sometimes badly mutilated trees. The various habitats support specially adapted plants which can also be grouped, according to Weaver and Clement's (1938) classification, into (a) drought escaping, (b) drought evading, (c) drought enduring and (d) drought resisting plants.

Based on the nature of soil and vegetation Rajasthan can be divided into three major regions: (i) Fertile eastern Rajasthan, (ii) Arid western Rajasthan, and (iii) semi-arid middle Rajasthan. The vegetation in general consists of lithophytic, psammophytic, hydrophytic and halophytic communities on different types of habitats. The flora resembles more to tropical Africa and Perso-Arabia than that of Indo-Malaya, but the flora may be regarded as a mixture of the Western (Arabian, Persian and African), the Eastern (Indo-Malayan) and of general elements which are found in varying proportions in the different parts of Rajasthan. The eastern part has much richer flora than the western part due to its greater relief, heavier rainfall and a larger variety of suitable habitats. The floristic relationship between the two regions of Rajasthan comes closer in the psammophytic communities.

The gradual east to west decrease of rainfall is reflected in the poor representation of natural flora. The comparatively thick tree cover of the east becomes scarce in the west. The farm areas and agricultural fields are reduced to the minimum, leaving the major barren portion as grazing grounds.

On the basis of water source the vegetation of Rajasthan can be ecologically categorized into the following:

(1) The existence of which depends directly upon the rainwater—the ephemerals. These include the rainy season and the winter season ephemerals.
(2) The existence of which is sustained by subterranean water also — the perennials.
(3) The group of plants which are annuals to all appearances, but which perennate by some underground parts and sprout into activity in the succeeding favourable season.

In the winter season ephemerals group, there are many plants of the rainy season which sprout up again in early winter as a result of the dew or occasional winter downpour. These can be termed as 'chance seekers' or 'opportunists'.

The growth and abundance of the main plant communities occurring are closely related to the edaphic conditions and the characteristic topography of the area.

PROBLEMS

These may be listed as follows: (a) How to prevent the blowing of more sand from the west and south?

(b) How to check the rolling or scudding of sand into the fertile tracts like the agricultural fields, farm areas and other well vegetated lands? (c) How to remove excess salts from saline and alkaline soils? (d) How to ensure the cultivation of fodder for the livestock? (e) How to prevent all out destruction of infant vegetation that results in the denudation of the areas? (f) How to improve the faulty land use practices? (h) How to preserve existing perennial vegetation and protect the herbaceous cover? (i) How to raise compatible vegetation in the existing environment in spite of heavy biotic destruction? (j) How to plan so that it meets the demands and needs of the people and livestock?

In the symposium on the Rajputana desert by the National Institute of Sciences in India in 1952, various workers have drawn attention to many important problems connected with the Rajasthan desert, stressing and at the same time demanding the immediate tackling of these problems. Some of the important lines of action that can be advocated include the afforestation of the area by planting and introducing some of the indigenous and exotic species for this purpose near the railway tracks, road-sides, governmental office, schools, colleges, and other places of importance; in creating oases of vegetation around important places and stations, in contour bunding, in contour subsoiling, in ploughing deep at right angles to the direction of the wind, in preparatory tillage before the break of monsoon, in fallowing, in strip cropping, in leaving sufficient crop residue on the ground after harvesting in the rotation of crops; in cover crops, in manuring; in creating wind-breaks and establishing shelter belts; in utilizing the solar energy and in modelling wind-mills at suitable places and in coordinating all the studies by the various organizations in the areas under an overall organizing body. A wide publicity in this direction indicating the improved and correct methods to be adopted in Rajasthan will prove beneficial to the economy of the areas as a whole and at the same time assure a bright future to the region.

A proper method of transforming the habitat for better land utilization lies in the choice of species in the afforestation of the Rajasthan desert. The control of the 'sea of sand' and its management is of national importance and poses as one of the most vital problems before the country today. The main purpose of planting trees is to get good deep rooting system which will bind the loose soil up to a considerable depth. Depending upon the soil, the exposure, the degree of moisture and the slope, the indigenous plants which invade and are frequent in the area should be sown and tried. A few basic principles may be utilized such as: (1) Any natural vegetation growing on its own accord should be protected beyond all reservations. (2) Typical sand binders — both ephemeral and perennials — should be established on drifting sand, taking into consideration the velocity of the wind and the degree of sand movement. Indigeneous perennial sand binders which can endure extreme temperatures and dry conditions should be given preference to ephemeral sand binders. It has been noted that once the seedlings are established the sandy soils have enough moisture below the surface layers to help the plants for their survival (Joshi, 1958).

During our field studies at various regions of the area we have observed that dunes have to reach a certain stage of maturity before which no healthy establishment of woody plants is possible. Afforestation is an ecological experiment on a regional scale. The aim of the experiment is to arrest the advance of the sand by reclothing it with plants. The existing vegetation, its occurrence on various types of habitats and the factors of the environment that govern the growth of plants are the important features to be reckoned with before starting the plantation of useful indigenous plants. Nair (1954) has given a list of 73 plants for afforestation of Rajasthan. We venture to suggest the following additional plants:

Artemisia scoparia Willd. (Well suited for semi-stable sandy plain areas, perennates by root-stocks), *Argemone mexicana* Linn. (A good winter season plant for loose sandy plains, dunes and low-lying areas), *Boerhaavia diffusa* Linn. (The plant is best adapted to sandy areas having a strong woody tap root which penetrates very deep into the substratum. The long branches spread out in all directions which show flotation, (Salisbury, 1952), *B. repanda* Willd. (Good for stable dunes and hard ground areas), *Corchorus depressus* (Linn.) Stocks. (Well suited for hard ground and stable dunes), *Ephedra foliata* Boiss. (Useful climber on *Capparis*, *Gymnosporia*, *Prosopis* and rarely on *Calligonum* in sandy areas), *Euphorbia nivulia* Buch.-Ham. (Grows commonly in rocky areas), *Farsetia Jacquemontii* Hook f. & T. (Good binder of loose sandy plains), *Indigofera linifolia* (L.f.) Retz. (The plant is suitable for both the sandy areas as well as for hillocks), *I. linnaei* Ali. (Good sand binder), *I. tinctoria* Linn. (Useful plant for stable soils and hill slopes), *Leptadenia pyrotechnica* (Forsk.) Decne. (A good colonizer of sandy plains and dune areas), *Lycium europaeum* Linn. (An extremely useful plant for the crests of the longitudinal ridges of dunes), *Securinega leucophloea* Walldst Skit. (A plant of hard stable plain areas and gritty situations), and *Zizyphus xylopyrus* Willd. (Good for plains and for hill areas).

DISCUSSION

One of the ways to improve conditions in Rajasthan is by adopting protective means to restore the natural vegetation. Further, in view of the importance of vast barren and desolate tracts of Rajasthan, afforestation work should be enhanced at a greater speed to withstand the fury of wind-blown sands from the west and south-west.

In recent years afforestation, reclamation and control problems of sand dune regions are being tackled by the Central Arid Zone Research Institute at Jodhpur. Furthermore the Rajasthan canal, excavation of which was started in March 1958, augurs well for pioneering a social revolution. This project, though started late, promises to spell a new life to the thirsty land, ill-fed and ill-clad millions.

The steps taken during all these years for wind barriers, for measures to improve desert conditions by means of shelter belts, for laying a green belt along the Indo-Pakistan border and for experimenting on the suitability of Egyptian and Australian plants for the Rajasthan desert and to face many other similar problems are bound to prove fruitful in the near future. Afforestation work, however, must be carefully planned and operated. At the same time a closely coordinated programme of research involving analysis of the environment and its utilization, exploring the conservation and utilization of surface and ground water potentialities, and studying the physiology and ecology of promising species to solve the erosion problem might yield good results.

Available data show that the meteorological conditions have not deteriorated in Rajasthan. It would probably be possible to reclaim land from the desert areas by the adoption of suitable land conservation and reclamation methods.

An understanding of the role of vegetation by the local people may enable them to understand its importance in improving the area. The correct perspective lies, therefore, in proper planning of afforestation and irrigation in Rajasthan.

SUMMARY

The paper deals with the problems of Rajasthan desert which are based on many years of field observations. The influence of environment comprising (a) physiographic, (b) climatic, (c) edaphic, and (d) biotic factors on the vegetation has been described. The various ecosystems of Rajasthan desert and the choice of species for the afforestation of the area are dealt with. Suggestions for the improvement of the area have been given.

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*Not seen in original.

ADDENDUM

Since the paper was submitted at the symposium (1964), further information has been added by various authors given below:

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DISCUSSION

U. S. Madan: *Argemone mexicana* has been recommended as a species for introduction, but it is a great pest. The author is requested to enlighten in this matter.

B. N. Mulay: Although it is a pest, it is a useful sand binder.

I. M. Qureshi: It has been suggested that *Argemone, Leptadenia, Tephrosia, Indigofera*, etc., be used for afforestation. This appears confusing as afforestation includes much more than mere introduction of only herbs and shrubs which may be used only at a preliminary stage to afforestation.

B. N. Mulay: I quite agree. A complete list of plants including trees has been given by Dr Nair (1954).

Fr. Santapau: A mysterious disease was reported in parts of Gujarat and Saurashtra some years ago. It was then discovered that seeds of *Argemone mexicana* were dried, ground and mixed with the edible oil seeds. *Argemone* is a dangerous plant.

B. N. Mulay: It is used in treatment of leprosy.

SOME USEFUL CUCURBITS FOR THE ARID ZONE IN RAJARSTHAN[1]

by

DALBIR SINGH

THE Indian Desert lies between 24° and 30.5°N and 70° and 76.2°E. Most of the area is sandy and the vegetation is scanty and specialized in several respects. The main task in improving the land area is the regeneration of a better plant cover. Besides this, the successful introduction and domestication of some economically important plants may also improve the economy of these areas. This paper is confined to members of the Cucurbitaceae alone, as this family has not received due consideration in the scores of publications on the subject. During a period at Jodhpur from 1960 to 1963, a large number of cucurbits was noted in Jodhpur and the adjoining areas. Many are used as vegetables and desserts by the local population. Species which occur naturally at Jodhpur and adjoining areas include *Citrullus lanatus* (Thunb.) Mansf., *C. colocynthis* Schrad; *Ctenolepis cerasiformis* Clarke, *Cucumis melo* L. (various forms), *C. melo* var. *pubescens* Willd., *C. prophetarum* L.; *Corallocarpus conocarpus* (Dalz. & Gibs.) Clarke, *C. epigaeus* (Rottl. & Willd.) Clarke; *Dactyliandra welwitschii* Hook. f., *Momordica balsamina* L., *M. dioica* Roxb.; *Melothria maderaspatana* Linn., and *Luffa acutangula* var. *amara* (Roxb.) Clarke.

The Cucurbitaceae are of tropical and subtropical distribution and are usually annual, tendril-bearing, somewhat succulent, prostrate or climbing vines. Many occur in deserts and a large number are perennial, perennating through large tuberous root stocks. The tubers vary in size; *Echinocystis* for example, which occurs wild in California, Arizona and adjoining areas, has tubers nearly as large as a man's body, weighing about 50 lb. (Benson, 1957). *Acanthosicyos horrida*, which occurs in the extremely dry South-West African Desert, presents the most remarkable adaptations to xeric conditions among the cucurbits. The peculiar shrubby growth, reduced leaves, spines, leathery perianth, deep penetrating (up to 15 metres) woody root, stock, and absence of tendrils are not common characters of the Cucurbitaceae.

For selecting plants better suited to our arid zone, a thorough understanding of the ecological, physiological and genetical basis of their drought resistance is necessary. However, significant success may also be achieved by introducing plants from similar arid lands in other countries, particularly from those which have some species in common. Many cucurbits occurring in the Indian desert are also found in the South African Desert, which has in addition other cucurbits of economic importance. The following plants deserve consideration:

Acanthosicyos horrida Welw. ex Hook. f.: This perennial species is, as already noted, an example of extreme adaptation to xeric environments. It survives on dry sand dunes and emerges again every time it is covered by the sand. The ripe fruits are edible, but the green ones are bitter and unpalatable. The seeds are also edible and contain a considerable quantity of fat. In South Africa they are regarded as an excellent substitute for almonds (Meeuse, 1962).

Acanthosicyos naudinianus (Sond.) Jeffrey (= *Citullus naudinianus* (Sond.) Hook. f.: Perennial with very short, straight, rigid and spinescent tendrils; the fruits and seeds are edible.

Citrullus colocynthis Schrad.: Perennial, occurs widely in the Indian desert. Its fruits contain the well-known crystalline glucoside, co'ocynthin, a drastic purgative; seeds contain 20 per cent of oil (Evenari and Koller, 1956). It is remarkably drought-resistant, and could be used in a breeding programme to produce either perennial or drought-resistant watermelons, or both.

Citrullus ecirrhosus Cogn.: One of the few cucurbits without tendrils which inhabit "Namib", a desert area with a very low rainfall. The fruits are bitter like those of *C. colocynthis*, and may have some pharmaceutical value.

Cucurbita: *C. foetidissima*, the buffalo gourd, occurs wild in Mexico and arid parts of the United States of America. The seeds contain 31 per cent protein and 27 per cent oil. *C. palmata*, another pumpkin, from arid parts of the USA contains 21 per cent protein and 27 per cent oil in the seeds (Duisberg, 1953). The oil is of the drying type and may be used in the paints and varnish industry.

Cucumis: The seeds of *C. prophetarum*, which occurs in the Indian desert, contain a good percentage of oil. *C. metuliferus* E. Mey.e x Schrad., occurs in the South African Desert in two forms, bitter and non-bitter; the non-bitter fruits are reputed to be an excellent vegetable like cucumber. *C. humifructus* Steut. is interesting, being the only geocarpic cucurbit known. It occurs only on soils consisting of deep fine sand. The fruits are edible.

Coccinia rehmannii Cogn. occurs on dry sandy soils; its juicy fruits and tuberous roots are edible.

1. Contribution from the Department of Botany, University of Rajasthan, Jaipur.

Echinocystis species are characterized by their large tuberous edible root-stock.

To test the possibility of their introduction and domestication in the Indian desert, seeds of some of the above cucurbits were obtained from South Africa and the United States of America, and sown at Jaipur in February 1964. The germination percentage of the seeds and the vegetative growth of the plants during these preliminary experiments were excellent. Some plants flowered but the fruiting was not satisfactory in all. The plants of which the seeds germinated are tabled below.

Name of plant	*Percentage germination*	*Days taken to germinate*	*Pre-treatment*
Acanthosicyos horrida	80	15	Presoaking in water induced early germination
A. naudinianus	—	—	No effect
Citrullus ecirrhosus	75	9	Germinated only after soaking in water for 48 hr
Cucurbita foetidissima	60	15	—
C. palmata	30	15	—
C. digitata	50	20	—

GENERAL REMARKS

The cucurbits are regarded as an important source of vegetable and desserts. Their seeds, which contain oil and protein as reserve foods, are eaten to a limited extent only. The oil is extracted from the seeds of a few cucurbits for use in the ayurvedic system of medicine. Only recently, in two widely separated parts of the world, namely, the United States of America and China, the significance of the oil-yielding capacity of the Cucurbitaceae has been realized on a large scale. Seeds of *Cucurbita foetidissima*, *C. palmata* and *C. digitata* are being investigated as a possible source of oil and protein in the United States of America (Duisberg, 1953). In Southern China, seeds of *Hodgsonia macrocarpa*, a newly domesticated cucurbit of this area, are considered promising for extracting edible oil (Chien, 1963). It will not be out of place to record some facts about the domestication of *H. macrocarpa* in China. It was discovered in South-west Yunnan province of China in 1933. Efforts to domesticate this plant were started by the staff of the Botanical Garden in Shishong, Baana in 1958. After experimentation, the botanists finally succeeded in bringing this wild plant under cultivation. It can now be raised from cutting and layering.

H. macrocarpa is a perennial with a life-span of approximately 70 years and flowers annually. It bears fruits as large as watermelons. Each fruit contains six seeds, each a little bigger than a hen's egg and the average seed possesses 2 to 3 kernels. The kernel is said to have an oil content of 70 to 80 per cent.* The fat is palatable and rich in vitamin A and D. *H. macrocarpa* occurs in the Eastern Himalaya in India and can possibly be domesticated there and in other parts of the country; also in the semi-arid parts of Rajasthan with some irrigation. The plant is highly resistant to drought and waterlogging.

The Cucurbitaceae are, therefore, promising as new oil and protein crops. Their seeds which contain oil and protein can be conveniently stored and transported, an important factor in the arid areas. However, to domesticate these cucurbits successfully in the Indian desert, further experimentation is necessary. This calls for team-work by ecologists, physiologists, soil scientists and chemists, if the work is to be a success.

SUMMARY

The xerophytic adaptations of desert cucurbits are described briefly. Some species of *Acanthosicyos*, *Citrullus*, *Coccinia*, *Cucumis*, *Cucurbita* and *Echinocystis*, which are of economic importance, are recommended for introduction and domestication in the Indian desert. In addition to their use as vegetables and desserts, the Cucurbitaceae are regarded as promising new oil and protein crops.

*This is higher than the oil content in groundnut (36-45%), sesame seed (50-57%), linseed (32-43%), castor seed (35-55%), rape and mustard seeds (35-48%), and almost equal to coconut (65-75%). It must be admitted that these figures for oil content in the kernels of *H. macrocarpa*, 70 to 80 per cent, are very high compared with those recorded for other cucurbits and need confirmation.

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DISCUSSION

Raychaudhuri: What are the acre yields of *Hodgsonia macrocarpa* ?

Dalbir Singh: I cannot say. I was trying to emphasise that cucurbits are cultivated more for their fruits and vegetables and that efforts should be diverted to increase their seed production for protein and oil. At present the efforts are more towards inducing seedlessness.

Fr. Santapau: Is it more useful to grow cucurbits for vegetables or for seeds ?

Dalbir Singh: It depends on different purposes for which they are grown.

Fr. Santapau: It would be better to cultivate the *Cucurbita* species, first as vegetables, and use the seeds for oil. The cucurbits are plants which need plenty of water. Is *Cucumis prophetarum* typical of the desert areas ?

Dalbir Singh: *Cucumis* and *Acanthosicyos* are from arid and semi-arid areas.

Fr. Santapau: Have you attempted to grow any of the species mentioned by you ?

Dalbir Singh: The germination percentage of five species was studied and is reported in the paper.

C. P. Bhimaya: *Citrullus colocynthis* is no more considered a medicinal plant. The British Pharmacopoeia has removed it from the list in view of the very strong reaction it produces as a purgative.

THE GEOGRAPHY OF GRASS[1]

by

R. O. WHYTE[2]

THIS subject of global significance is discussed with special reference to India and its neighbouring regions. Since the Symposium on the Rajputana Desert was held by the National Institute of Sciences in India in 1952, a great deal has been learnt about the grassland communities of India. Up to that time most of the work on grasses in India had been of a taxonomic nature, and great advances had been and are still being made in that respect (Bor, 1960). A few scientific articles described isolated communities in particular parts of India, and gave some indication of ecological succession. By and large, however, the picture was fragmentary and confused. Following the emphasis on the ecological management of grassland in India at the 8th Silvicultural Conference at Dehra Dun in 1951 (Whyte, 1956) and the consequent initiation of the Grassland Survey of India by the Indian Council of Agricultural Research in 1953/54, the pieces of the jigsaw puzzle began to fall into place. Perhaps the most important result of the travels of the survey team from 1954 to 1962 is that one now finds throughout India officers fully familiar with their own local types of grass cover and the nature of ecological succession within these types.

The work has important practical applications and scientific implications. The former have been considered fully in preparing the second edition of "The Grassland and Fodder Resources of India" (Whyte, 1964). The latter are to be discussed in detail in "The Grass Cover of India", being the final report of the Grassland Survey (ICAR Sci. Monograph in press).

From the practical point of view, it is now possible for a trained ecologist to visit any site, to assess and diagnose the status of the grass cover, and to give advice on its improvement. It is possible to state what the effect of continued misuse is likely to be, and what would happen if full protection could be given for a specified period. If the biotic factor has been operating to excess for too long a period, mere protection is not likely to have an early effect. More attention will have to be given to the microclimate of the soil and ground surface in studies on the regeneration of natural grassland. Ecological progression towards the known superior species and/or communities of the area may be assisted by surface scratching of the soil followed by surface seeding, combined if possible with contour furrowing or water spreading. In the more difficult sites, complete ploughing and reseeding may be essential. Thus the techniques of ecological management are fully known, but they cannot be applied because it is impossible to obtain the degree of control of the grazing bovines essential to any method of grassland management. Village grazing lands around Ajmer in Rajasthan, for example, are being reissued by the village panchayats to cattle owners at a grazing intensity twenty times what the natural grasslands of the area are known to be capable of carrying, with no allowance for sheep, goats or camels. In this situation, it is more interesting and profitable for the research worker to turn to the scientific problems relating to grass genera and species and to the grass communities of India.

Those aspects of the geography of grass which are mentioned below represent a number of possible directions for future research by Indian workers, based on the results of taxonomic, ecological and genetical work obtained so far. The studies should not be limited to India, but should consider the data on India in relation to those available from the countries and regions to the west, north, east and southeast. Thus it will be possible to make a major contribution to the phytogeography of grass covers and their component species, an aspect of plant science on which too little work is being done at the present time (Good, 1953; Harlan, 1956; Polunin, 1960). This paper is a brief summary of the information available.

And what better than the Gramineae for studies of plant geography that may give results applicable to other plant families. "On the scope of absolute completeness of distribution the Gramineae stand out preeminently. Not only are members of this family found over the widest extremes of altitude and latitude, but their degree of distribution within this total outline is particularly dense and continuous. Almost alone among flowering plants, grasses form the dominant element in the vegetation over great areas of the world, and nearly everywhere else too the proportion of these plants in the vegetation is very high" (Good, 1953).

GEOGRAPHY OF COMMUNITIES

An interesting comparison may be made between the types of grass covers and their ecological

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succession in the arid and semi-arid tracts of India and those of other regions of similar ecoclimates. Very generally, it may be said that some comparable if not identical communities extend through the Sahelian zone south of the Sahara from the Atlantic to the Sudan. Links may be found between this west-to-east zone in Africa and the predominantly north-south zones in India, along the Red Sea coasts and in parts of Sa'udi Arabia, in the Hadhramaut, the Persian Gulf and West Pakistan. It will also be interesting to define the border zone between the monsoonal grass covers and those of the Near East dominated by a winter rainfall ecoclimate. The border may run along the mountains of Baluchistan, appear as a catena-like formation around the Khyber Pass, and as a mosaic of environments in eastern Afghanistan, including the Hindu Kush, and continue into the western end of the Himalaya, characterized alternately by monsoonal or winter rainfall conditions or by a combination of both. Further comparisons may be made between the grass communities of India and those of southeast Asia (van Steenis, 1964) and northern and northeastern Australia (Blake, 1938; 1940). It would seem to be profitable to make a correlation between these comparable types of grass cover and the ecoclimatic conditions created by the monsoonal influences in their annual movements north and south between the major latitudinal high pressure systems. On the other hand, striking contrasts may be made between the Indian grass communities and those of Iran, western Afghanistan, southern USSR, and Tibet. Again a detailed study of the border zones will yield important results.*

Such a study will introduce many items of greater detail including the question of the relation between or significance of communities dominated by perennials and annual species respectively. It now appears that there are no major belts of annual grass climax covers along the more arid parts of the climatic gradients which extend from desertic to sub-humid conditions. Annual communities of much more limited extent may appear as permanent climax features in the midst of perennial communities, due to specific combination of soil and climate. Consideration should also be given to the extent to which the zonation of comparable grass covers now coming to be recognized in India and other parts of southwestern Asia, as already in Africa (Rattray, 1960), are related to the accepted major phytogeographical regions. Certainly some agreement may be obtained with Eig's Saharo-Sindian vegetation type, less apparently with his Sudano-Deccanian (Eig, 1931-32). There is also some agreement with the African-Indian Desert floristic region of Good (1953); there would, however, appear to be a distinction between the grass covers on the northern and southern sides of the Sahara, and it is the southern or Sahelian type that reappears in western India. Within the major floristic regions and the zones of comparable grass covers, we should consider the proposal of Cain (1950) that life-form spectra for climax or near-climax vegetation are the only ones that can reflect sensitively climatic correlations. Spectra for association variants might reflect minor climatic variations. Spectra for successional communities of various sorts might reflect edaphic conditions and give a good measure of the changing environment as succession proceeds.

GEOGRAPHY OF REPRODUCTION

Grasses are among the most successful plants occupying adverse environments, due to their possession of a variety of morphological and physiological characters (Evans, 1964). These characters include effective protection of florets and reduction to a minimum of the time when the florets are open. For out-breeding populations, it is necessary to have close control of the season of flowering and of the daily time of flower opening — in both respects the grasses are preeminent. Uniformity in flowering time, in both equable and extreme climates, may conceal a great variety in the paths by which the individuals in a population reach anthesis. This variety is exposed when populations are transferred to other environments; a reservoir of genetic variation is thus provided when a species invades new areas.

Control of the reproduction cycle in grasses by environmental conditions (day length, temperature, light intensity and nutritional status) is most rigorous at its onset, at the change-over from vegetative growth (Evans, *loc. cit.*). The breeding system of grasses may be greatly modified by environmental conditions. Incompatibility is probably beyond the influence of environment, but the occurrence of apomixis, male sterility, cleistogamy, monoecism and dioecism are all subject to climatic influences. The anthers of grasses are among the floral organs most susceptible to adverse environmental conditions during their differentiation (Evans, *loc. cit.*).

TAXONOMIC GEOGRAPHY

Bor (1960) has stated that "in the Gramineae there exists the most extraordinary mosaic of characters which even now are changing in response to the forces of evolution and selection. Indeed the mosaic of simple and complex characters in the same plant or even in the same spikelet would seem to indicate that the evolutionary changes of the past were not always at the same pace or even in the same direction ... we are at the moment witnessing a revolution in ideas concerning the

*A preliminary review of this transect of mesoonal and contrasting types of grass covers has been completed by the writer under the title of *Grasslands of the Monsoon* (1968).

taxonomy of the Gramineae. New concepts, new methods of approach, all contribute to the elucidation of this most difficult family, but it seems obvious that a great deal more information must be gained before even a tentative scheme with a moderate chance of acceptance can be produced."

What contribution can the grass geographer, and particularly the grass geographer working in the arid and semi-arid zones in India make to this progress? Field workers with large tracts of country at their disposal may be able to follow a grass species from its centre of maximum frequency along the climatic gradient to the points at which it becomes rare or disappears. On a wider scale of time and space, such geographical studies might begin on the basis of the theory of Bews (1929). He postulated that the progenitor of grasses arose in the humid tropical forests, and that migration to less uniform, more exacting and variable environments was accomplished by mutation and natural selection. Modifications of various kinds in the primitive progenitor (Hubbard, 1948) would ensure greater protection for the seed and a complicated dispersal mechanism as the present-day end-products of trends of evolutionary change (Bor, 1960). But who is to know in which direction a species may be progressing through mutation and natural selection, outwards towards the arid and semi-arid unknown, or back to the comforting habitat of the humid tropical forest?

The logical outcome of this hypothesis, against which a number of contrary examples can be produced, is that taxonomic advancement proceeds in the opposite direction to ecological progression. For example, the species of *Aristida* in India, or of *Stipa* in Iran and elsewhere have become the most advanced taxonomically in their progress into extreme environments. They are at the same time and for the same reason the lowest in ecological succession on any particular site on which they occur, increasing in frequency with deterioration and particularly with increasing aridity of the environment due to the action of the biotic factor in one of its forms.

Another approach which may be adopted in comparing the distribution of grass tribes, genera and species is by using the agrostological index that Hartley (1950, 1954) took as a basis for comparison of widely separated regions. Hubbard (1934) and Hubbard and Vaughan (1940) recognize 28 tribes on the basis of leaf anatomy and of the number and size of the chromosomes as well as on the floral structures used by earlier botanists. Hartley concentrated on the six largest and most widely distributed grass tribes, Agrosteae, Andropogoneae, Aveneae, Eragrosteae, Festuceae and Paniceae. Using the available published floras, he determined for each region the proportion of species of each grass tribe to the total grass flora. From these figures the average proportion of species of each tribe throughout the world was obtained. Naturally, data were inadequate for large regions, including many parts of South America, Africa and Central Asia. Mapping of the existing distribution of each tribe in relation to these averages facilitates comparison of the distribution with that of the environmental factors. The number of species of any of the major grass tribes in any region expressed as a percentage of the total number of grass species present, bears a direct relation to the climate of the region. Temperature is usually much more important than rainfall, midwinter temperatures being of critical significance under certain conditions. However, it seems doubtful whether, at the present stage of limited availability of published data, this method can give really useful results.

CYTOGENETICAL GEOGRAPHY

The Gramineae have already provided and will continue to be a fruitful field for cytogenetical studies, to clarify the taxonomic relationships indicated above, to provide a historical and geographical basis for the origin and spread of the tribes within the family, and to assist in plant exploration and breeding. Hartley (1950) has suggested possible centres of origin for some of the tribes that he studied: Agrosteae are of great geological age and, therefore, their origin is difficult to trace; Andropogoneae have spread from a centre in southeast Asia; Aveneae have no single region of maximum frequency in the eastern hemisphere, are relatively scarce in the western; Paniceae have a predominantly new world distribution, tending to be of the greatest relative importance in forest regions.

Grasses that pioneer into semi-arid and arid environments must possess a great reserve of genetical variability — the flexibility of species becomes important. Different species spectra may arise in wet and dry years in the arid zone with wide variability of rainfall between seasons. Types will, therefore, always be available within a natural population to cope with conditions in whatever ecological niche they may find themselves. The lower the rainfall, the wider the annual variations in its amount and geographical distribution. Short-term and medium-term climatic changes may also have to be overcome (Whyte, 1963b). This brings us into the complex field of chromosome ecology and chromosome geography, of internal hybridity and the effects of migration (Darlington, 1956).

Polyploidy has undoubtedly played an important role in the evolution of the Gramineae; according to Stebbins (1947), 70 per cent of the known wild species are of polyploid origin. The major role of polyploidy in the evolution of grasses has been in the fixing and spreading of hybrid combinations at either the varietal, subspecific or specific level (McWilliam, 1964). Polyploidy has also provided one of the most rapid known methods of producing radically different but nevertheless vigorous and well-adapted genotypes. This is achieved through the production of new combinations of characters rather than through the origin of new characters themselves. Polyploidy has thus tended to be a conservation rather than a progressive force in evolution. Polyploids in general display wide ranges of tolerance of extreme climatic and edaphic conditions and thus have a wider geographic distribution than their diploid ancestors (Hayman, 1960; Kihara, 1954; Stebbins, 1956; Stebbins and Love, 1941; Stebbins and Zohary, 1959). One of the main factors favouring the spread of polyploid forms is undoubtedly the availability of new ecological niches (McWilliam, 1964). Radically new genotypes created by polyploidy will thus have their greatest adaptive value "in rapidly changing environments" (due to climatic fluctuation and change, or to increasing aridity following devegetation ?). These new genotypes will be less important in species that are already widespread and are still rich in ecotypic differentiation. Polyploidy tends to be more common in cross-pollinated and long-lived perennial species with efficient means of vegetative reproduction — to overcome the initial period of partial sterility before becoming stabilized and fully fertile (McWilliam, *loc. cit.*).

Leading cytogeneticists in the USA, such as J. R. Harlan, R. P. Celarier and J. M. J. de Wet, have studied the evolution, present taxonomic position and cytogeography of some of the major Indian genera, and Indian students working in the USA and India have contributed to this fundamental work (K. L. Mehra, A. P. Singh and others).

We have also to consider the significance of autopolyploidy and apomixis together in facilitating the advance of species into adverse environments. To what extent is apomixis (a term covering all types of reproduction which replace or substitute for the usual sexual process) an important characteristic for the spread of grass species in arid zones (Harlan and de Wet, 1963), with particular reference to the revival of variability through the crossing of apomictic lines ?

Apomixis is common among the grasses and in most is facultative rather than obligate (Evans, 1964; McWilliam, 1964). It is now doubtful whether there are any wholly obligate apomicts (Clausen, 1954). Environmental conditions may influence the degree of apomixis in grasses; in *Dichanthium* day length during development of the inflorescence influences the degree of apomixis. "Such facultative apomicts have exploited an extremely effective solution to the contrasting demands of sufficient reproducibility to perpetuate successful gene combinations, and sufficient variability to adapt to changing environments" (Evans, 1964).

Is it true that grasses of the arid zone show greater variability in nature than the types of the humid tropical forest growing in an unchanging and uniform environment ? Were Indian grass breeders like B. D. Patil (Patil and Singh, 1963) fortunate in having chosen to work on species such as *Cenchrus ciliaris* and *C. setigerus*, arid zone species full of a rich variability awaiting cytogenetical study and development ?

Patil (1964) notes that apomicts do not necessarily remain unvaried in *Cenchrus ciliaris*, but an apomictic plant arising in the F_1 and F_2 generation from a cross

apomict × apomict
or
sexual × apomict (apomict dominant)

may produce some tillers that are morphologically different from the major part of the F_1 plant. The seeds from that portion lead to the origin of new lines combining the characters of the parents. Thus three or four lines instead of one may be obtained in a short period. Some of the new tillers may have characters favouring spread, particularly in arid zones. In addition, introgessive hybridization between species of *Cenchrus* provides new stabilized genotypes which are adapted to occupy intermediate areas between the parent species.

CONSERVATION OF GENOTYPICAL RESOURCES

Remarkably few species of the Gramineae have been developed as cultivated plants. It is one of the objectives of the International Biological Programme to attempt to find further wild plants for use in tropical regions. It is to be hoped that grasses will also come within the scope of this programme. The geography of grass and grass communities provides an essential basis for plant exploration and introduction. An important corollary to such activity will be the establishment of protected areas of natural vegetation in all the genetically strategic regions of the world, many of them in the arid and semi-arid zones. These areas of natural vegetation which have suffered and are still suffering greatly due to misuse and so-called progress will make it possible to study taxonomic and ecological progression in their component species, and not least in members of the Gramineae (Whyte, 1963a). Governments possessing resources of this importance should be aware of their international responsibilities in this respect, and should take the necessary action before it is too late.

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DISCUSSION

S. P. Raychaudhuri: There is some difficulty in locating grasslands of India in a land-use map. Could Dr Whyte throw any light on this ?

R. O. Whyte: It is not feasible to prepare a grassland map. In the monsoon, the whole of India is a grassland. After the monsoon, it is almost a desert from the forage viewpoint.

P. C. Raheja: How is it that *Aristida*, a retrogressive species, is considered as an advanced grass ?

R. O. Whyte: The most advanced genera are the lowest in the stage of regression.

I. M. Qureshi: Could you suggest some grasses which could be introduced from abroad in saline and alkaline soils ?

R. O. Whyte: India has all the suitable grasses with all the salt tolerance characters, and does not need any introductions.

SOME MEDICINAL PLANTS SUITABLE FOR CULTIVATION IN THE INDIAN ARID ZONE

by

I. C. CHOPRA AND B. K. ABROL

IN considering medicinal plants, we are not concerned with species which provide food reserves, wood, etc., but which yield active principles belonging to the category of substances generally classified as "secondary", namely alkaloids, glucosides, essential oils, resins, gums, etc. While carrying out surveys and studies of cultivation of medicinal plants, we have found that there are several plants which may easily be grown in semi-arid and arid zones of the country. Some of these species have proposed the additional ability to check the extension of desert areas. In this paper, we have stressed the importance of a few xerophytic plants which are worthy of cultivation in the semi-arid and arid regions.

AGAVE (AMARYLLIDACEAE)

The greatest diversity of *Agave* occurs in the arid and semi-arid transition zone in the highlands of Central Mexico, where a large number of species and varieties occur. In the Puebla Desert, covering parts of the States of Puebla, Oaxaca and Hidalgo, there are a large number of endemic species. This region is also one of extensive cultivation.

The swollen meristems and enlarged parenchyma of the *Agave*, together with its large succulent leaves protected by a cutinized epidermis, permit some well-adapted species to survive for several years without moisture in regions such as the Sonoran Desert of Baja California. Extensive explorations by Corell and others (1955) show that a number of species had a rather high sapogenin content, usually confined to the leaves. Among these are *A. promontori* Trel., *A. vilmorniana* Weber., *A. roseana* Trel., *A. cerulata* Trel., *A. sobria* Brdge., *A. nelsonii* Trel., *A. sullivanii* Trel., *A. toumeyana*, *A. atrovirens*, *A. mirabilis* Trel., *A. mapisaga* Trel. and *A. aurea* Brdge. One of these, *A. roseana*, has yielded 2·5 per cent of hecogenin, the highest yet found in *Agave*. Hecogenin is a steroidal sapogenin and is a suitable plant precursor for the synthesis of cortisone, anti-fertility and other steroidal hormones. Some species of *Agave* have been already grown in India; they have the added advantage of checking the growth of deserts and are worthy of extensive cultivation.

ALOE (LILIACEAE)

This genus of about 180 species of xerophytes, indigenous to East and South Africa, flourishes in a variety of climates and on the poorest of soils. The fleshy and strongly cuticularized leaves help the plants to survive the driest of weathers.

When a leaf is cut transversely and held with its cut end downwards, a yellowish juice flows from the pericycle. The juice is collected and concentrated; on cooling it solidifies and constitutes the commercial drug, aloes.

The official aloe species are: (a) Curacao or Barbados aloes from *A. vera* Tourn. ex L. var. *officinalis* (Forst.) Baker; (b) Socotrine aloes (yellowish or blackish-brown) from *A. perryi* Baker; (c) Zanzibar aloes (livery brown) also from *A. perryi*; and (d) Cape aloes from *A. ferox* Mill. and its hybrids. Others are Natal aloes, derived probably from *A. candelabrum* Berger and resembling Cape aloes, Moka or Mocha aloes derived from *A. succotrina* Lam., in Arabia, and Jaffarabad aloes is produced from *A. vera* at Jaffarabad, India.

Aloes contain a mixture of glucosides collectively called "alone" which is the active constituent of the drug. Curacao aloes contain 30 per cent of aloin, Socotra and Zanzibar aloes a little less, and Cape aloes only 10 per cent. The principal constituent of aloin is barbaloin, other constituents are isobarbaloin, β-barbaloin, aloes-emodin and resins. The odour is due to traces of an essential oil. Aloe has a bitter, disagreeable taste, is largely used as a cathartic and is very useful in chronic constipation. It produces pronounced pelvic congestion and is used for treatment of uterine disorders, generally in combination with iron and carminatives. Aloe is one of the constituents of several proprietary laxative preparations. Aloe species are cultivated in several arid regions of the world; there is considerable scope for their culture in the Indian arid zones.

BALANITES AEGYPTIACA DEL. SYN. *B. ROXBURGHII* PLANCH (SIMARUBACEAE)

A small spiny tree, characteristic of drier parts of Arabia, Egypt, Eritrea, tropical Africa, Burma and India. The tree bears ovoid fruits having a sweet edible pulp possessing an unpleasant odour. The seed kernels have long been known to contain a water-soluble saponin which is toxic to cold-blooded animals (Weil, 1901). Kon and Wella (1939) have isolated a new sapogenin which appears to belong to the group of steroid sapogenins and according to them is very closely related to tigogenin. The saponin is reported to be an active haemolytic agent and its toxicity for tadpoles is similar to that of digitonin. The kernel of seeds yields 43 per cent of a bland yellow, tasteless oil (Hooper, 1902, 1911-12). The seeds, fruits, bark and leaves are reported to be anthelmintic and purgative. In Indian indigenous medicine the fruit is also considered useful for boils, leucoderma and other skin diseases. The African Arabs use the pulp as a fish poison. In Uganda the oil is used as a remedy for sleeping sickness and in Spain as a purgative (Chopra, Abrol and Handa, 1960).

The thick protective cuticle on its twigs and leaves makes it, according to Drar (1955), a xerophytic " admirably adapted to habitats where resistance to drought is the limiting factor".

CASSIA (LEGUMINOSAE)

The dried leaflets of *C. angustifolia* Vahl and *C. acutifolia* Del. constitute the senna of various pharmacopoeias.

C. acutifolia, Alexandria Senna, is indigenous to the Sudan, but is also found growing wild in the Hejaz and other parts of Africa. It is collected from wild and cultivated plants in these regions, and to a small extent from plants cultivated in India.

C. angustifolia, Tinnevelly Senna, is cultivated on dry land in South India. A dry-land crop yields 150 kg of cured leaves and 38-75 kg of pods; yields from an irrigated crop are 370-600 kg of cured leaves and 82 kg of pods (Abrol *et al.*, 1955; Iyer, 1950).

Senna is valued in medicine for its cathartic properties and is especially useful in habitual constipation. It increases the peristaltic movements of the colon. The tendency to gripe caused by Senna may be obviated by combining it with aromatics or saline laxatives. The pods have the same therapeutic effect as the leaves but cause less griping. senna is contra-indicated in spastic constipation and in cases of colitis. Henderson (1935) reported that Senna speeded passage through the caecum and ascending colon, by diminishing the normal anti-peristaltic waves in this area and reducing the absorption of water, thereby causing a bulkier and softer faecal mass. Tutin (1913) reported that the only anthraquinone derivatives present, either free or in glucosidal combination, in senna were rhein and aloe-emodin. Straub (1936, 1937) found 1 per cent of an easily hydrolysable glucoside which yielded emodin and was actively cathartic, and also a second glucoside which was more difficult to hydrolyse and slower in its laxative effect. Stoll and his coworkers (1941) reported isolation of two glucosides, sennoside A and sennoside B, which are believed to be the laxative principles of senna. Fairbairn and Saleh (1951) isolated a water-soluble non-rhein glucoside which is as active as sennosides A and B and which exerts a synergistic effect of these glucosides.

GLYCYRRHIZA GLABRA LINN. (LEGUMINOSAE)

The liquorice and its numerous varieties are to all appearance a spontaneous growth in the Mediterranean area (Spain, Portugal, Sicily, Greece) and in Asia Minor (Iran, Crimea, Turkestan). Possibly its original home was the Asiatic part of the Mediterranean basin from where it spread to southern Europe (Palumbo, 1932). The climate is dry in these regions. The most xerophytic variety is *G. violacea* Boiss. The underground portion which forms the drug consists of a slender branching rhizome bearing a number of rootlets. The plant grows best on sandy or clay soils in valleys which are subject to occasional inundation. The usual method of propagation is by replanting young pieces of stolons. The underground organs are sufficiently developed by the end of the third year at which stage it is economical to harvest them. Enough always remains in the ground for the plants to renew themselves during the ensuing three years. Much of it is peeled and cut into short lengths before drying, but the drug is generally available is unpeeled (Treasl, 1946).

The active content of liquorice is a characteristic principle, glycyrrhizin, also known as glycyrrhizic acid, which on hydrolysis yields glucuronic acid and glycyrrhetinic acid. Glycyrrhiza appears also to contain spasmolytic and esterogenic principles.

Powdered liquorice is used for various pharmaceutical purposes, in the preparation of pills and as a flavouring agent. Aqueous extract of glycyrrhiza is frequently incorporated in cough medicines by virtue of its demulcent and expectorant properties. It has been observed to be effective in the treatment of doudenal and gastric ulcers. Card *et al.* (1953) found that glycyrrhetinic acid, when given to a patient with Addison's disease, had effects similar to those of desoxycortico-sterone and cortisone. According to Costello and Lynn (1950) the drug contains significant, though small, amounts of oestrogenic material. The plant has been cultivated successfully in Jammu and Kashmir and is worthy of trial in semi-arid regions.

HYOSCYAMUS MUTICUS (SOLANACEAE)

This is a desert herbaceous perennial indigenous to Egypt and exported to various countries. According to the British Pharmaceutical Codex, Egyptian henbane contains about 0·6 to 1 per cent of total alkaloids, of which 90 per cent is hyoscyamine. The Indian Pharmacopoeia requires it to contain not less than 0·5 per cent of hyoscyamine. The most important use of hyoscyamine is to provide relief from painful spasmodic conditions of the non-striated muscles, characteristic of lead colic and irritation of the bladder. It is also employed to allay nervous irritation which is symptomatic of various forms of hysteria and irritable cough. Externally, cataplasms or fomentations of fresh hyoscyamus leaves have been used to allay pain, although it is not certain how effective this treatment is. Attempts to cultivate this xerophytic plant in countries other than Egypt have not met with success. An excellent study of the conditions in which this important plant grows has been made by Saber and Balbaa (1954). The species should also be tried in our arid and semi-arid areas.

We have mentioned some plants which may be cultivated in semi-arid or arid regions, but they are not the only species which may be used for the purpose. Others of lesser importance may also be of worth attention. For example, *Acacia senegal* Willd., growing wild in Rajasthan, is cultivated over very large areas in Kordofan, Sudan, to yield true gum arabic. There are several other *Acacia* species which may also be tried.

A number of plants of xerophytic origin are now grown in large quantities in regions of much lower aridity with markedly higher yields. Examples are: the olive tree, the castor oil plant, West Indian aloes, fenugreek, etc. Investigations are needed to indicate whether these crops would give economic returns in arid zones, using suitably selected strains or ecotypes. Chouard (1957) has already tried this type of " reacclimatization ".

Conversely, experiments could be made in acclimatizing and domesticating other indigenous and exotic plants native to arid regions. Chopra *et al.* (1960) and Paris and Dillemann (Aschan, 1903) have given exhaustive accounts of the medicinal plants of the different arid zones in the world. Many could be selected for trials on acclimatization and domestication.

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DISCUSSION

Fr. Santapau: Quite a number of medicinal plants are needed both in India and abroad. In every village in Saurashtra, there is a *Vaidya* or *Hakim* who derives his knowledge of medicinal plants from his forefathers but the knowledge is kept a close secret. They work with astonishing success. They are trained in recognizing and collecting plant species at appropriate times and using the medicinal plants of the country.

HABITATS AND PLANT COMMUNITIES OF THE INDIAN DESERT[1]

by

Y. SATYANARAYAN[2]

INTRODUCTION

APART from the early floristic accounts by King (1879), Macadam (1917), and preliminary ecological notes by Blatter and Hallberg (1918-1921) very few studies have been conducted on the ecology of western Rajasthan. Blatter and Hallberg (1921) termed the vegetation types of western Rajasthan as "formations" which are exclusively controlled by edaphic factors. The five habitats distinguished by them are: (1) aquatic, (2) sand, (3) gravel, (4) rocky, and (5) ruderal. Champion (1936) has recognized the following principal types of vegetation in Rajputana: (1) 5 b. Cl. northern desert thorn forest; (2) 5 b. C 2, northern *Acacia* scrub forest (20-40 in rainfall); (3) 5 b. C 3, northern *Euphorbia* scrub; and (4) D.Tr. E 10. inland dune scrub. More recently, Mathur (1960) has further classified the above types, enlarging on Champion's classification and has recognized the following types: (1) dry teak forests, (2) *Anogeissus pendula* forests, (3) mixed deciduous forests, (4) *Boswellia* forests, (5) *Butea monosperma* forests, (6) tropical thorn forests, (7) sub-tropical thorn forests. Recently, Joshi (1956, 1957 and 1958), Jain and Kotwal (1960), Jain (1963), Nair and Joshi (1957), Shanti Sarup and Bhandari (1957), Shanti Sarup and Vyas (1958), Shanti Sarup (1957, 1958), Satyanarayan (1963) and Satyanarayan and Shankarnarayan (1964) have conducted such investigations. Shanti Sarup and Vyas (1957) have distinguished six plant associations according to different "situations", viz. (1) hills, (2) mixed hills and plains, (3) plains, (4) sand-dunes, (5) moist rock streams, and (6) saline-river beds and loamy soils. In his studies on the succession of vegetation in the arid regions of West Pakistan plains, Chaudhri (1960) has followed a geo-botanical approach to the classification of vegetation. The habitats studied by him are: (1) detached low hills, (2) waterlogged area, (3) flat saline soils, (4) riverine tracts, and (5) areas of shifting sand-dunes. Bharadwaj (1961) has distinguished three primary land-form regions in western Rajasthan: (1) the predominantly sand-covered Thar, (2) plains with hills including the central dune-free country, and (3) hills. The secondary land-forms recognized by him are (1) plains with sand dunes, (2) plains of predominantly older alluvium, and (3) deltaic plains.

In an earlier study, the vegetation types of Central Luni Basin were grouped into five formations: (1) mixed xeromorphic thorn forest, (2) mixed xeromorphic woodland or wooded desert, (3) dwarf semi-shrub desert, (4) psammophytic scrub desert, and (5) succulent halophytic desert (Satyanarayan, 1963).

In this paper, the plant communities of the Central Luni Basin and their habitats are briefly described.

ENVIRONMENT

1. *Land-forms*: The major land-forms in Central Luni River Basin of western Rajasthan are: (a) plains formed by older alluvium, (b) plains formed by younger alluvium, (c) longitudinal and transverse sand-dunes formed in Pleistocene and Recent times, and (d) hills and mountains of granites and rhyolites of Pre-Cambrian age. Sandstone and limestone formations also occur in western Rajasthan, but their ecology is not discussed in this paper.

2. *Climate*: Climatic aridity (low rainfall, variability of precipitation, high temperatures) increases from the south to the north-west. The major part of the area is semi-arid, gradually merging into the arid zone in the west and north-west. The mean annual rainfall varies from 500 mm in the south and south-east to about 250 mm in the north-west and is confined to the summer months of June to September. Maximum summer temperatures exceed 40°C in May and June but the nights are generally cool. The average maximum and minimum temperatures in winter are 25° and 9°C respectively. Frosts have not been reported to occur in the area. Humidity is generally low but diurnal variations have been recorded even in monsoon months. Strong winds are common during April to October. They generally follow a south-westerly course, the maximum wind speeds being in June.

METHODS

For quantitative studies, quadrats 50 metres by 50 metres were established in different habitats, ten to fifteen quadrats constituting a stand. All trees, shrubs and herbs in each quadrat were listed

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by counts. Density, dominance, percentage composition and frequency were calculated according to the methods suggested by Curtis and McIntosh (1950). Density values alone are discussed in this paper.

VEGETATION IN VARIOUS HABITATS

Granite hills: Studies on the windward side of the granite hills of Jalore have shown that the average density of trees and shrubs is 9·6 per cent, of which the tree species have a density of 7·0 per cent. Out of 24 trees in five 100 sq metre quadrats, 60 trees, of which *Anogeissus* totalled 49, were in the 5-15 cm DBH class, 23 trees, of which *Anogeissus* totalled 21, in the 16-35 cm diameter class, and only one tree in the next higher class. The data indicate the vitality of the species even on inhospitable sites.

The percentage density values of the common shrubs are: *Commiphora mukul* (0·4), *Euphorbia caducifolia* (1·2), *Grewia tenax* (0·2), *Zizyphus nummularia* (0·6) and *Vogelia indica* (0·2). *Cocculus cebatha* and *Asparagus* spp. are common climbers on *Salvadora* and *Acacia senegal* trees.

On the leeward side of granite hills, *Anogeissus pendula* is the dominant species with a density of 14·0 per cent out of a total density of 15·0 per cent. The associated species are *Acacia senegal, Salvadora oleoides* and *Prosopis cineraria*. The density of shrubs is only 1·4 per cent, of which *Zizyphus nummularia, Euphorbia caducifolia* and *Acacia jacquemontii* constitute 0·8, 0·4 and 0·2 per cent, respectively. *A. senegal* is the only species with hundred per cent frequency, while the rest have a frequency of less than 20 per cent. Among the 51 trees, in five 100 sq m quadrats, 33 trees were in the 5-15 cm DBH class, 17 trees in the 16-35 cm DBH class and only one tree in the next higher class.

Rhyolite hills: There is little difference in the plant cover on the leeward and windward side of rhyolite hills. The density varies from 3·0 to 5·6 per cent. Of this *Acacia senegal* and *Grewia tenax* have relative density values of 31·1 and 28·3 per cent respectively and form the dominant species. Both species have hundred per cent frequency. Associated trees are *Anogeissus rotundifolia, Balanites aegyptiaca, Capparis decidua* (occasional), *Commiphora mukul, Gymnosporia spinosa* and *Euphorbia caducifolia*. The common shrubs and undershrubs are *Lycium barbarum, Mimosa hamata, Blepharis sindica, Fagonia cretica, Tephrosia purpurea*. Grass cover is fairly good and consists of *Aristida depressa, A. hystrix, A. royleana, Cenchrus biflorus, Chloris barbata, Cynodon dactylon, Dactyloctenium sindicum, Digitaria adscendens, Eleusine compressa, Eragrostis ciliaris, E. pilosa, Latipes senegalensis, Melanocenchris jacquemontii, Oropetium thomaeum, Sehima nervosum, Tragus biflorus* and *Urochloa panicoides*.

Piedmonts: The piedmonts of granite hills, with slopes varying from 3 to 8 per cent, grade either gently or abruptly into the older alluvial plains. The weathered rock debris often gets mixed up with blown sands. The upper piedmont area is generally gravelly in nature. Its slopes are dominated by a shrubby growth of *Salvadora oleoides* along with medium to large-sized clumps of *Euphorbia caducifolia*, which is the co-dominant species. Associated trees and shrubs, which are very sparsely distributed, and generally cut down to ground level are, *Anogeissus pendula, Acacia senegal, Gymnosporia spinosa, Grewia tenax, Cassia auriculata* and *Balanites aegyptiaca*. The ground cover consists of *Barleria prionitis, B. acanthoides, Volutarella divaricata, Boerhavia diffusa* and *Corchorus aestuans*. Grasses are few and are in a highly overgrazed condition, the common species being *Oropetium thomaeum, Enneapogon elegans* and *Aristida* species.

The lower piedmont slopes, which are covered by a deeper layer of sand deposit, support a community of *Salvadora oleoides-Prosopis cineraria-Euphorbia caducifolia*. The top soils are generally gritty sands to sandy loams. The vegetation cover is more on the lower piedmont slopes than on the upper. The dominant species, *Salvadora oleoides*, occurs in both tree and shrub forms. *Prosopis cineraria* generally occurs in its life-form but has reduced vitality. The associated tree and shrub species which exhibit both life-form and growth-form are *Gymnosporia spinosa, Acacia leucophloea, Zizyphus nummularia, Capparis decidua, Grewia tenax, Balanites aegyptiaca* and *Azadirachta indica*. *Cocculus cebatha* is a common climber on *Salvadora* and *Prosopis* trees. The ground cover consists of *Aerva persica, Tephrosia purpurea, Indigofera cordifolia, Heliotropium marifolium, Sericostoma pauciflorum, Panicum turgidum, Leptadenia pyrotechnica, Aristida hirtigluma, Eleusine compressa, Cenchrus biflorus, Eragrostis bifaria* and *Melanocenchris jacquemontii*.

Quantitative studies have shown that the average density of tree cover on the upper piedmont slopes is 1·6 per cent and is composed of *Acacia leucophloea* (0·8 per cent), *Salvadora oleoides* (0·6 per cent) and *Zizyphus nummularia* (2·0 per cent). The shrubs put together have a density of 25·8 per cent, of which *Cassia auriculata* forms 14·6 per cent, *Zizyphus nummularia* 4·0 per cent, *Anogeissus pendula* 4·0 per cent and *Euphorbia caducifolia* 1·6 per cent. Except *A. leucophloea* and *Salvadora oleoides* (both of which have more than 40 per cent frequency), the rest have less than 20 per cent frequency.

Older alluvial plains: The major portion of the Central Luni River Basin is older alluvium. They are generally level lands, with 0 to 2 per cent slope. The soils are sandy loam in texture. The soil depth varies from 30 to 200 cm below which a hard kankar pan is found. Ecological studies in the Saila Community Development Block showed that the density of trees is very low, being only 4·9 per cent, of which *Salvadora oleoides* constitutes

1·7 per cent, *Prosopis cineraria* 1·9 per cent and *Capparis decidua* 1·3 per cent. The last-mentioned species also occurs in a bushy growth form with a density of 1·0 per cent. Bushes of *Zizyphus nummularia* have a density of 0·1 per cent. Shrubs and undershrubs together have a density of 4·1 per cent, of which *Z. nummularia* constitutes 0·1 per cent, *Acacia jacquemontii* 0·5 per cent, *Leptadenia pyrotechnica* 0·1 per cent and *Aerva persica* 3·4 per cent. Of the species listed *Salvadora oleoides*, *Prosopis cineraria* and *Aerva persica* have more than 60 per cent frequency and *Capparis decidua* has 50 per cent frequency.

On older alluvium covered by blown sands, the density of tree vegetation is 4·4 per cent, of which *Prosopis cineraria* constitutes 1·0 per cent, *Gymnosporia spinosa* 1·2 per cent, *Capparis decidua* 1·0 per cent, *Acacia senegal* 0·6 per cent, *Salvadora oleoides* 0·2 per cent, *Zizyphus nummularia* 0·6 per cent. The undershrubs *Acacia jacquemontii* and *Leptadenia pyrotechnica* have density values of 3·4 and 1·6 per cent respectively. Except for these shrubs which have 50 per cent frequency, the rest have less than 25 per cent frequency. The presence of *Acacia senegal* indicates the occurrence of rock outcrops close to the surface.

The common species of the ground flora on older alluvial plains are *Cassia auriculata*, *Indigofera pauciflolia*, *Eleusine compressa*, *Tephrosia purpurea*, *Pupalia lappacea*, *Justicia simplex*, *Boerhavia diffusa*, *Commelina benghalensis*, *Peristrophe bicalyculata*, *Cenchrus biflorus*, *C. ciliaris*, *Aristida adscensionis*, *A. funiculata*, *Eragrostis ciliaris*, *Tragus biflorus*, *Leucas aspera*, *Achyranthes aspera*, *Digitaria adscendens*, *Urochloa panicoides*, *Eragrostis unioloides* and *Sida cordifolia*.

Younger alluvial plains: These plains are confined to the banks of the rivers Luni, Jawai and their tributaries. The soils of the younger alluvium are generally loamy sands to sandy loams in texture, and calcareous. As generally the well waters in these plains are sweet or only slightly brackish, they are intensively cultivated and as such, very little of natural vegetation is found except in *Orans* and *Birs*.

As in the older alluvial plains, the density of vegetation is low, the density of trees being 3·6 per cent and that of shrubs 8·6 per cent. Among the trees, *Prosopis cineraria* has a density of 2·0 per cent, *Acacia arabica* 1·0 per cent, *Acacia leucophloea* 0·4 per cent and *Tecomella undulata* 0·2 per cent. In the shrub layer, *Capparis decidua* has a density of 1·0 per cent, *Acacia jacquemontii* 0·2 per cent and *Cassia auriculata* 7·4 per cent.

In general, on soils of the Younger alluvium, *Acacia arabica* var. *cupressiformis* is quite common. Besides, in villages and around wells, the cultivators maintain a number of trees like *Azadirachta indica*, *Ficus benghalensis*, *F. religiosa*, *F. mysorensis*, *Tamarindus indica*, *Zizyphus mauritiana*, *Albizzia lebbek*, *Inga dulcis*, *Moringa pterygosperma* and *Ailanthus excelsa*.

There are several weeds and grasses which are common in the younger alluvial plains. These are *Digera arvensis*, *Achyranthes aspera*, *Justicia procumbens*, *Tephrosia purpurea*, *Solanum xanthocarpum*, *Xanthium strumarium*, *Indigofera cordifolia*, *Mollugo cerviana*, *Amaranthus viridis*, *Cynodon dactylon*, *Desmostachya bipinnata*, *Cenchrus catharticus*, *C. setigerus*, *Eragrostis pilosa*, *E. tremula*, *Digitaria adscendens*, *Eleusine compressa* and *Dactyloctenium sindicum*. Where the soils are slightly heavier, *Sporobolus coromandelianus*, *Cyperus rotundus*, *Chloris virgata* and *Dicanthium annulatum* also occur.

On river-beds, the common species are *Xanthium strumarium*, *Crotalaria burhia*, *Leptadenia pyrotechnica*, *Aerva persica*, *Cynodon dactylon*, *Desmostachya bipinnata*, *Erianthus munja*, *Echinochloa colonum*, *Cyperus rotundus*, *C. arenarius*, etc. The dominant species is, however, *Tamarix troupii*, which due to constant biotic factors hardly attains a height of 1·5 metres.

Sand-dunes: Longitudinal and transverse sand-dunes are extensive in western Rajasthan and occupy approximately 58·5 per cent of the total area. The sand-dunes are found in various stages of development, but the majority are stabilized sand-dunes, some of which are under cultivation. Some of the stabilized dunes still possess an active crest. On uncultivated dunes the density of vegetation is 0·47 whereas it is only 0·17 on cultivated dunes. On the contrary, the density of shrubs is 1·63 on cultivated dunes and 0·85 on uncultivated dunes. The density of undershrubs is 2·7 on cultivated dunes and 1·63 on the uncultivated dunes. The higher density and cover of shrubs and undershrubs on the uncultivated dunes can be explained by the fact that every year, only a portion of a dune is cultivated, while the rest of it is left fallow for 3 to 4 years, during which the shrubs and undershrubs invade and increase in number, until they are weeded out just before cultivation.

The principal trees found on sand-dunes are *Prosopis cineraria*, *Acacia senegal*, *Tecomella undulata*, *Zizyphus nummularia*, *Capparis decidua* and *Balanites aegyptiaca*. Along with *Balanites aegyptiaca*, *Gymnosporia spinosa* is another very common tree on uncultivated dunes. The common shrubs are *Calligonum polygonoides*, *Calotropis procera*, *Lycium barbarum*, *Acacia jacquemontii*, *Mimosa hamata*, *Leptadenia pyrotechnica* and *Melhania denhami*. Shrubs of *Zizyphus nummularia* and *Capparis decidua* are also found. The common undershrubs are *Crotalaria burhia*, *Tephrosia purpurea*, *Aerva persica* and *Sericostoma pauciflorum*. *Ephedra foliata* is a common climber on *Gymnosporia* trees. The characteristic grasses are *Panicum turgidum*, *Aristida adscensionis*, *A. funiculata*, *Eleusine compressa*, *C. biflorus* and *Desmostachya bipinnata*. Other herbaceous species are *Convolvulus pluricaulis*, *Indigofera cordifolia*, *I. linifolia*, *Heliotropium strigosum*, *H. subulatum*, *Cyperus arenarius*, *Arnebia hispidissima*, *Celosia argentea*, *Citrullus colocynthis* and *Tribulus terrestris*.

In the fallow fields on the dunes, the common weeds which occur are *Pulicaria wightiana, Perotis indica, Polycarpaea corymbosa, Phyllanthus niruri, Dicoma tomentosa, Celosia argentea, Justicia simplex, Boerhavia diffusa* and *Corchorus aestuans*.

Detailed ecological studies (Satyanarayan, Saxena and Cherian, unpublished) suggest that the occurrence of *Prosopis cineraria* and *Tecomella undulata*, which are characteristic of the alluvial plains, on the base of dunes, is due to the fact that both are phreatophytes and their existence is no doubt due to the penetration of their deep root system, into the alluvium buried below the dunes. Similarly, the occurrence of species like *Acacia senegal, Melhania denhami, Gymnosporia spinosa* and *Blepharis sindica*, which are all characteristic of rocky habitats, indicate that the dunes have been formed over rocky outcrop and isolated low hills of granites and rhyolites.

In general, the occurrence of a large number of trees and shrubs confirms the view that the dunes of western Rajasthan are of considerable age, and have been stabilized over a long period of time. It also indicates that successful afforestation is possible on the dune habitats.

Dissected sand-dunes: The dissected dunes are commonly found on both windward and leeward side of the granite hills. These dunes are considerably old in age, and have been dissected sometimes deeply by stream flashes from the hills. The density of vegetation is, however, rather low (8·4 per cent), of which *Acacia senegal* constitutes 3·0 per cent, *Salvadora oleoides* 0·6 per cent, *Balanites aegyptiaca* 0·8 per cent, *Commiphora mukul* and *Acacia jacquemontii* 2·0 per cent each. *Ephedra foliata* is a common climber on trees of *G. spinosa* and *A. senegal*. Of the species listed, *B. aegyptiaca* has a high degree of regeneration, there being 40 seedlings of the species per sq metre quadrant. *Acacia senegal* trees are comparatively younger than *S. oleoides* and *Gymnosporia spinosa*, as the DBH values vary from 7·5 to 25 cm in the former and 26·0 to 35·0 cm in the latter species.

The grass cover is highly deteriorated and consists of *Oropetium thomaeum, Tragus biflorus* and *Cenchrus biflorus*. A few clumps of *Dactyloctenium sindicum* are present. Weeds are very few, the common ones being *Boerhavia verticillata, Pupalia lappacea* and *Justicia procumbens*.

Undissected sand-dunes: On undissected sand-dunes deposited on the foothills, the density of trees is 1·4 per cent, of which *Acacia senegal* constitutes 1·2 per cent and *Prosopis cineraria* 0·2 per cent. *Salvadora oleoides* and *Gymnosporia spinosa* together have a density of 0·3 per cent. The shrubs have a density of 8·5, of which *Euphorbia caducifolia* has a density of 1·6, *Leptadenia pyrotechnica* 5·2 per cent, *Commiphora mukul* 0·8, *Grewia tenax* 0·8 and *Acacia jacquemontii* 0·1 per cent. The undershrubs have a density of 20·8, of which *Panicum turgidum* constitutes 12·4 per cent, *Sericostoma pauciflorum* 6·1 per cent, *Aerva persica* 2·3 per cent and *Crotalaria burhia* 0·5 per cent. Of these species, *Acacia senegal* has a frequency of 75 per cent, *S. oleoides* and *G. spinosa* 50 per cent, while the rest have less than 35 per cent frequency.

The ground cover consists of *Arnebia hispidissima, Heliotropium strigosum, H. subulatum, Fagonia cretica, Tribulus terrestris, Polygala erioptera, Cenchrus biflorus, Cenchrus setigerus, C. ciliaris, Aristida adscensionis* and *Eragrostis poaeoides*.

SUCCESSION OF VEGETATION IN WESTERN RAJASTHAN

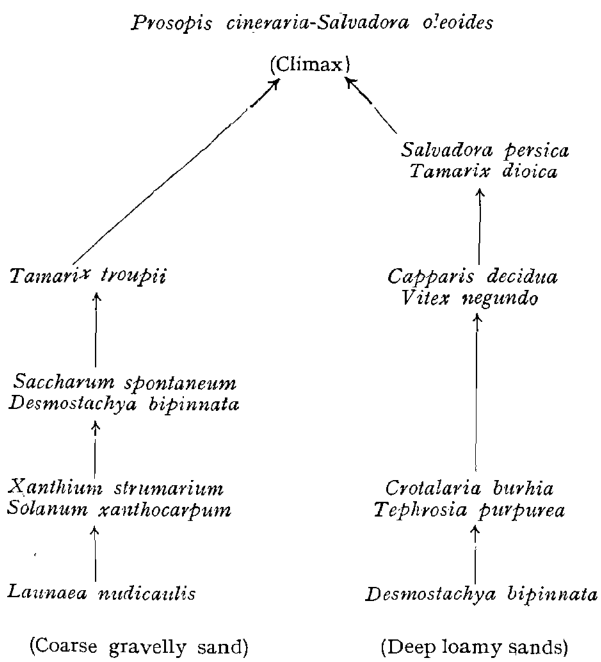
Blatter and Hallberg (1918) stated that it was originally their intention to adopt the Clementsian nomenclature of "Plant Succession", for the description of vegetation of the Indian desert, and that they had to abandon the plan for many reasons. They adopted Schimper's criteria "that formations are communities of plants determined by the qualities of the soils", and recognized five principal formations: aquatic, sand, gravel, rock and ruderal. These formations were subdivided into "associations" which are "communities of a definite floristic composition within a formation", as defined by Warming (1909). The associations were further categorized into "families" which are "communities of individuals belonging to a single species, and occupying a definite area of whatever shape or size, the boundaries of which are determined by the numerical distribution of the individuals, no account being taken of the eventual occurrence of other species within the area", as defined by Clements (1916).

Shanti Sarup (1952), Sarup and Vyas (1958) and Joshi (1956, 1957 and 1958) have used the term "association" rather indiscriminately, giving the status of association to seasonal (synusial) communities. The term "association" itself has been the subject of considerable controversy and these authors have not indicated which definition has been followed by them. In this paper an attempt is made to trace the succession of vegetation in the arid zone of Rajasthan. Puri and Jain (1961) have described the succession of plant communities in the Aravallis, based on their studies of a few localities in eastern Rajasthan. They have distinguished the region into three habitats, viz. rocky limestone, rocky substrata predominantly of sandstone and decomposed and secondary soils. They conclude, "the main climax communities in different habitats of the Aravallis and the adjoining sand plains are formed of tree species".

The present natural vegetation of western Rajasthan is a sparse low cover of thorny woodland formation with distinct variants in different topographical sites. Distinctive communities are found on different habitats as mentioned earlier. The original natural vegetation has been disturbed almost everywhere except for a few relics. Almost all communities are disclimax or bio-climax communities. As Goor (1955) has observed, " there is not a single place in the whole zone in which the natural development of vegetation has not been disturbed and it is impossible to find a plant society at its climax any where ". The course of succession on different landforms is discussed below.

I. *Alluvial plains*: In this habitat the course of succession proceeds along three different series depending upon edaphic factors and irrigation practices but ultimately converging the same climax community (*see* Diagram beloow).

Succession of Vegetation in Western Rajasthan



Schematic diagram: Succession on younger alluvial plains

(a) On alluvial flood plains with gentle slopes and coarse sandy loam soils the early colonizers are *Aristida mutabilis* and *Melanocenchris jacquemontii*. If protected from grazing this community is replaced by perennial grasses such as *Dactyloctenium sindicum* and *Eleusine compressa*. In spite of biotic interference, undershrubs such as *Tephrosia purpurea, Crotalaria burhia* and shrubs like *Balanites aegyptiaca* gain ground at this stage. If left undisturbed, spinescent shrubs like *Zizyphus nummularia, Capparis decidua* increase in density and gain ascendancy culminating in the climax species of *Prosopis cineraria* and *Salvadora oleoides* (*see* Digaram on page 64).

(b) On heavy-textured alluvial soils such as sandy clay loams and clay loams, the seral species in the hierarchy of succession are slightly different. As in the earlier case *Aristida mutabilis* and *Melanocenchris jacquemontii* constitute the pioneers. Greenish blue patches of *Riccia* sp. are also fairly common forming patches here and there. On protection from grazing the pioneers are succeeded by *Dactyloctenium sindicum, Cenchrus ciliaris* and *Cenchrus setigerus* which are ultimately dominated by *Dichanthium annulatum*. Hardy shrubs like *Cassia auriculata* and *Indigofera paucifolia* invade at this stage and in their turn are replaced by *Capparis decidua* and *Zizyphus nummularia* culminating in *Prosopis cineraria-Salvadora oleoides* climax.

(c) Where irrigation is practised there is a slight deflection in the course of succession. The initial colonizers are the same but soon *Cynodon dactylon*, which forms the next stage, covers the ground rapidly as a green mat. The appearance of *Cynodon* is a precursor to the stage of *Dichanthium annulatum* and *Cenchrus setigerus* type (Dabadghao, 1960). *Cynodon* can resist regressive forces tenaciously until it concedes to *Dichanthium, Chloris* and *Sporobolus* species, depending upon the soil salinity. In the absence of any biotic factors, *Cassia auriculata* and *Indigofera paucifolia* make their appearance and thereafter the course of succession is the same as on the heavy soil types.

II. *Sandy plains*: On sandy plains the early colonizers are *Indigofera argentea, Eragrostis tremula* and *Mollugo nudicaulis*. These are succeeded by grasses such as *Dactyloctenium sindicum, Cenchrus catharticus, C. setigerus* and leguminous species like *Tephrosia purpurea* and *Crotolaria burhia*. The tussock grasses *Lasiurus sindicus* and *Panicum antidotale* form the next stage of succession. *Aerva persica* and *Calotropis procera* also make their appearance and are soon followed by *Leptadenia pyrotechnica* and *Gymnosporia spinosa* which form extensive colonies. This ultimately leads to the climax of *Prosopis cineraria* and *Salvadora oleoides*. (*see* Diagram on page 64)

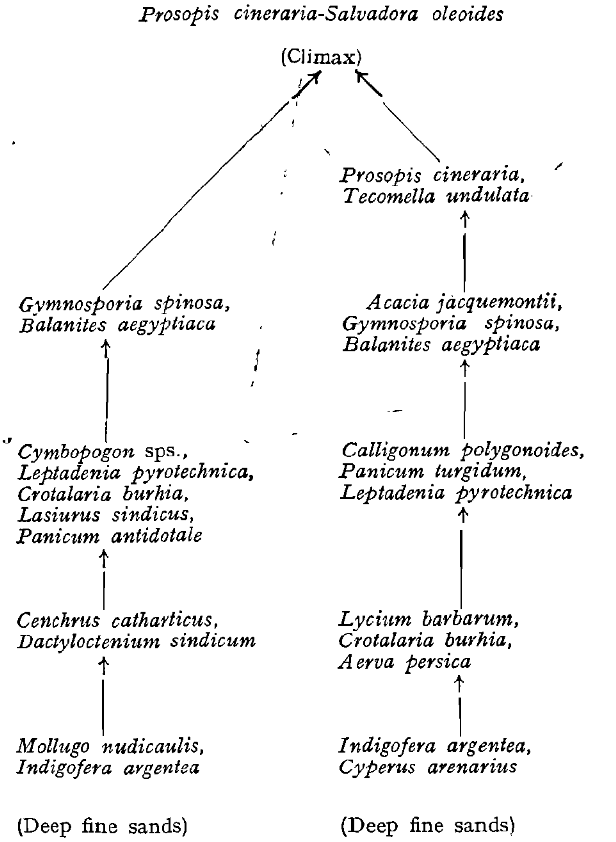
III. *Sand-dunes*: The most common dune pioneers are *Cyperus arenarius, Indigofera cordifolia, Indigofera linifolia* and *Farsetia jacquemontii*. Of these neither *Indigofera argentea* is a psammophilous species which is easily covered by sand, nor its long roots are easily uncovered by sand. *Citrullus colocynthis* is another species common on the dunes at this stage. The grasses and forbs which appear at this stage are *Aristidd hirtigluma, Dactyloctenium sindicum, Aerva persica* and *Crotalaria burhia*. The substratum is now suitable for the growth of *Leptadenia pyrotechnica* and *Lycium barbarum* which are later dominated by *Panicum turgidum* and *Calligonum polygonoides*. If undisturbed, *Acacia jacquemontii* and *Gymnosporia spinosa* and quite often *Balanites aegyptiaca* form the penultimate stage to the climax community of *Prosopis cineraria* and *Tecomella undulata*. *Salvadora oleoides* is rarely found on dunes.

IV. *Riverine tract*: The course of succession is slow in this habitat and is often held up at the pre-climax stage by biotic activities.

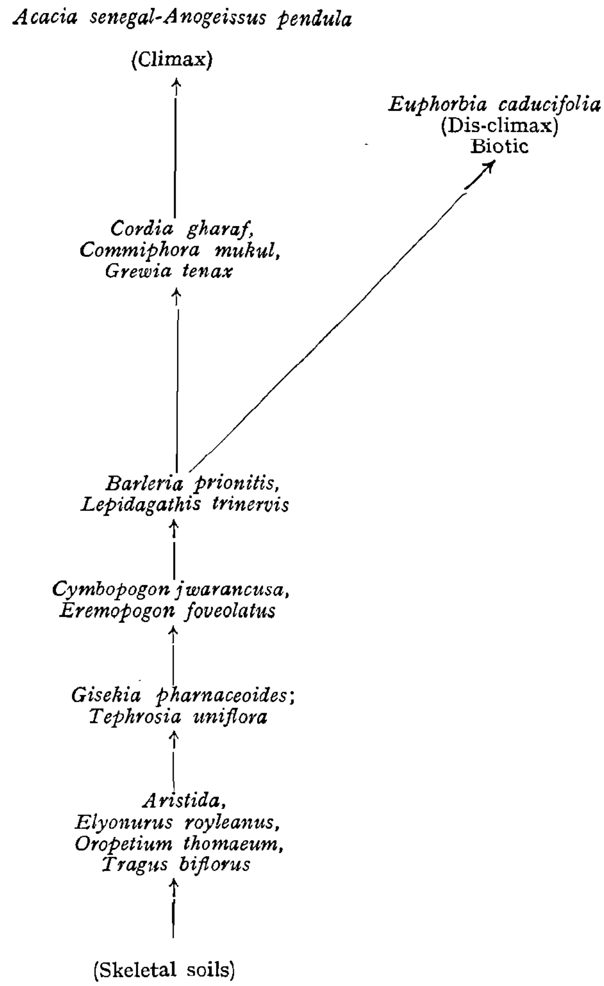
Schematic diagram: Succession on older alluvial plains (Quaternary)

On coarse gravelly river-bed sands, where water stagnates in the short monsoon period, the initial colonizers are species of *Chara* and *Spirogyra* and as the water recedes and dries up *Cyperus rotundus*, *C. iria*, *Phyla nodiflora*, *Mollugo nudicaulis*, *Pluchea lanceolata* and *Launaea chondrilloides* colonize the sands. These, in turn, are succeeded by *Fagonia cretica* and *Solanum xanthocarpum*, followed by *Xanthium strumarium* and *Saccharum spontaneum* to be finally replaced by a community of *Tamarix troupii*. This is generally found in a badly lopped condition and is rarely found in the tree form.

On the levees and flood plains of rivers, the pioneers are *Aristida adscensionis*, *Eleusine compressa*, *Dactyloctenium sindicum* and *Desmostachya bipinnata*. These species have to compete with ubiquitous weeds like *Tephrosia purpurea* and *Crotalaria burhia*. If undisturbed, this stage is replaced either



Schematic diagram: Succession on sandy plains and sand dunes



Succession on

Schematic diagram: detached hills of granites, rhyolites and sandstones (Pre-Cambrian and Vindhyan)

by *Vitex negundo* or *Z. nummularia* and *Capparis decidua* leading to the next higher stage of *Salvadora persica* and *Tamarix dioica*.

V. *Saline alluvial soils*: The early colonizers on this habitat are *Cyperus rotundus* and *Eleusine compressa*. These are associated with *Zygophyllum simplex, Trianthema portulacastrum* and *Cressa cretica*. At this stage *Sporobolus marginatus, S. helvolus* and *Aeluropus lagopoides* invade the area. Where the soil is clay loam or sandy clay loam, *Dichanthium annulatum* is also fairly common. As the substratum is gradually built up, *Haloxylon salicornicum* and *Suaeda fruticosa*, which are typical halophytic species, establish themselves. This stage remains more or less stable. But by progressive reduction in salinity, the succession can proceed further to the climax species of *Salvadora persica-Prosopis cineraria* through the intermediate stage of *Capparis decidua, Calotropis procera* and *Zizyphus nummularia*.

VI. *Isolated hills*: The exposed rocks in the initial stages are colonized by small tough grasses like *Oropetium thomaeum, Tragus racemosus* and *Elyonurus royleanus* particularly in the crevices and depressional area. Associated species such as *Gisekia pharnaceoides, Tephrosia uniflora* and *Bouchea marrubifolia, Arachne racemosa* and *Panicum obscurans* are also fairly common at this stage. With the slow building up of the substratum, *Cymbopogon jwarancusa* and *Eremopogon foveolatus* invade the area. At this stage, the spinescent low shrubs like *Barleria prionitis* and *Lepidagathis trinervis* make their appearance. These pave the way for the shrub stage of *Commiphora mukul* and *Grewia tenax*, which, if undisturbed, leads to the climax species of *Acacia senegal* and *Anogeissus pendula*. In case of biotic degradation, a pure colony of *Euphorbia caducifolia* establishes itself interspersed with species of the shrub stage like *Cordia gharaf* (*see* Daigram above).

It has been observed that the tall *Euphorbia* clumps afford protection to the seedlings of several species such as *Anogeissus pendula, Gymnosporia* *montana* and *Cordia gharaf*, which once established, soon kill the host plant.

Although several of the communities described above appear to end up ultimately in the climax community of *Prosopis cineraria* and *Salvadora oleoides* on the plains, while in piedmont and hills it ends up in the community of *Acacia senegal* and *Anogeissus pendula*. On the younger alluvium, the succession is held up at the pre-climax stage and remains fairly stable.

DISCUSSION

The different systems of ecological classification have been influenced by two distinct schools of thought, the dynamic concept of the Anglo-American school and the static concept of the European school of phytosociologists. The greatest confusion over classification has arisen because of the erroneous impression based on the Clementsian concept, that a given climatic region has but one potential climax.

On the other hand, in a polyclimax interpretation, the term *climax* is used in its ordinary sense — the culmination of development, and, therefore, it can be applied to every relatively stable, self-perpetuating community that terminates succession and it does not imply any connection with climate (Oosting, 1956). Whittaker (1951) has preferred to employ the expression "prevailing climax" to the growth-form or plant population occupying the majority of sites in an area, with no implication of monoclimax and permitting the characterization of average environment and vegetation.

However, according to Shreve (1951), it is not possible to use the term "climax" with reference to desert vegetation. Each habitat in each subdivision of a desert area has its own climax, which must be given an elastic definition and must not be iuterpreted as having a genetic return to any other climax. It is merely that a particular group of species, which is somewhat definite proportions and with a fairly definite communal arrangement, is able to occupy a particular location, under its present environmental conditions.

In the dynamic concept of succession, all communities except the climax are considered as seral stages which are temporary. Each seral community makes the habitat favourable to the next higher community but is itself eliminated. In arid regions, the uniqueness of succession and climax, which may be tenable assumptions elsewhere, appear to be questionable, owing to the inability of the climate to effect radical modifications in the substratum. Under arid conditions, succession is a very slow process, mature soils are slow to develop and easy to destroy. Accumulation of organic matter is very slow and leaching processes are limited by the scanty precipitation (Vernet, 1958). The question, therefore, arises, whether succession of vegetation can take place in arid climates, in the absence of any modifications of the substratum? Because of the serious large-scale destruction of the original vegetation, it is very difficult to form a clear notion of what the climax ought to be and its theoretical reconstruction, only after comprehensive investigations of the area's phytosociology. The existing vegetation on sandy plains and dunes is due to the extreme degradation of natural vegetation through cultivation, overgrazing, lopping and burning. Under such conditions it is extremely puzzling to infer the hypothetical order of succession. Even on dunes, before the succession can progress, the land is brought under cultivation and the process of degradation begins all over again. McGinnies (1957) points out that in a desert the same species of plants that appear in the pioneer stages are often found in the climax stage.

It is also very important to recognize the differences in local habitat, because ungrazed pioneer vegetation on a poor soil may be very similar to that resulting from overgrazing on a good soil. For instance, the community of *Oropetium thomaeum*, *Tragus* spp. and *Melanocenchris jacquemontii* may indicate either a pioneer stay or more often, a highly regressive state, brought about by overgrazing. Even after a careful study of the vegetation, it is rash to assume the existence of a steppe climax just because no trees at all are present (Vernet, 1958).

These objections also hold good for several of the climatic indices proposed for delineation of the arid and semi-arid zones, often put forward without taking into consideration the dynamics of vegetation. Bharucha and Shanbhag (1957) have shown that Koppen's as well as Thornthwaite's old and new classifications fail to subdivide the climatic types of Rajasthan. The aridity indices of Gaussen (Legris and Viart, 1959) and pluviothermic quotient of Emberger (Seth and Waheed Khan, 1959) have also been found to be inapplicable for the bioclimatic classification of Rajasthan.

As indicated by Champion (1936) the climatic climax of Rajasthan is essentially a tropical thorn forest formation. In adjacent areas Rahman Khan (1954) has placed the "rakh" forests or "arid scrub forests" of the Indus Valley, Khairpur, Bahawalpur, Baluchisthan and S-W Punjab plains under the group tropical thorn forests dominated by *Prosopis cineraria-Salvadora oleoides.* In his account of the succession of vegetation in the arid regions of West Pakistan plains, Chaudhri (1960) states that the four main primary series of succession on (1) coastal swamps, (2) riverine tracks, (3) detached hills, and (4) arid saline areas all lead to the mono-climax community of *Salvadora oleoides* and *Prosopis cineraria*. According to him, *Acacia senegal* on the hills is only a pre-climax stage, which is replaced by *Prosopis* and *Salvadora* as soon as sufficient soil collects on the rocks. He concludes that *Calligonum polygonoides* community on sand-dunes and *Saccharum spontaneum-Tamarix dioica* community in the canal irrigated and waterlogged areas represent two series arising as a result of degeneration of the climax. In his account of the vegetation of the plains south of Salt Range in Pakistan, Iftikhar Ahmad (1964) has listed *Prosopis cineraria* and *Salvadora oleoides* as the dominants and *Capparis decidua* and *Tamarix articulata* as abundant trees. It is thus evident that the climax formation of *Prosopis cineraria-Salvadora oleoides* covers an extensive area from the Aravallis over the Thar into Pakistan.

Bharucha (1954) tends to favour the poly-climax concept. He has recognized the climatic climax on the Aravallis as being comprised of *Acacia senegal* and *Anogeissus pendula* but finds it difficult to envisage the climax vegetation of "sandy wastelands".

However, during reconnaissance surveys conducted in several parts of western Rajasthan, the author never came across *Acacia senegal* or *Anogeissus pendula* on the plains nor *Prosopis cineraria* and *Salvadora oleoides* on the hills. The available evidence, therefore, lends support more to the poly-climax theory, there being at least two distinct climax communities, that of *Acacia senegal-Anogeissus pendula* on the hills and *Prosopis cineraria-Salvadora oleoides* on the plains.

Succession, although necessarily slow under an arid region, does take place in western Rajasthan, provided biotic interference is withheld. Bhimaya *et al.* (1964) have shown that in compartments fenced and protected since 1952, there has been a reduction in the number of regressive species like *Euphorbia caducifolia*, regeneration of *Anogeissus rotundifolia* and establishment of perennial grasses like *Eleusine compressa* in the place of coarse annual species like *Oropetium thomaeum* and *Melanocenchris jacquemontii*.

More detailed studies should be conducted to reconstruct the course of succession of the different landforms of western Rajasthan. While study of succession is not an end in itself, its theoretical reconstruction is of great practical utility, as with a definite knowledge of the different stages, it would be possible to "telescope" succession, by reseeding specific habitats, with species desirable from fodder and afforestation viewpoints.

ACKNOWLEDGEMENTS

The author desires to express his gratitude to Dr. P. C. Raheja, Director, Central Arid Zone Research Institute, for his keen interest and constant encouragement.

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DISCUSSION

Fr. Santapau : Does *Euphorbia neriifolia* occur in Rajasthan? I think the species referred to is either *E. caducifolia* or *E. nivulia*.

M. M. Bhandari : The plants mentioned as *Euphorbia neriifolia* and *Farsetia jacquemontii* should be corrected as *E. caducifolia* Haines and *Farsetia hamiltonii* Royle respectively.

Y. Satyanarayan : The revised nomenclature is correct.

C. S. Christian : I have been impressed by the value of natural vegetation of Rajasthan. Your soils are often reasonably fertile and species such as those of *Cenchrus, Elyonurus, Dactyloctenium*, etc., are all valuable species which we would like to introduce into our arid areas in Australia but often we would need fertilizers to do this. This may suggest that they are nutritious species adapted to higher level of soil fertility.

S. P. Raychaudhuri : Is there evidence of degeneration of valuable species in case of soils degenerated by water erosion in red and lateritic soils as, for instance, in *Teak* and *Butea monosperma* and other tree species ? Is such degeneration noticed in case of desert soils due to the deterioration by soil erosion ?

Y. Satyanarayan : In spite of water erosion and gully formation on sands deposited on the foothills, the growth of species is better than on the hills.

Fr. Santapau : Reference has been made to the effect of biotic factors involved ?

Y. Satyanarayanan : The term biotic factors has been used in the broad sense. No specific activity was studied.

Fr. Santapau : Was the damage done by goats on the different species studied ?

Y. Satyanarayan : No such studies have been conducted.

GEOMORPHOLOGY

GEOMORPHOLOGY AND EVOLUTION OF THE RAJASTHAN DESERT[1]

by

K. P. RODE[2]

THE problem of the Rajasthan Desert is being felt acutely in recent years particularly since Independence after the various undeveloped princely states, in which it was divided, had been amalgamated into a single unit. The development of this region is a special problem and the Government of India has given special priority to it in the Five Year-Plans of national development. The appreciation of the urgency of this problem by the official scientific organizations can also be gauged by the fact that a special commission for the development of this region has been set up by the Government of India in collaboration with international agencies.

The problem of the Thar Desert has assumed a sense of urgency also in view of the fact that reports are increasing as to the rapid eastward advance of this desert over parts of western Utter Pradesh (UP).

It has, therefore, become necessary to understand the phenomenon of the desert so that we may be able to tackle the problem of checking or ameliorating desert conditions from the affected regions.

THE NATURE OF DESERT

Desert is a vast sandy region where conditions are most inhospitable for life to exist. Trees and even lowly vegetation find it difficult to survive in such a region. Desert region is usually covered with a thick mass of loose sand or may be rugged with craggy or bouldery rock masses with or without any sand, whereas the subsoil water-table is always very deep in these regions. The absence of subsoil waters for considerable depths inhibits the growth of vegetation and makes human existence intolerable.

The fine clayey soil is usually all blown away by winds leaving in places huge thickness of loose sand in heaps and dunes. There are no flowing streams even though bouldery and pebbly stream-beds often appear here and there in low grounds to suggest the old drainage channels. Sometimes, as in Lybia, the level may sink down considerably below sea-level and may yet be all dry or may be occupied by sheets of salt water. The stream system is often directed inland and rarely reaches the sea. Rainfall is extremely scanty, rarely exceeding 10 in., and even this amount falls irregularly in storms and cloud bursts. Deserts are usually high pressure zones, and winds blow from land towards sea and as such are dry. There is no humidity in the air.

Due to extensive evaporation of subsoil moisture rising through capillary channels the underground water-table is largely depleted and there are no rains or rivers to replenish it. The water table, therefore, sinks deeper and deeper. No vegetation can survive and the surface rocks and sands are all barren and become exposed to sun and winds. There is enormous radiation of heat at the surface and the atmospheric temperatures rise remarkably high during day and fall precipitously low during night, causing rocks to disintegrate. This brings about sudden changes in atmospheric pressures and high winds and storms become common. Sands are raised copiously and are blown furiously over vast distances. Hills of sand may form and disappear in no time. Dunes are made at one place and unmade at another and give the appearance of dune migration. Surface irregularities are levelled up, and we find ultimately a vast sea of sand with dunes simulating waves.

DESERTS HISTORICALLY OF LATE GROWTH

There are numerous indications that human habitation was abundant in many desertic regions even in historical times and it is obvious that the region was not so inhospitable for life to exist. The extensive wide channels and beds of rivers, though now absolutely dry except immediately after the rains, give ample evidence that the region had once a well developed drainage but which due to some unknown causes has later disappeared. This comparatively late development of desert topography calls for a proper understanding of the causes of desert formation so that we may be able to check the advance of the desert and if possible to ameliorate the intolerable conditions obtaining in the existing desert regions.

THE POSSIBLE CAUSES OF DESERT FORMATION

Deserts have been studied from different points of view and this has led to very diverse approaches

1. Contribution from the Department of Geology, University of Rajasthan, Udaipur.
2. Professor and Head of the Department.

to the problem of their origin. Eminent scientists specializing in different disciplines appear to view the problem from widely different angles. The various features which characterize the deserts are often given such importance as to indicate that these features by themselves, even individually, have been the direct cause of desert formations. Thus, we find the meteorologists studying climatic conditions like the fluctuations of temperature, atmospheric pressures, wind directions, etc., often cite them as the principal causes bringing about desert conditions. The biologists studying the animal distribution in relation to vegetation attribute the scantiness or absence of vegetation in the desert to excessive grazing, intensive cultivation or indiscriminate deforestation and as such these are supposed to cause desert formation. Geographers see in the huge masses of loose sand in desert the work of winds which are supposed to have transported enormous quantities of sands from sea beaches. They attribute the failure of monsoons either to the shadow action of the transverse mountain ranges in the path of the monsoons which rob them of their water content before they reach the desert region, or to the absence of such ranges on the opposite side to arrest the rain-bearing clouds, before passing over. They also suggest that the location of the region in the interior of continent away from sea brings about insolation of the area beyond the reach of monsoons.

The geologists see in the extreme variation in diurnal temperatures the potent agent in exfoliation and crumpling of rocks leading to excessive sand formation. They also see in the inland drainage the cause of salt lake formation so characteristic of deserts.

One cannot underrate the effectiveness of the various climatic, biological and geographical factors in the accentuation of inhospitable conditions prevailing in the desert regions. The important point, however, is whether these factors are by themselves capable of bringing about the formation of full desert topography over vast regions of the earth.

DISTRIBUTION OF DESERTS

Deserts are not small surface features of local significance such as could be determined by local conditions. Vast areas on the earth's surface are desertic in the true sense and they constitute as much as one-fifth of the total land surface of the earth. Further, they do not occur haphazardly but form a more or less continuous belt not confined to the Tropics (Map, Fig. 1). Starting from the Manchurian-Mangolian region constituting the Great Gobi Desert almost within sight of the western Pacific Ocean, the belt runs westward and gradually widens in area. Thus, we see the desert in the Chinese and Russian Turkistan, Persia, Caspian Sea region and Arabia has now widened enormously further west to cover nearly the whole of North Africa comprising the Great Sahara. One arm passes southward through Tanganyika and Rhodesia to Kalahari. This is continued on the other side of the Atlantic and is to be seen in Patagonia and the Atacama facing the eastern Pacific Ocean, while the other arm extends through Texas into Colorado in the western United States. In the south-east, in the Australasian region again, we have the Great Australian Desert.

Besides these we have vast regions which can be described as cold deserts and which characterize higher latitudes.

These vast desert regions of the earth do not lend themselves to any one of the climatic, biologic or geographic factors which could be regarded as the prime cause in their formation. Deserts occur in all the latitudes and in all climatic zones. They occur in the interior of continents as also near the sea coast. They occur on the wrong side of the mountains as also on their right side. They are not all ill-situated with respect to monsoon directions. Animal agencies with or without intelligence could not all have worked together to give rise to deserts over such vast regions. These various factors could not, therefore, have been the causes of desert formation, they may be only the effects like symptoms.

THE ROLE OF SUBSOIL WATER-TABLE

The most important characteristic which is common to all the deserts is the great depth of subsoil water-table, so deep as to be beyond the reach of surface vegetation. If this is so the problem of the desert can be reduced to ascertaining as to how this deepening of the water-table has been brought about. This is largely a geological phenomenon and is only temporarily affected by atmospheric agencies. When we study this problem a little closer it is always seen to be in intimate relationship with the river system. The water-table is fed and maintained by the inflow from the rivers while the rivers also, in their turn, are supported by outflow from the subsoil water-table in the form of springs and it is evident that the upsetting of either of these upsets the other. Thus, the vanishing of rivers from any regions would cause the deepening of the water-table and this may ultimately lead to the formation of deserts (Fig. 2).

Let us study this problem in relation to Rajasthan which affords an instructive example and this study may possibly offer a real solution to this difficult problem.

PHYSIOGRAPHY OF THE RAJASTHAN DESERT

The Rajasthan Desert, which is better known as the Thar Desert, occurs between the Aravalli Ranges

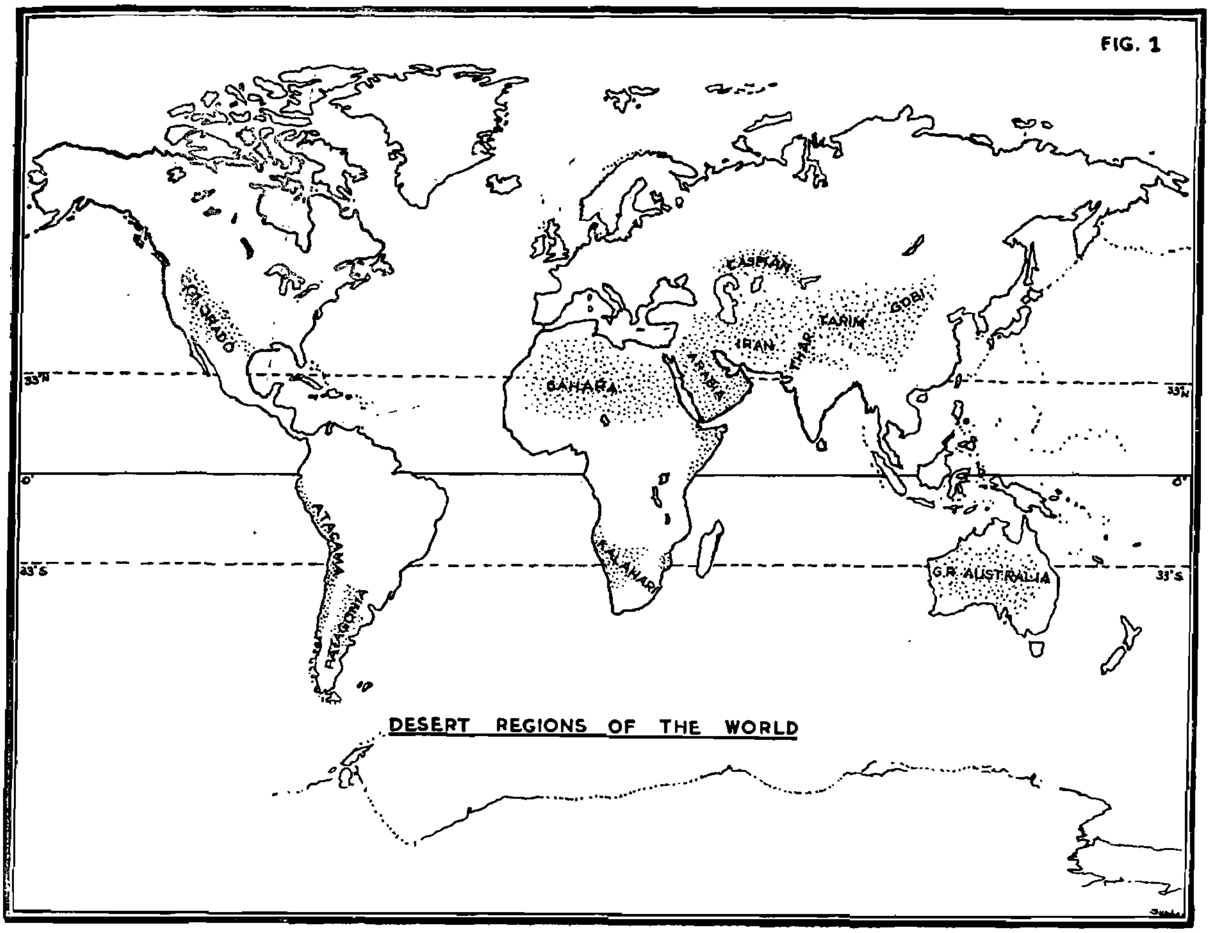

Fig. 1 — Deserts of the world

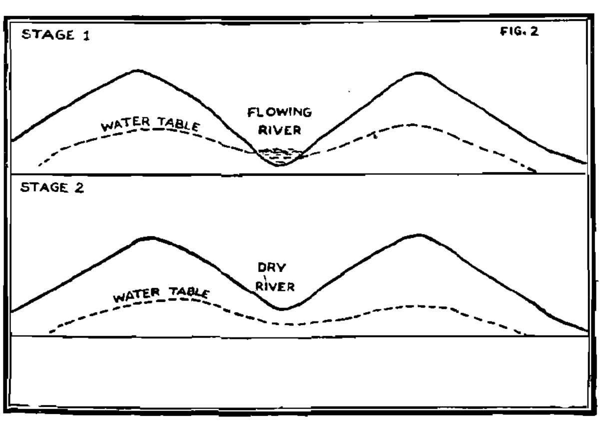

Fig. 2 — River and water-table relation

on the east and south-east and the Sulaiman-Kirthar Ranges on the west. The eastern part of this desert, east of Jaisalmer, forms a lowly elevated plateau, 500-1500 ft above sea-level with numerous rock masses jutting out of the desert sands and is drained by the Luni river. This semi-desert has a number of saline lakes, and a fair degree of habitation distributed over this region. The region between this plateau and the Indus is the Thar Desert proper, with a monotonous expanse of low sandy plains, hardly rising above 500 ft. It encompasses the whole territory of Bahawalpur and portions of Sind, Jaisalmer and Bikaner. This is traversed by the Indus and the Nara and by the channels of the dead rivers Ghaggar, Raina and Naiwal.

To the west of the Indus and extending up to the Sind-Baluchistan ranges there is a lowly elevated region which is again a semi-desert, with a number of saline lakes, the dhands, all having a rough N-S elongation. Thus, the river Indus, mighty as it is, traverses the Thar Desert along its western margin.

To understand the evolution of the hydrography of this region, it would be instructive to study the drainage patterns of the whole of Rajasthan and extending up to the Indus.

THE HYDROGRAPHY OF RAJASTHAN

Briefly, this region can be divided into four distinct drainage systems: (i) The eastern system comprising the Chambal basin together with the Gambhiri, the Banganga and the Mendha. All of these have a general eastern flowage and are tributaries of the Jamuna. (ii) The south-western system comprising the Mahi, the Sabarmati, the Saraswati, the W. Banas and the Luni, all of which flow S-W, into the Rann of Kutch and the Gulf of Cambay. (iii) The western system comprising the Nara and the Indus flowing south-west into the Arabian Sea. (iv) The northern system comprising the dead rivers the Ghaggar, Naiwal, Raina, etc.

The whole drainage system is illustrated in the map (Fig. 3).

A study of this map would immediately bring to notice certain peculiarities in the courses of the various rivers and their tributaries. Certain directions appear to be the most favoured ones which are followed by the various rivers irrespective of whether they belong to the one or the other of the drainage systems mentioned above. Thus, the direction NE-SW appears prominent in the Indus, the Raina, the Ghaggar, the Luni, the various tributaries of the Jamuna and the Chambal as well as in the Mahi, the Sabarmati, the W. Banas.

The second favoured directions is the N-S which also is recognizable in the Indus, the Nara, the Luni, the Sabarmati, the Mahi, and the various tributaries of the Chambal — the Parvati, the Kali Sind and the Betwa.

It is most remarkable that these two directions effectively control the drainage patterns of all the rivers from Allahabad to Karachi, west of the Jamuna and north of the Narbada.

Another remarkable feature of the drainage of Rajasthan is in respect of the overall courses of the rivers.

The rivers of the Jamuna system, viz. the Ken, the Betwa, the Kuwari, the Parbati, the Kali, the main Chambal, all rise only a short distance north of the Narbada, flow first north, later north-east and then suddenly turn south-east before joining the Jamuna.

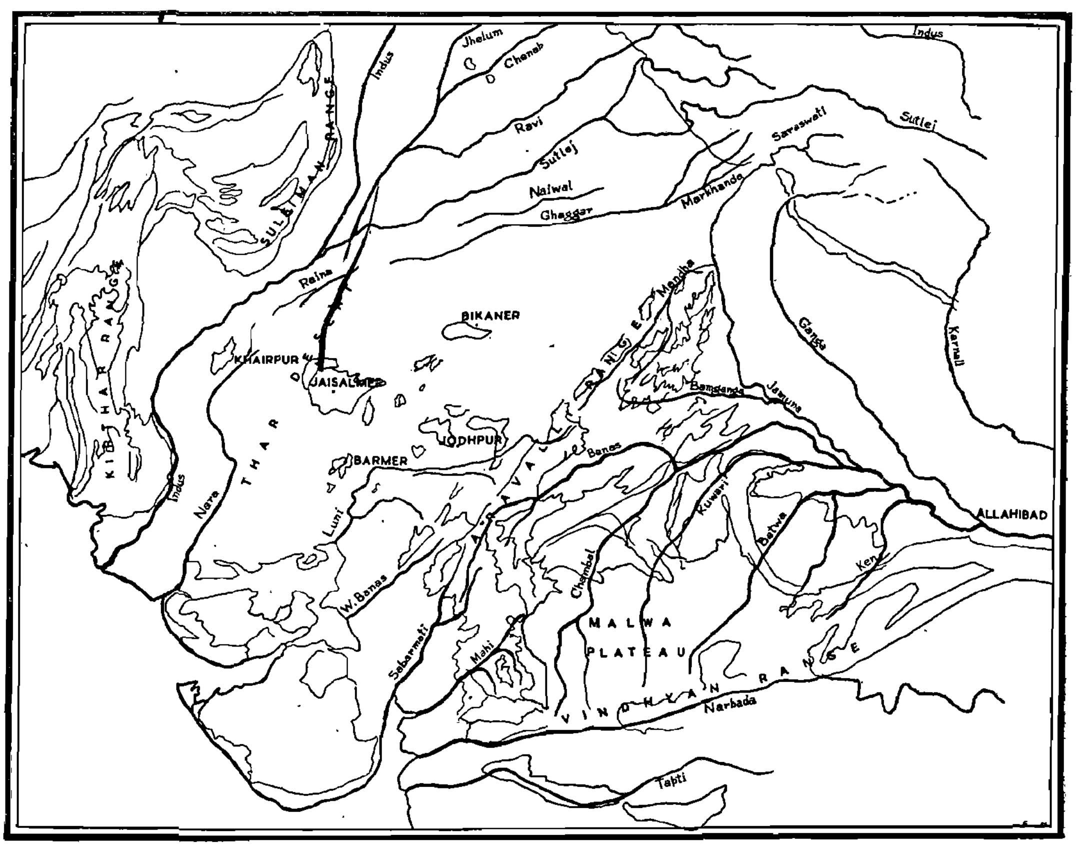

Fig. 3 — Morphology and evolution of Thar Desert

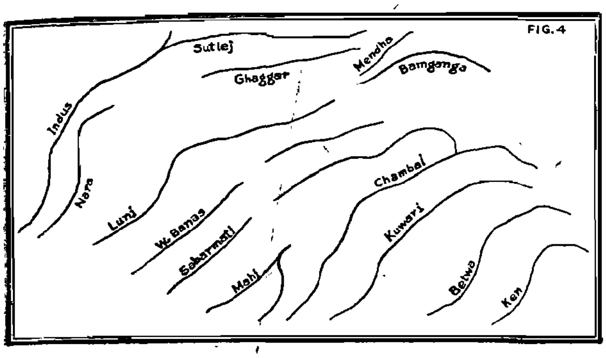

Fig. 4 — Pattern of river system

Of the rivers of the S-W Rajasthan, the Mahi also rises near Mhow a little north of the Narbada and not far west of the Chambal. It flows first north and then, instead of flowing north-east like the Chambal, takes a sudden turn to the south-west to join the Gulf of Cambay. The other rivers of this group, viz. the Sabarmati, the Saraswati, the West Banas, all have a nearly parallel course in the S-W direction to join the Gulf of Cambay. The Luni starts from near Sambhar Lake and has an initial trend to the S-W and then turns the S-S-W to join the Rann of Kutch. More or less in the same way the Sutlej-Indus river system has a long course in the S-W direction and turns south and south-west before the Indus falls in the Arabian Sea. The river Nara has a course mainly in the southern direction and is remarkably parallel even in sinuations to the lower course of the Indus.

The courses of the fossil rivers Ghaggar, Naiwal and Raina also have a S-W course strikingly parallel to that of the Sutlej.

We thus see that the various rivers in this part of India exhibit remarkable parallelism in the general trends of their courses.

These correspondences become even more striking when we study the actual location of these river courses. Thus the S-W flowing course of Mahi is in direct alignment with the N-E flowing course of the Chambal.

The S-W flowing Sabarmati is in alignment with the N-E flowing Banas.

The West Banas flowing S-W is in alignment with the N-E flowing Khari tributary of the Chambal.

The main channel of the S-W flowing Luni is in direct alignment with the N-E flowing Mendha river. We can go still further north-west and see that the fossil river course of Raina (in Sind) is in alignment with the dead river Ghaggar.

What is the significance of these correspondences both in the parallelism as well as in alignments of the various river courses? Why are they all having such parallel courses? Why should there be alignments in the courses of rivers which are flowing in opposite directions? Evidently they cannot all be merely accidental nor can they be attributed to superficial atmospheric agencies. They must somehow be related to the underground rock structures. These structural relationships of the rivers are not easily made out, but can only be inferred by a study of large geological maps. We find, for example, that the course of the Indus, south of Dera Ismail Khan, is intimately following the outcrop of the pre-alluvial rock formations making the Sind-Baluchistan ranges and thus virtually marking their eastern border. It is, therefore, possible that there exists a definite genetic relationship between the Sind-Baluchistan ranges and the main Indus channel and that the latter forms, as it were, the tectonic border of the former. Somewhat similar relationship appears to exist between the Aravalli rock formations and the Chambal basin. It does, therefore, appear possible that the river courses have some sort of intimate connection with the structure of the rock formations of the region through which they flow. The general parallelism of the river courses as noted above in the case of the Chambal, the Luni, the Ghaggar-Nara system and the Sutlej-Indus system may then indicate that the rock formations in their regions have some sort of structural relationships among themselves and with the tectonic trends of rock formations which are largely obscured under the cover of the desert sands. The author has shown elsewhere (Rode, K. P., 1954, Memoirs of the Rajputana University, Department of Geology, No. 4) that the structural patterns exhibited by rock formations constituting the Sulaiman-Kirthar Ranges, on the one hand, and those of the Aravalli Ranges, on the other, are extremely similar and appear to be in the nature of two superposed rock sheets in which the Aravallis form the basement while the Sulaiman-Kirthars form the upper sheet (Fig. 5).

It thus appears plausible that the two structural sheets were at one time actually superposed one over the other and that they have later separated through the process of sheet movements during the Luni series of movements. On the basis of this conception it becomes easily understandable why the various rivers in this region show such parallelism in their courses. Thus, when the Sind-Baluchistan sheet was resting over the Aravalli basement, the Sutlej-Indus course must have been coincident with the present course of the Chambal which has a remarkably similar trend pattern. Later as the upper sheet moved westward the Sutlej-Indus also shifted gradually passing successively through the positions of Banas-Sabarmati, Mendha-Luni and Ghaggar-Nara, before it reached its present position.

It thus appears quite probable that when the Sutlej-Indus was occupying the position of Ghaggar-Nara, the latter must have been a mighty river like the former as is clearly proved by the vast bed of the Ghaggar which is in places over 4 miles in width. During this period the whole region of Bikaner, Jaisalmer and Bahawalpur must have been

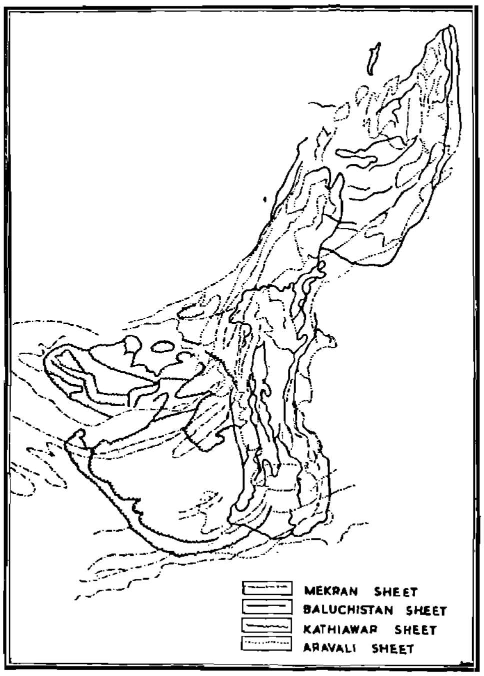

Fig. 5 — Morphology and evolution of Thar Desert

covered by alluvium as fertile as the Punjab, and the desertic conditions now seen there must have been altogether absent. This is corroborated by the historical evidence according to which not many centuries back this region was a thick forest.

If Rajasthan was even in historical times a rich fertile country, why it should have developed into a desert region now becomes a pertinent question. As stated in the treatment above we can follow the sequence of events which have changed the face of this region beyond recognition.

The Sulaiman-Kirthar sheet which during the Ghaggar position of the Sutlej-Indus was occupying the Bahawalpur-Khairpur position later shifted further westward to its present position. The Sutlej also moved to the north but the old channel continued to function even though with much depleted waters from the Himalayan hills through the streams of Markhanda (Chautang, Saraswati, etc.) in the region of Simla, Ambala, Patiala districts. Largest part of the Himalayan waters, however, got diverted into the Sutlej or the Jamuna, while the medial region became impoverished in water supply. The Markhanda became a straggling stream and could hardly supply water to the Ghaggar basin. At this stage even minor changes in the level in the alluvial country could cut off the Ghaggar from the Markhanda. In this way the Ghaggar became a dead river, its basin became dry and the water-table sank deeper and deeper. The river alluvium which was so fertile now could not stand the ravages by the atmospheric agencies, like winds, solar heat, etc. The fine clays which held the alluvial sands together were blown off leaving the sands loose and dry. The same sands which were the support of the green vegetation later became the mantle of the desert and a full desert topography came into existence.

It will thus be seen that the prime cause of the desert formation in this region is the impoverishment and consequent deepening of the subsoil water-table due to the diversion of the Himalayan waters away from the Ghaggar. It naturally follows that any scheme to fight the desert must take this prime factor into consideration.

If through some human ingenuity this supply of waters to the Ghaggar can be restored on a more or less perpetual basis, the desert can be banished from this region of the earth almost permanently.

The author feels that this can be easily brought about if we adopt the following scheme:

1. The Himalayan streams in the Simla-Sirmur region can be bunded at suitably high altitudes and to this, if necessary, a portion of the Sutlej waters can be diverted. This is now about to be realized when Bhakra Nangal project is completed.
2. From these high level dams canals can be led into the Markhanda and the Ghaggar to rejuvenate these dead rivers.
3. If the intervening alluvial region between the Markhanda and the Ghaggar, be too low for waters to flow into the Ghaggar a system of closed channels may be introduced in the critical region.
4. In the early stages much water would seep into the sands in the river-beds and thus be apparently lost, but that would ultimately elevate the underground water-table which is the prerequisite for banishing the desert.
5. In course of time the water-table would be elevated sufficiently and the loss through seepages would decrease.
6. This permanent rehabilitation of the water-table would permit perennial growth of vegetation and normal conditions of fertility would be re-established.

It is, therefore, suggested that any schemes of rehabilitation of these regions must take this factor into prime consideration as without this all efforts would be temporary palliatives, involving enormous recurring expenditure without any commensurate results.

DISCUSSION

A. K. Sen: What are the forces that brought about the drifting of the sheets? Could earlier drainage lines not disappear with sheet movement?

K. P. Rode: Lava eruptions in upper layers of the crust, particularly sedimentary formations, serve to separate upper layers from lower the through sill-like intrusions. Upper sheets float over the heavy intrusive material and would glide *en masse* as the lava mass flows to regions of lower level, i.e. towards oceans. Circum-Pacific volcanism has played the most important part in these sheet movement successively stage by stage and these stages are recorded by river courses, which exhibit parallel or semi-parallel relationships. Rapid movement of river courses may bring about obliteration of part of river-beds under alluvial deposits now turned into desert sands.

E. Hovmoller: Disagreement was expressed with the author's contention that the desert would be formed purely due to tectonic reasons.

GEOMORPHIC FEATURES AROUND THE SEMI-ARID REGION OF BELLARY, MYSORE STATE[1]

by

R. VAIDYANADHAN

INTRODUCTION

THE two major arid to semi-arid regions in India are in Rajasthan and in the south-western part of the Deccan Plateau. Whereas the geology of these areas have been extensively studied (Heron, 1953; Bruce Foote, 1896), the geomorphic features of the same have only been briefly touched upon. It is only during the past two to three decades that the geologists have focused their attention to the detailed study of land-forms and their origin in different parts of the world (Howard and Spock, 1940). It must be admitted, however, that an impetus for such a study is the availability of data in the third dimension (along railroads, highways, canals, quarries, wells, etc.) which is an essential pre-requisite to any geomorphic study.

Bellary region in Mysore State is the most arid part of the Deccan Plateau (Subrahmanyam, 1956) characterized by a long dry season (for more than eight months), the temperature of the coldest month being above 20°C and the hottest month about 48°C and a low rainfall (between 500 and 1000 mm). A study of the geomorphic features of the area together with some quantitative data collected on the nature of the slopes of the hillocks, the nature and thickness of recent sediments over bedrock have brought to light features here typical of arid and semi-arid regions of the world.

PHYSICAL SETTING AND GEOLOGY

Bruce Foote (1869, p. 2) gives a description of the physiography of the whole of the Bellary district of which the area under detailed study forms a part (Fig. 1).

This area and the region north of it is occupied by great spreads of black soil " out of which the granitoid hills rise like so many islands ". The area is about 1450 ft. above mean sea-level and the maximum relief is about 1800 ft. (Copper Mountain, 6 miles south-west of Bellary is 3290 ft. above M.S.L.). But more commonly the highest hillocks around Bellary and further north are only 500 ft. above ground level. The streams are dry for a major part of the year but overflow during short periods when heavy rainstorms are known to occur in this area. During such periods the rain-water is discharged essentially in sheets over the whole area rather than along the shallow streams. This has resulted in soil erosion on a large scale. The area is almost devoid of any vegetation except for thorny bushes and trees (Acacias) here and there.

The hillocks are made up of gray and pink granites and they are occasionally porphyritic. These contain small schist inclusions, and thin aplite veins and pegmatites are seen following and sometimes across joints in these rocks. Numerous sets of joints are present (Bruce Foote, 1869, p. 56) but the most prominent among them are trending (i) NW-SE, (ii) NE-SW, and (iii) almost horizontal.

DESCRIPTION OF THE GEOMORPHIC FEATURES

Dome: The most conspicuous feature in this area is the hillock in Bellary town known as the Fort Hill. The Fort Hill is a partial dome in that it slopes almost steeply to the north and east but gently in other directions. North-east of the Fort Hill is another one extending NW-SE called the Face Hill. The rock is highly jointed and the southern face of the Fort Hill abounds in tors. These are the result of extremely close jointing separating the rock into cubical blocks. At the northern and eastern part of the hillock curvilinear division planes of wide radius separate plates and sheets of rocks from a few inches to more than 3 ft in thickness. Their depth of occurrence and freshness preclude the possibility of their formation by external weathering agencies and their accordance with exposed surfaces supports the concept, put forward originally by Gilbert, of dilatation or fracture due to unloading (Mabbutt, 1952).

Whalebacks and flat domes: The former are longitudinal oval-shaped hillocks with narrow crests. One such is found to the north-west of the Face Hill (Fig. 1). At the extremities of huge hills and a chain of hillocks are found flat to slightly elevated oval domal rocks, whose topmost point is between 20 and 50 ft above ground level. These are presumably evolved from secondary domelets or whalebacks and are called flat domes. Curvilinear joints are more common among the whalebacks and flat domes and these are made use of by quarrymen in the excavation of rocks for building purposes.

Inselbergs and koppies: About 4 miles north-east of Bellary, near Sanganakallu, are another group of

1. Contribution from the Department of Geology, Andhra University, Waltair.

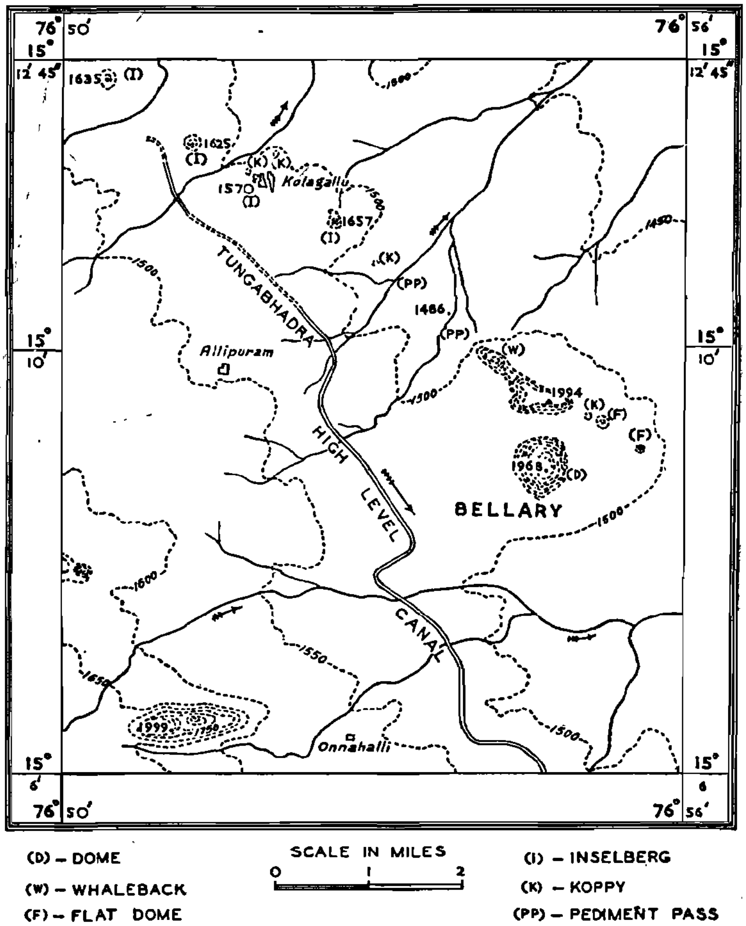

Fig. 1 — Map of Bellary area showing the geomorphic landforms

hillocks standing out of a vast blanket of alluvium. The outline of the hillocks is rugged and these hillocks extend along certain directions. A series of hillocks extend roughly NW-SE from about a mile east of Bellary town to a distance of 7 miles north-west of it. Face Hill is apparently a part of this series. It is obvious that these hillocks must have been once connected and now stand separated after having undergone erosion for a long time. The slope of the hillocks is about 34 - 38° to horizontal and the top surface of the soil is inclined about 2° to the horizontal till it meets a similar surface from an opposite hillock. Closeby there are small mounds which have a slope angle varying from 80° to 88° and occupy usually an area from 1200 to 1600 sq ft. Comparison of these features with those described elsewhere (King, 1951) suggests the bigger ones to be 'inselbergs' and the smaller ones 'koppies'. There are three small 'castle koppies' immediately north-west of the village of Kolagallu.

Erosion surfaces: Apart from the continuous NW-SE extending Sandur range, 6 miles south-west of Bellary, there are quite a number of hillocks in the area under study. A survey of all the hillocks within a radius of about 20 miles from Bellary gave the following summit heights for the highest hillocks near the villages mentioned below:

Fort Hill	1968′	North of Bellary
Face Hill	1994′	,, ,,
Onnahalli	1999′	SW ,,
Daroji R.S.	2090′	WNW ,,
Kurugodu	1951′	NNW ,,
Sindigeri	1922′	North ,,
Sanganakallu	1968′	NE ,,
Gadekallu	1817′	East ,,
Vidapanakallu	1900′	SE ,,

Some of these are partial domes and some rugged inselbergs. The accordance of summit heights here suggests that these are perhaps the remnants of an erosion surface sloping gently due ENE. According to King (1949) the bornhardts, that is, the steep sided domal rocks, are found where there are traces of two cycles of erosion. It is possible that the above accordant summits may be the remnants of an younger erosion surface and the older surface may be the one over the Sandur range and further south.

The former is around 2000 ft above mean sea-level and the latter around 3000 ft in the Bellary region. A detailed analysis of the erosion surfaces in the southern part of Cuddapah basin, east of Bellary region, is published elsewhere (Vaidyanandhan, 1964).

Pediment: The soil around the hillocks is usually reddish brown and farther away it is black. The areal extent of the former around the inselbergs and koppies varies in direct proportion to the size of the hillocks and the nature of the drainage. The soil is mostly made of angular quartz and felspar grains.

One of the notable features in the region is the break in slope between the hillfront and the ground surface at the bottom of it. The junction is invariably sharp. An angular junction of the mountain slope and the ground is seen along the southern face of the Face Hill and northern face of the Fort Hill. A faceted junction is seen west of Onnahalli, where a dyke cuts across the country rock. A talus (though made up only of granite blocks) covered, but yet steep junction is seen on the south-western face of the Fort Hill and a compound junction on the northern slope of the Copper Mountain. Similar junctions have been described elsewhere (Howard, 1942) between mountains and ground surfaces only in arid and semi-arid regions. In all these cases the ground surface happens to be a pediment, which is a cut-rock erosion surface truncating rock structure and forming a smooth piedmont plain. These pediments are usually veneered by rock debris and negligible thickness of soil. The pediments are formed at the base of the retreating slope of a mountain or hillock after which they are modified by sheet and rill wash. Sometimes bedrock can be seen jutting out of the top debris or soil.

In order to confirm whether the surfaces immediately beneath the hillfronts in this area are pediments, data along vertical sections across them were collected wherever available. The Tungabhadra High Level Canal (Fig. 1), now under various stages of construction, and the many wells and quarries around Bellary town and the neighbouring villages afforded exellent opportunity to study the thickness of the rock debris and soil over bedrock. From measurements at 115 places along a length of detailed 9 miles of the canal it was found that where the about bedrock was touched during the course of excavation the maximum thickness of overburden was 11·5 ft and the minimum 1·3 ft. A traverse from near the inselbergs toward south gave a broad indication of an increase in thickness of the overburden due south and south-east. A very important feature is the absence of any weathering profile which is an evidence for the rock surface being a pediment.

Pediment pass: The gaps across a chain of inselbergs and koppies where opposing pediments coalesce are called pediment passes (Howard, 1942). The characteristic feature of a pediment pass is the occurrence of pointed heads of boulders of rock debris and partially exposed rock surface at those places. Almost midway between Bellary and Kolagallu are two places where the above features are seen. At the pediment pass (PP in Fig. 1) nearer Kolagallu a stream flows across it. In the stream bed as well as on either side are seen the rock debris and the cut-rock surface and farther north-east and south-west along the stream, the thickness of the alluvium increases.

Pediplain: King (1953) has outlined on the basis of his extensive studies among the arid and semi-arid tracts of South Africa, the characteristics of a pediplain in the form of certain " cannons ". Features similar to many of those described by him are present in this area and further north and east.

The waxing slope, free face, detrital slope and waning slope under pediment (cannon 4) are seen on the northern section of the Copper Mountain. Erosion of the free face and the debris slope by rill wash forming gully heads is evident in the same section at certain places (cannon 11). The cut-rock surface and absence of weathering profile are seen along the Tungabhadra High Level Canal. The break in profile between the pediment and the hillock, usually abrupt (cannon 21), has been noted in many places. The ultimate cyclic landform, according to King, is the pediplain (cannon 35) which is the resultant of the coalescent pediments. The flood plains are not usually extensive as is exemplified in the area between the Hagari river to the east and the Tungabhadra to the west. Hence it is suggested that the area around Bellary has attained a stage of pediplanation.

ACKNOWLEDGEMENTS

My grateful thanks are due to Prof. Chalmer J. Roy of the Iowa State University, Ames, Iowa, USA, for initiating me to the study of pediments; to the Executive Engineer, Tungabhadra High Level Canal, Dn. 2, Bellary, for help in the procurement of data along the canal and to the University Grants Commission for the award of a travel grant for field work in this area.

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GEOMORPHOLOGICAL ASPECTS OF THE FORMATION OF SALT BASINS IN WESTERN RAJASTHAN[1]

by

BIMAL GHOSE[2]

REVIEW

PREVIOUSLY it was considered that salts are derived from various weathering products. But this theory could not get support as the chlorides which are the main constituent of salts could not be accounted for from rock weathering. Then the marine inundation theory and also the wind-borne theory of Holland and Christie (1909) were postulated.

Holland and Christie (1909) carried out aspirator experiment at Pachbhadra salt basin in western Rajasthan to collect air-borne particles. From the analysis of these particles they postulated that the source of salt of the salt basins of Rajasthan is the Rann of Kutch. According to them salts are transported by wind and deposited in the lakes. Subsequently, however, some objection were raised which are (1) if the source of these salts is the same the chemical composition of salts of all the lakes should have been the same; and (2) it is not understood how wind can deposit salt at particular places, even across the Aravallis year after year leaving some of the adjacent lakes free of salts.

Hume in 1867-68 (vide Holland and Christie) and Blanford (1876) proposed that these salt lakes of Rajasthan are the relics of an inland sea. This was, however, rejected by Holland and Christie on the basis of the past geological events. Godbole (1952) made an effort to revive this theory with slight modifications, substituting the Tethys Sea for an inland extension of the Arabian Sea. But this theory has as many weaknesses as that of Holland and Christie. Some of the shortcomings in his theory are as follows:

(1) No marine rock has been found associated with either salts or gypsum. On the other hand, fresh-water fossils have been found in salt and gypsum deposits (Ghosh, Dutta and Taploo, 1944; and Jacob and Sastri, 1950).

(2) The chemical compositions of salts of all the lakes are different and do not tally with that of sea brine (Table 1).

(3) The Sambhar lake lies astride the axis of the Aravallis and there is no marine rock in the vicinity (Auden, 1952). Moreover, the supposition that the Tethys transgressed across the Aravallis would provoke further question whether this region was subject to a much greater tectonic movement than there is evidence for (Heron, 1938).

(4) The sea as reported was shallow. This quantity of salt and gypsum could not have been obtained from such a shallow sea. According to Bateman (1950), for 5 ft thick bed of gypsum (such as Jamsar gypsum bed) one and half a mile deep sea is needed.

TABLE 1: Composition of brine of salt lakes and of the Indian Ocean (on dry basis) in round figures (after Godbole)

Constituents	*Sea brine*	*Sambhar lake brine*	*Kuchaman well brine*	*Kharaghoda well brine*	*Didwana well brine*	*Pachbhadra well brine*
Sodium chloride	77·76	87·3	84·2	70·8	77·2	85·7
Potassium chloride	2·5	0·13	—	2·0	—	—
Magnesium bromide	0·22	0·05	—	0·35	—	—
Sodium sulphate	—	0·6	10·5	—	20·6	—
Sodium carbonate	—	0·8	—	—	0·6	—
Calcium carbonate	0·3	—	0·5	0·6	—	—
Calcium sulphate	3·6	—	0·5	2·1	—	2·9
Sodium bicarbonate	—	—	—	—	1·6	—
Magnesium sulphate	4·7	—	2·6	2·3	—	9·4
Magnesium chloride	10·8	—	—	22·4	—	1·9

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Geomorphologist at this Institute.

The significant point that emerges from the above consideration is that the origin of the salt basins is neither marine nor aeolian.

It has also become obvious that the previous workers mixed up two entirely different issues in their approach. Chemical origin of salt is quite a different problem from the geomorphic origin of the salt basins and the depressions. The former is a geochemical and the latter is a geomorphological problem. In the present paper these will be discussed separately with reference to the Central Luni Basin.

GEOCHEMICAL ASPECT OF SALT FORMATION

There are many economic minerals which are either residues of weathering or products of weathering. With the increasing knowledge in geochemistry, however, it has become clear that much of the formation of salts results from chlorides, sulphates and such other materials present in the atmosphere and they come down with precipitation. Eriksson (1958) has given an excellent account of recent works done on the chemical climate and saline soils of arid zones, and he along with Egner (1955) compiled the available data for minor constituents in the atmosphere (Table 2).

TABLE 2: Minor constituents in the atmosphere at ground level

Constituents	*State*	*Fraction µg/cu m by volume*
Water		10^{-2}
Carbon dioxide	Gas	$3{\cdot}3\times10^{-4}$
Methane	do	$1{\cdot}5\times10^{-6}$
Carbon monoxide	do	10^{-6}
Nitrous oxide	do	5×10^{-7}
Hydrogen	do	5×10^{-7}
Ozone	do	6×10^{-7}
Ammonia	Gas	2×10^{-9}
Sulphur dioxide	do	10^{-8}
Nitrogen oxide	do	10^{-9}
Hydrochloric acid	do	10^{-8}
Iodine	do	2×10^{-13}
Chloride ion	Particulate	1
Sulphate ion	do	1
Ammonia ion	do	1
Nitrate ion	do	0·5
Sodium ion	do	1
Calcium ion	do	1
Magnesium ion	do	0·5
Potassium	do	0·5

According to Eriksson (1956), if the annual rainfall is of order of hundreds of millimetres the amount of chemical compound brought down to the ground will be of the order of hundred of mg/sq m or of several kg/ha. It is, however, not always true that higher precipitation will always bring down the more hygroscopic chemical compound. The amount of precipitation of the chemical compound depends on the moisture content and the degree of condensation. Arid regions, therefore, may receive more of hygroscopic chemical compounds in spite of low rainfall.

Chlorine compounds present in condensation nuclei in the atmosphere are mainly of marine and volcanic origin. Conway (1942) was the first to make a serious attempt to study the circulation of these chlorides. Later on Junge (1953, 1956) detected chlorine in gaseous form in the atmosphere at Round Hill Field Station and also in Hawaii.

Rubey (1951) indicated that chlorine and sulphur, defined by him as " excess volatiles " are of volcanic origin. During volcanic eruptions these elements have been added to the earth's atmosphere throughout geological time (Urey, 1952). On the basis of this concept Eriksson (1958) has estimated that the (i) total volcanic production of chlorine per annum is of the order of 10^{10} kg, (ii) total volcanic production of sulphur $7{\cdot}3\times10^{8}$ kg, and (iii) volcanic production of chlorine on land is 3×10^{9} kg and volcanic production of sulphur is $2{\cdot}2\times10^{8}$ kg.

Clarke (1924) and Behne (1953) estimated the amount of chloride and sulphur in igneous and sedimentary rocks (Table 3).

TABLE 3: Amount of chloride and sulphur in igneous and sedimentary rocks

Rocks	*Chloride in per cent*	*Sulphur in per cent*
Igneous	0·015	0·20
Sedimentary	0·015	0·20

According to Conway (1942) assuming the yearly average runoff as 273 kg/ha/year the contributions of chloride and sulphur from rocks are 0·04 kg/ha/year and 0·44 kg/ha/year respectively. He also found that total production of salt by human contamination is $0{\cdot}9\times10^{10}$ kg/year and from fossil carbon it is $0{\cdot}018\times10^{10}$ kg/year.

Narayanaswami (1939) estimated chloride from rain-water collected near Bombay and found that 43·2 in. (109·7 cm) of rainfall precipitated 145 kg/ha of chloride. The experiment was carried out far away from the sea and there was no change of contamination from sea spray.

From the above discussion it is evident that conjectures of Holland and Christie are not correct. A small portion of the mineralized salt from the Rann of Kutch may, no doubt, be transported by wind. Similarly, salt from the Pachbhadra basin would also be carried farther inland by wind and deposited somewhere in the north-east. According to their theory then a series of salt basins arranged linearly should have been formed along the path of the wind.

GEOMORPHIC EVOLUTION OF SALT BASINS

The eastern limit of the arid Rajasthan is the Aravalli mountain system. Heron (1938) has pointed out that the initial surface of the Aravalli system was peneplaned and again rejuvenated towards the end of the Mesozoic era to the extent of 3500 ft. It is polycyclic in character which has been compared by Chatterjee (1963) with the Appalachian Highland of the eastern United States. The chronological history of the system in the Middle and Upper Tertiary period is not fully known yet, when the Himalayas continued to rise and the monsoon climate was established.

There were, however, four glaciations during the Pleistocene (time range about one million years) and the glaciers descended to an altitude of 8500 ft to 6000 ft at different times (De Terra, 1936; Krishnan, 1952). The interglacial period was pluvial with high rainfall. De Terra (1939) has linked up the Siwalik boulder conglomerate with the second glacial period and the evidence of Palaeolithic man in the Punjab and Kashmir Valley with the second interglacial period. From all these evidences it can be inferred that till the last phase of the Pleistocene period the climate of the north-western India including arid Rajasthan was humid.

From the study of aerial photographs covering the Luni and the Jawai catchments, Ghose (1965) has observed relics of a large number of prior stream channels in the Central Luni Basin. These have been disorganized, dead or buried under sand since the aridity set in. Reconstruction of these dead stream channels revealed that previously this region had a well-integrated drainage system which had a

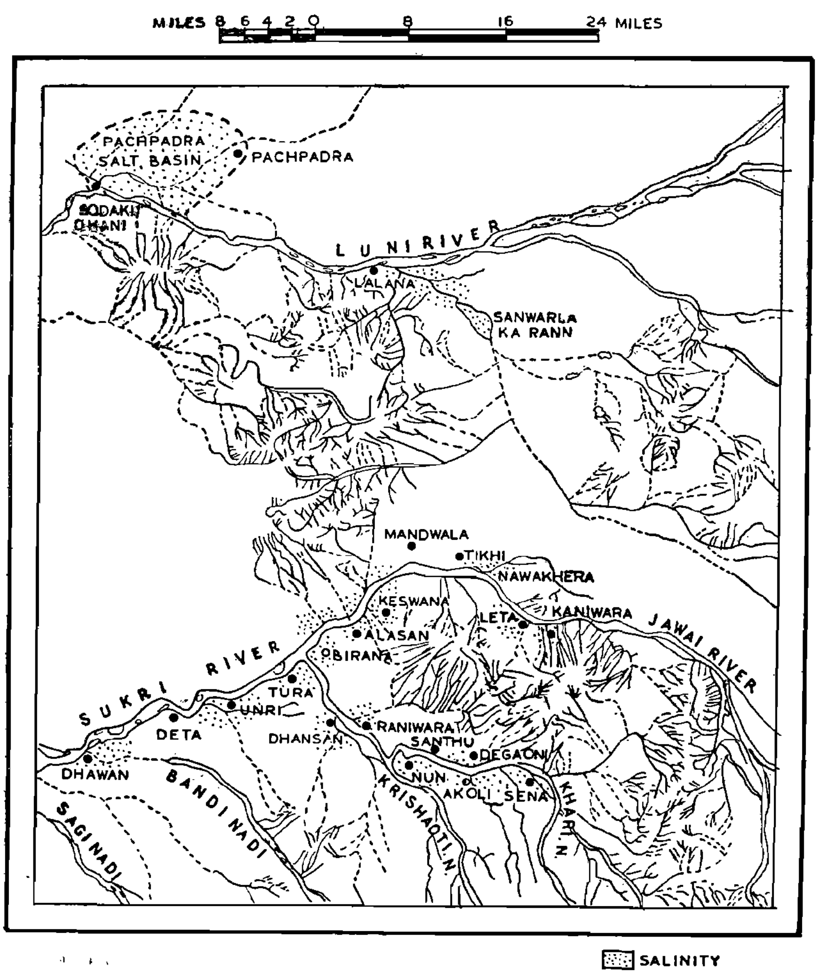

Fig. 1 — Salinity in Central Luni Basin

longer history than the Himalayan rivers. This dead drainage system was responsible for removal of the initial surface of the sedimentary rocks and the formation of the vast alluvial plains. It can be said that during the establishment of this drainage system this region had a humid climate. The segments of these dead stream channels can be found throughout the Central Luni Basin in the form of depressions and isolated channels disconnected from their head water sources. The salt basins of Pachbhadra, the Rann of Sanwarla, etc,. are actually the isolated remnants of the dead drainage channels. The former is on the confluence of the Luni river and two tributaries from the north, while the latter is on the Mitri river (Fig. 1).

The prior drainage system was active for a long time and reached maturity before becoming totally disorganized. During their life cycle these streams carried enormous silt load and deposited the finer materials at their confluences which eventually blocked their mouths. With the onset of aridity scanty rainfall could not keep these streams alive. At present, immediately after rainfall water sinks underground and flows subterraneously along these buried channels with all the soluble salts washed down from the catchments. But due to silting up of the channels near the confluences subterraneous water could not get a through passage to the trunk streams. The result was the subterraneous water-logging, capillary rise of water, evaporation and gradual increase in salt concentration. This process has been active since the arid climate set in and eventually the lower reaches of these stream segments were transformed into salt basins. This process is still continuing and in addition to the older salt basins, new ones are coming up along lower segments of smaller tributary channels. As the catchment areas of different channels are different appearance of salts on the surface of all the channel segments could not be simultaneous. Bigger the catchments, more will be the subterraneous runoff and the rate of salt accumulation. Thus, the salt basins like that of Pachbhadra could come into existence much earlier than the new ones on smaller tributaries whose catchment areas are comparatively very small.

The data on salt concentration in the subsurface water of some village which lie close to one another have been tabulated in Table 4 (personal communication from R. C. Mondal*). It will be seen that villages situated on or near the confluences of the tributaries and the main channels have much more salts in the subsurface water than those situated farther from the confluences. This explains the wide differences in salt concentrations in two nearby villages, such as Sena and Alwara, Gol and Alasan, etc. For example, while the subsurface water from village Akoli, situated on the confluence of dead stream, has a salt concentration of 3200 p.p.m., the water from Sena located only about three miles away on the bank of the main river has a concentration of 448 p.p.m.

*Mr R. C. Mondal is the Analytical Chemist of the Central Arid Zone Research Institute, Jodhpur.

TABLE 4: Showing the salt concentration in well water situated on the banks of the Jawai and the Khari and their tributaries.

Situation	*Sample of subsurface water from villages*	*Salt concentration in p.p.m.*
Village on the left bank of the Khari river	Sena	448
	Alwara (near the confluence of a tributary)	3200
	Akoli (do)	5120
	Nun (do)	7680
Villages on the right bank of the Khari river	Degaon (near the confluence of a tributary)	4992
	Santhu	1280
	Raniwara	1280
On the left bank of the Jawai River	Kaniwara (near the confluence of a tributary)	3520
	Leta	384
	Keswana	512
	Alasan (near the confluence of a tributary)	3840
	Unri	428
	Deta	960
On the right bank of the Jawai river	Nawakhera (near the confluence of a tributary)	1600
	Tikhi	384
	Mandawala (near the confluence of a tributary)	2368
	Gol	320

Map references 45 C. Survey of india

ACKNOWLEDGEMENT

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DISCUSSION

E. Hovmoller: Whether the salt basins are found in a linear order in the path of the prevailing winds ?

B. Ghose: No.

V. N. Kunin: Is the salinity in the Luni river channel increasing progressively downstream ?

B. Ghose: Down the stream the subsurface water has higher level of salinity than upstream.

ORIENTATION, DISTRIBUTION AND ORIGIN OF SAND-DUNES IN THE CENTRAL LUNI BASIN[1]

by

S. PANDEY, S. SINGH & B. GHOSE[2]

INTRODUCTION

ABOUT 58 per cent of the arid western Rajasthan is covered with sand-dunes of different forms, magnitudes and orientations. The sand is being further transported by the south-west prevailing wind from these dunes and dry river-beds, and deposited on the good agricultural land. This process of wind action is thus deteriorating the fertile land into waste land. The transportation of sand is caused by bad management of dunes by the cultivators. It is one of the major problems of this region and the dynamics of it require detailed investigation. Bagnold (1954) was of the opinion that the geomorphologist could not rest contented by his study of the shape of dune and movement of sand, until he knew the interrelationship between the prevailing wind and the dune formation.

In India practically no work has been done in this direction except the general studies of physiography of the region by Blanford (1876), Oldham (1893), Heron (1938) and Pithawalla (1952). In other arid regions of the world several workers have studied the close correspondence that exists between the wind regime and orientation, distribution and origin of dunes. Aufrere (1931) studied in the Saharan desert, Bagnold (1954) in the Libyan desert, Madigan (1936) in the Australian desert, Beadnell (1954) and Wingate (1934) in the Egyptian desert separately and found the close correspondence between the dune orientation and wind direction. Not only in the arid tracts this phenomenon exists but several other workers have also found this in the coastal regions where dunes exist. Landsberg (1956) presented substantial evidence to prove that a very close correspondence exists between the resultant of the wind regime and the axial direction of parabolic dunes on the coasts of Britain and Denmark. Jenning (1957) after studying the dune orientation of the King's Island concluded that in some circumstances the relationship does not seem to be straightforward as in other cases and he reconciled himself by suggesting the modified way of handling wind data. Apart from the predominant influence of wind on dune orientation this study has revealed that the axial direction of dune is also modified by variable factors like depth of sand, proximity to the source of sand, vegetal growth, fluctuation of ground water level, drainage lines and exposure of bedrocks.

The forms of dunes are important for their classification. Bagnold (1954), on the basis of the dynamics of wind, classified dunes into barchan and seif. Melton (1940) classified dunes in different groups taking into consideration the velocity of the wind, vegetation and rock outcrops. Hack (1941) empirically classified dunes into transverse, parabolic and longitudinal.

Wind blows from various directions and does not always move sand and form dune topography. Dune formation is intimately related to the relative force, duration and direction of wind. While handling the wind data the speed of wind was grouped under "strong", "moderate" and "gentle" as defined by Loomis (1936).

This study cannot be regarded complete until the interaction between the wind and the sand grains is analysed. From a detailed study Bagnold (1954) concluded that since natural solid particles were of irregular shape, the individual particle of same average size would not have the same rate of fall. Heywood (1959) has prepared an exhaustive bibliography of original papers on this subject. Krumbein and Pettijohn (1938) have described it in their book. Ghosh (1952), Gupta (1958) and Rao (1962) studied the grain size and mineralogical composition of sands of this region and concluded that these are of aeolian origin.

The authors have discussed in this paper the interrelationship between the wind regime, orientation, forms, distribution and origin of dunes of the Central Luni Basin. Apart from this, the shape, size and origin of dune sand, dune systems and dune cycles have also been studied to provide a basis for land management in the dune country.

MODE OF INVESTIGATION

The study has been conducted with the help of aerial photographs on a scale of 1: 40,000 taken in 1958 and detailed reconnaissance field surveys during 1963-64. The features of aerial photographs were interpreted under the stereoscope. A map Fig. 1 showing the orientation and distribution of dunes

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Assistant Geomorphologist, Research Assistant and Geomorphologist at the Institute.

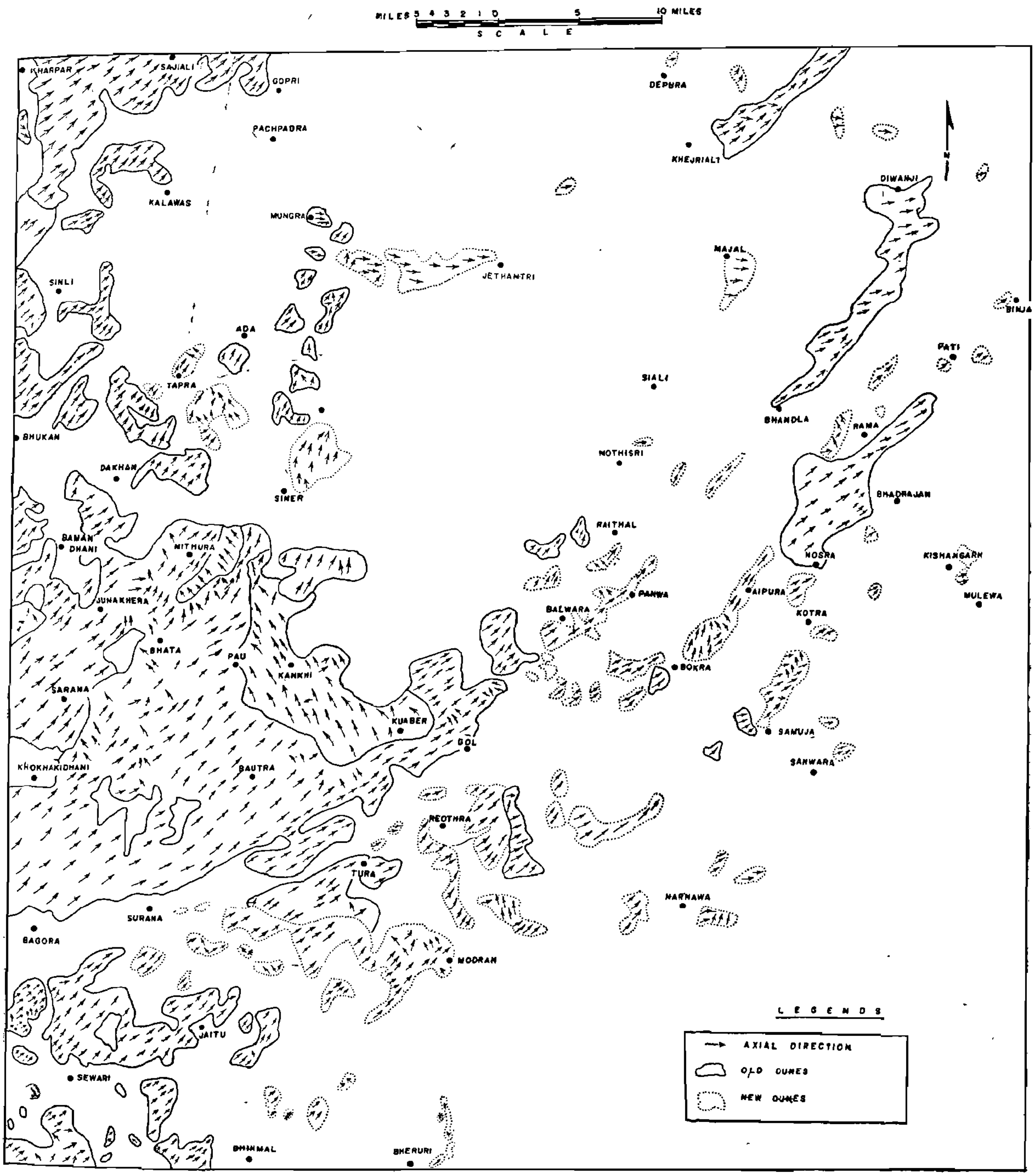

Fig. 1 — Orientation and distribution of sand-dunes in Central Luni Basin

of old and new systems of the Central Luni Basin on a scale of 1: 126,720 was prepared by photogrammetric methods with the help of Zeiss stereopret and sketchmaster and reduced to the scale of 1: 253,440. This was compared with the topo-map of 1934. The dunes of old and new systems were identified on the aerial photographs by demarcating grey tones with high relief and white tones with minor relief respectively. To establish the different phases and periods of dune formation further field studies by close augering were made.

In this region there is no observatory to record wind data. The wind data of Jodhpur (26°18′: 73°01′), Barmer (25°45′: 71°23′) and Deesa (24°14′: 72°12′) at 08 hrs and 17 hrs have been taken from the Climatological Tables of the Meteorological Office, Poona, for making wind roses. The percentage of number of days under 8 compass directions have been taken into consideration. Since the study is to establish the relationship between the axial direction of the dunes and the direction of the sand shifting prevailing winds, the wind data of these stations situated in the north, west and south respectively and being nearest to this region may be extrapolated. The wind speed under each month has been classified under 1·60-19·31 km per hr, 20·92-61·15 km per hr and 62·76 km per hr and above groups. The sand samples collected from the dunes were analysed for their grain size distribution and microscopic examination.

ENVIRONMENT

The Central Luni Basin is a part of the arid and semi-arid western Rajasthan. It occupies an area of about 11,000 sq km, extending from lat. 25°0′N to 26°0′N and long. 72°0′E to 73°0′E. The general physiography of the region is extensive alluvial plains formed in the Pleistocene and Holocene times overlain by sand sheet and dunes in the western part. Steep hills of rhyolite and granite of the Pre-Cambrian period break the monotony of plains and dunes. About one-third of the total area consists of dunes. The Luni is the principal river, its tributaries being the Jawai, the Sukri, the Bandi and the Sagi. They are all ephemeral streams and their beds remain dry almost throughout the year except during occasional torrential rains. The annual rainfall varies from 500 mm in the south and south-east to 250 mm in the north and north-west. The maximum summer temperature exceeds 40°C in the months of May and June when wind attains its maximum speed. The western part of the region is arid while the eastern part is semi-arid.

FORMS AND DISTRIBUTION OF DUNES

In this region predominantly three types of dunes are found, viz. longitudinal dunes, transverse dunes, and parabolic dunes. The longitudinal dunes are mostly found in south-western and north-western parts. The total area under this type of dune is 1,269 sq km. Near Khari, Khokha-ki-Dhani and Sarao villages long longitudinal dunes with gentle declivity occur. The transverse dunes including barchans are found near Debhawas, Odwara, Panwa, etc. and cover an area of 85 sq km. The small transverse dunes and mounds are also formed in the leeward side of the drainage channels. The individual and coalesced parabolic dunes are found in the north-western part. They cover an area of 415 sq km. The closely spaced parabolic dunes have somewhere been fused together by the action of cross winds.

Apart from the distinct colonies of these three types of dunes, there are also colonies of complex types in which all the three types of dunes are found. These colonies cover an area of 604 sq km.

A large quantity of sand has also been heaped against the hills and dissected by small streams. Fresh sand has also been deposited on top of hills and under shrubs and bushes.

WIND REGIME AND DUNE ORIENTATION

(i) *Direction*

From a comparison of the wind roses of Jodhpur, Barmer and Deesa (Figs. 2A, 2B, 2C) and from the map (Fig. 1) showing the axial directions of dunes in the Central Luni Basin it may be stated that there exists close correspondence between the resultant wind direction and the orientation of longitudinal and parabolic dunes. The resultant wind directions at Jodhpur and Barmer in the months of May, June, July and August are S43W, S47W, S47W, S47W and S38W, S49W, S46W and S45W respectively (Pramanik, 1952). In Tables 1 and 2 average wind speed and number of days of duststorms have been given.

At Jodhpur 12, 21 and 18 per cent of the total days of May, June and July respectively have the wind speed range of 20·92-61·15 km per hr; at Barmer 15, 15 and 6 per cent of the total number of days of May, June and July respectively have wind speed range of 20·92-61·15 km per hr; while at Deesa wind speed does not exceed 1·60-19·31 km per hr wind speed range during these months except occasional gales and storms. The sand shifting "moderate" and "strong" winds blow from the month of May to July and thence forward the speed starts decreasing. Apart from the strong influence of the W and SW winds duststorms and eddies modify the topography and orientation of dunes. The other predominant direction of wind at these places (Figs. 2A-2C) are from NW and NE during winter months, but they are considerably weak and cannot shift sand. They do not disturb the evolutionary continuity of dunes.

The axial direction of the dunes of the old and new systems are almost the same (Fig. 1) which indicates that practically no change in the wind regime has taken place in the Recent times.

(ii) *Coalesced parabolic dunes*

(a) Gol-Sajiali section: The coalesced parabolic dunes have been formed previously by the SW prevailing wind on the sand sheets roundabout the

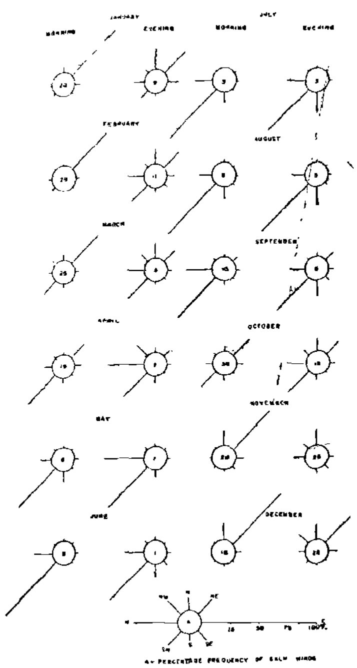

Fig. 2A — Normal percentage frequencies of wind direction — Jodhpur

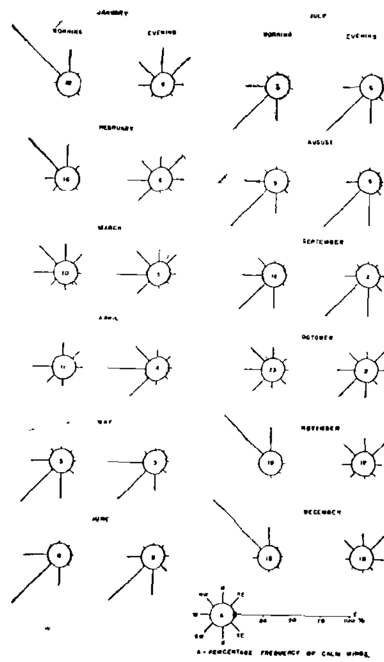

Fig. 2B — Normal percentage frequency of wind direction — Barmer

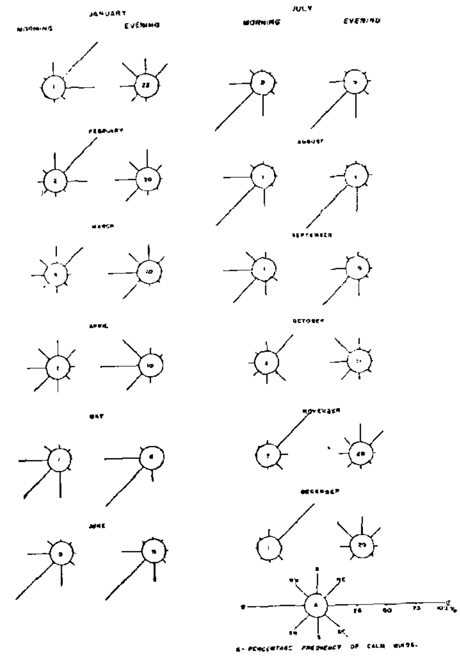

Fig. 2C — Normal percentage frequency of wind direction — Deesa

TABLE 1: Mean wind speed (in km per hr)

Station	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Jodhpur	10	10	10	10	16	20	19	14	11	8	8	9
Barmer	8	8	9	9	10	12	11	9	9	8	6	6
Deesa	9	9	9	14	18	18	13	13	9	8	6	8

TABLE 2: Number of days of duststorms

Station	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Jodhpur	0	0	0·3	1·1	2	3	0·9	0·2	0	0	0	0·1
Barmer	0	0	0·1	1·0	0·4	1·0	0·8	0·4	0·1	0	0	0
Deesa	0	0·1	0	0·4	0·5	0·6	0	0·1	0	0	0	0

NOTE: Frequencies above 2·0 are given in whole numbers.

Pachbhadra salt Basin. The axial direction of these dunes is N50°E, i.e. approximately from SW to NE slightly tending towards the east. They are situated in successive chains about 5 km apart. Their fronts have been fused together. In between the chains of the coalesced parabolic dunes, longitudinal dunes have formed with the same axial direction. The average length of these dunes is 1-1·6 km and 201 m width. The height ranges from 30 to 46 m. The windward gentle slopes are almost dissected by short streams and subjected to wind scouring. The leeward side is steep. The orientation of coalesced ridge is roughly in N-S direction from Gol to Kharapar and of the rest in NW-SW direction.

(b) Kaluri-Dakhan-Bhata-Sarana section: In this section the coalesced parabolic dunes are found also in chains about 8 m apart. They have formed on the alluvial plains. The axial direction is N45°E, i.e. from SW to NE. The area between the chains of dunes is almost free from sand sheet unlike the Gol-Sajiali section. The general height of these dunes varies from 68 to 137 m. The whaleback sand ridges near Mithura, Junakhera and Muthli may be due to sand deposited against the low ridges and later on covered with more sand. Near Ada, Bithuja and Mungra there are individual parabolic dunes closely spaced with SW-NE orientation. Near Buriwala and Thapra villages of this section fresh sand deposits have been observed in the form of mounds. The windward gentle slope of these dunes are almost free from dissection but wind scoured trenches exist.

(iii) *Longitudinal dunes*

(a) Bautra-Bhinmal section: In this section longitudinal dunes of variable length, i.e. ranging from 1·6 to 18 km with almost constant width of 201 m exist. The axial direction of these dunes ranges from N45°E to N50°E, i.e. almost SW-NE. The axial direction of dunes on the banks of the Jawai river ranges from N55°E to N60°E. The dunes on the banks of the Sagi and the Bandi rivers are oriented NW-SE across the prevailing wind direction. To the north of the Jawai river these longitudinal dunes are comparatively more closely spaced than the dunes to the south of this river. Near Bautra some longitudinal dunes have fused together. A long dune extending from Nandia to Dhuria-ki-Dhani has N40°E orientation. On the left of this dune, there are transverse and parabolic dunes, while on its right side longitudinal dunes are present.

(b) Nosra-Ghona section; In this section longitudinal dunes have formed in the leeward side of the Bhadrajan group of hills except dunes between Bándla to Khutani. The orientation of these dunes varies from N45°E to N50°E. These dunes have been formed by the SW wind which passes through the gaps of the Chhapan-ka-Pahar, Jalore hill and Israna hill. The length of these dunes varies from 1 to 5 km. The width varies from 201 to 503 m and the height from 8 to 9 m.

(iv) *Transverse dunes*

These dunes occur in Debhawas-Aipura and Sakrana-Kotra sections. In these sections transverse dunes have formed due to obstructions in the path of the prevailing wind. The orientations of these dunes varies from N35°W to N40°W, i.e. almost NNW-SSW direction. The length of dunes is almost 2 km and width 402 m. The average height is 12-15 m. Near Sedria there are longitudinal dunes with N55°E orientation. They are still in the evolutionary stage and are being formed as foredunes.

(v) *Longitudinal and parabolic dunes*

These exist in the Bagra-Narnawa section. They are small longitudinal and parabolic dunes with N60°E orientation. They are found widely scattered. The height of these dunes varies from 8 to 12 m. Near Bagra there is a parabolic dune with almost two parallel wings fused together in the leeward side. It is situated in between the two streams. The height is 12 m. The swale is shallow and sandy.

(vi) *Shrub-coppice dunes*

This type of dune is met with in Panwa-Majal section. There are a few barchans and mostly shrub-coppice dunes. They are also being formed by the SW prevailing wind. Sand from the adjacent dunes of the old system are transported by wind and deposited against field fences, shrubs and bushes. The trend of these deposits are also SW-NE. But somewhere they are across the wind. This type of dune is also being formed in between the high dunes due to resorting of sandy materials from one dune to another. The orientation is irregular and chaotic.

(vii) *Complex dunes*

In the section of Pau-Dharna the longitudinal, transverse and coalesced parabolic dunes of different orientations are found. The impact of the relief and rough surface is quite evident. They have formed on the piedmont slopes due to obstruction put by the Chhapan-ka-Pahar. The W and SW winds rebound and drop sand across their axes. The axial directions of the longitudinal and parabolic dunes vary from N45°W, i.e. the orientation is WNW to ESE. In the Sinner-Indrana section the axial direction is NW-SE. At certain places in this section long with gently curved dune ridges have been formed by alternative action of strong wind along the dunes and of weak wind across. Alternatively it may be that one of the paired ridges might have been blown off by the wind.

ORIGIN OF DUNE SAND

The orientation and distribution of sand-dunes depend upon the source of sand and size of grains. Deposition and form of sand-dunes also depend upon the size of the sand grains as the coarse grains drop at a short distance while the fine grains continue their flight down wind to varying distances depending upon the velocity of the summit wind and the violence of the eddies in the leeward side of the dunes. It has been observed in barchan dune that the average size of sand grain increases as the size of the dune decreases. The bigger size grains contribute more weight and pressure and thus require more wind energy to be carried vertically as well as horizontally. In this tract it has

TABLE 3: Grain size distribution of sand

Site of dune	*Diameter 0·84 mm*	*Diameter 0·42 mm*	*Diameter 0·25 mm*	*Diameter 0·12 mm*	*Diameter 0·07 mm*	*Diameter less than 0·07 mm*
Kuaber	—	2·35%	17·80%	65·31%	14·54%	—
Balwara	—	—	7·31%	76·30%	13·79%	2·60%
Muthli	—	—	—	69·84%	30·16%	—

been seen that the density of dunes decreases down wind. Near the Rann of Kutch and in the Barmer area the density of dunes is comparatively more and gradually decreases in the NE direction.

The dune sand is aeolian in origin. This has been determined by the study of the size and shape of grains of sand of sand-dunes and the Luni and the Jawai rivers. From the graph (Fig. 3) and from the data in Table 3 it becomes clear that the diameter of grains of about 70 per cent of each sample is 0·12 mm. This is much below the average diameter of 0·3 mm for aeolian sand as reported by Bagnold (1954) for the Libyan desert. These grains are well rounded. The roundness of grains has been caused as they travel along the ground colliding with each other, bouncing off obstructions and wearing off their rough irregularities. There are, however, a very small percentage of angular to subangular grains of 0·12 mm diameter and less. As per Lahee (1961) the sand grains of 0·15 mm diameter and below may maintain such shapes in wind.

The study of the soil profiles of sand-dunes also confirms that sands are of aeolian origin. Mechanical composition of a typical profile is given in Table 4. It will be observed that fine sand is the predominant fraction throughout the depth which indicates that the deposition has taken place exclusively by wind action.

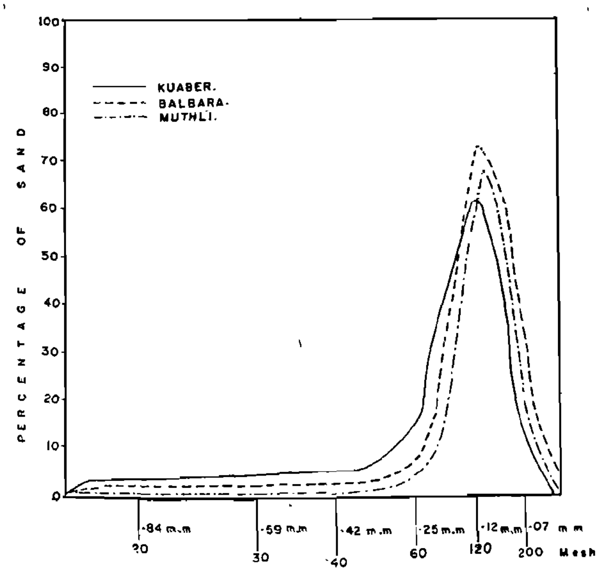

Fig. 3 — Particle size distribtion of surface horizon of sand-dune

TABLE 4: Soil profile on sand-dune

Depth	*Clay* %	*Silt* %	*Fine sand* %	*Coarse sand* %
0-5 cm	4·0	1·0	91·0	4·0
5-25 cm	3·7	1·1	90·0	5·2
25-50 cm	3·4	0·9	88·6	7·1
50-100 cm	3·0	0·7	90·7	5·6
100-200 cm	3·7	1·6	91·0	3·7
200-300 cm	2·4	1·7	92·8	3·1
300-400 cm	2·2	1·0	86·1	10·7
400-500 cm	3·0	1·0	90·0	6·0
500-600 cm	3·0	1·1	87·5	8·4
600-700 cm	3·6	1·7	91·3	3·4

The predominant minerals in sand are quartz, hornblende and felspar. The metamorphic rocks of the Aravallis and the igneous rocks of the tract consist of almost the same minerals. It indicates that sand had been brought by the rivers of the Luni drainage system. During arid climate the sand became dry and loose. They were transported by the prevailing wind by saltation process and deposited in the form of dunes in this area.

DUNE SYSTEM

In this tract two systems of dunes — old and new — are noticed. Their distribution has been shown in the map (Fig. 1). The old system occupies an area of 1911 sq km while the new system about 496 sq km.

(a) *Dunes of old system*: The old system consists of the dunes of high relief and maturity. They have developed into whaleback ridges and rounded swells due to deflation and fusion processes which modify the sharpness of topography of the previously formed parabolic dunes. The soil profile is in semi-matured stage. Calcium carbonate nodules and concretions have formed in these dunes and are found on the crests and flanks. The percentage of $CaCO_3$ varies from 3·8 to 5·5. The dunes are stationary. They are found in the western part of the region, including Jeran, Sarana, Kuaber, Pau, Dakhan, Kaluri, Sinli, Akorli, Ada, Ashotra, Uter, Balwara, Rama, etc., villages. Heaps of sand deposited on the piedmont slopes belong to the old system.

(b) *Dunes of new system*: The dunes of the new system contain freshly deposited loose sand and lack the characteristics of the dunes of the old system which they have attained in course of time. They are of minor relief and are still in evolutionary stage. They are actively formed due to cutting of trees, intensive grazing and cultivation over the old dunes as these practices set the surface of these dunes in motion. The percentage of calcium carbonate is very low, i.e. 1·2 per cent, and no concretions or nodules are found. These dunes are formed in Odwara-Siali-Majal section and in between the chains of the old dunes.

DUNE CYCLE

The dune field consisting of old dunes in the western part of the tract has attained maturity stage. The transverse active dunes formed in between the chains of massive dunes are of minor relief than that of the high dunes. The height of the newly formed dunes varies from 5 to 8 m. This height is much smaller than that of high dunes. Aufrere (1931) who studied the dunes of the great erg regions of the Sahara indicated that the maturity of the dune cycle included the difference in heights of the transverse dunes of the interdune areas. The youth stage of a dune field is marked by more or less isolated dunes which develop transverse to the wind and take on the barchan form. Transverse dunes of Debhawas-Aipura and Sakrana-Kotra sections, the barchan dunes near Odwara and Panwa, freshly deposited sands in mounds and wind drifts of Raithal-Motisara-Majal section and the dunes formed on the flood plains of the Luni and the Jawai rivers indicate the youthful stage of these dune fields. The old stage of the dune cycle is indicated by more deflation and reduction in size and shape of dunes and increase in area of the interdune. In this tract there is no increase in area of the interdune sectors. This has been confirmed by comparing the map of Survey of India prepared in 1934-35 and the map prepared from aerial photographs of 1958. All these lead to the conclusion that the dune field has not attained old stage.

Smith (1939 and 1940) recognized two phases of dune cycle in western Kansas. In this tract the accumulation of fresh sand against fences, shrubs and bushes and other obstructions in the form of sand sheets, sand drifts and mound — circular or elongate — and the 'blow-outs' on the old dunes show that the dunes are running under aeolian phase. The old dunes are under eluvial phase of the cycle as they have matured morphology, slope washes later on developed into gullies and reduction in relief. But due to the unfrettered biotic interference, such as overgrazing, passage of men and animals, irrational felling of trees and intensive cultivation, the loose sand particles became amenable to deflation by wind. It has been observed that after the above biotic interference the aeolian phase of the dune cycle has been revived. Some fresh sands are deposited on the crests of dunes which are again carried on further to other dunes. The features of both the phases are formed in this tract. As a result of this the multicyclic dunal forms exist.

CONCLUSION

The dune field of the Central Luni Basin is mostly situated in its western part. It covers one-third of the total area of the tract. There are predominantly three types of dunes, namely longitudinal, transverse and parabolic. The number of longitudinal and coalesced parabolic dunes is larger than transverse dunes. These dunes have been formed by the westerly and south-westerly winds. The axial direction of dunes are SW-NE. The prevailing sand lifting winds blow in the months of May, June and July with an average speed of 19 km per hr. Apart from the influence of the wind the orientations of dunes have been affected by vegetation, drainage alignments, exposure of bedrocks and rough surfaces.

The sands were derived from the metamorphic rocks of the Aravallis and the granite and rhyolite rocks of the tract. The sand of the dunes is aeolian in origin and not beach sand. The source of the sand is not the Rann of Kutch.

In the stabilized and semi-stabilized dunes calcium carbonate content varies from 3·8 to 5·5 per cent and in active dunes it is 1·2 per cent. There are two systems of dunes. The old dunes are stationary and the new dunes are shifting and in the evolutionary stage. The western part of the dune field has attained maturity stage while the eastern part is in youthful stage of the dune cycle. They are undergoing the eluvial as well as aeolian phases.

The reworking of sand by wind is a localized phenomenon which does not set considerable amount of sand to be driven to a long distance.

ACKNOWLEDGEMENTS

Grateful thanks are due to Dr P. C. Raheja, Ph.D., D.Sc., F.W.A., Director, and Dr B. B. Roy, Ph.D., Head of Division of Basic Resource Studies, for giving facilities and valuable suggestions while going through the manuscripts. Thanks are also due to Dr C. T. Abichandani, Soil Scientist, for providing soil profile data, Shri Gheesa Lal and Shri Madan Singh for assistance.

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DISCUSSION

S. P. Raychaudhari: Whether wind erosion deposition classes have been determined ? Have data been utilized in formulating land-use classification for soil conservation measures in the way as erosion classes are made in respect of water erosion ?

S. Pandey: These are being worked out.

STRATIGRAPHY OF THE RAJASTHAN SHELF[1]

by

K. NARAYANAN

PREVIOUS WORK

Geological studies: The earliest geological investigations in West Rajasthan were carried out by Blanford (1876) who attempted to delineate the stratigraphy of the western part of the region. No geological map, however, accompanies his report. Even much earlier to this, in *circa* 1826, Dr Impey (as reported in Carter, 1861) had discovered the presence of sedimentary rocks with ammonites in the neighbourhood of Kuchchri, 25 km south, south-east of Ramgarh. Oldham (1886, 1888) mapped a large part of the erstwhile Jaisalmer (Jessalmer) State on a scale of 1″: 5 miles. The different stratigraphic units in the Mesozoic sequence were, for the first time, demarcated, named and described by Oldham. The area was re-examined by La Touche (1902) and later on Daru (1916-1917) mapped parts of the area covered by Survey of India Sheet Number 40N. Hacket (1881a, 1881b) studied the area around Sojat and Khatu. Much of Hacket's conclusions were critically reviewed by Heron (1932) who made a rapid survey of the area east of Jodhpur.

Fiestmantle's study (*Rec. Geol. Surv. India*, Vol. X, Part 1) of the ammonites from the top part of the Jaisalmer formation is the earliest detailed palaeontological work in the area. Spath (1933, 1938) has studied the ammonites from the Bedesir and Abur beds of the Jaisalmer area. The exact determination of the ages of the different Mesozoic formations in the Jaisalmer area is based mainly on his work as well as those of Hoffmann, Schmidt and Hiltermann (reported in Richter-Bernburg and Shcott, 1957, 1962).

Barooah (1946), Glaessner and Rao (1957) and Prasada Rao (1961) have studied the fossil fish and crabs from the fuller's earth of the Kapurdi Mines. Jacob *et al.* (1952) have studied the microfossils from the gypsum deposits of Jamsar and Siasar. Singh (1951, 1952, 1953a, 1953b) made a detailed study of the foraminifera of the Eocene beds of the Bikaner region and reported, for the first time, the presence of Kirthar beds in West Rajasthan. The present writer (Narayanan, 1959) identified Kirthar foraminifera in the Bandah formation in the area west of Ramgarh in Jaisalmer district. Subbottina *et al.* (1953) and Lubimova *et al.* (1958) have made some studies of foraminifera and ostracoda respectively from the Jaisalmer formation. Misra *et al.* (1961) reported for the first time the presence of rocks with marine Permian fauna in the vicinity of Bap. Singh and Khanna (1959) studied the megafossils of the Bedesir, Abur and Khuiala formations. Mehrotra *et al.* (1959a, 1959b and 1959c) studied the microfossils from the Laki part of the Eocene section (Khuiala formation and basal part of the Bandah formation) in the Jaisalmer area.

Varma (1960) studied the leaf impressions collected from the Lathi formation in the neighbourhood of Devikot and Srivastava (1960) studied the microflora in subsurface samples collected from the tubewells drilled by Exploratory Tubewells Organization (Government of India).

Bhola (1947), Ghouse and Datar (1961), Srivastava (1961) and Siddiquie (1962) have studied various aspects of the bentonite (and fuller's earth) deposits of West Rajasthan. Siddiquie (1963) also carried out studies which indicate that the pre-Tertiary sediments of the Barmer area appear to have a different provenance from that of similar sediments in the Jaisalmer area. Roy-Choudhury *et al.* (1959) studied the gypsum deposits of Nagaur area by core-drilling.

Reference has already been made to Oldham's classification of the Mesozoic beds of the Jaisalmer area. To a very great extent, all later work has only confirmed Oldham's work. Allison (*see* Arkell, 1956) of the Burmah Oil Company made a reconnaissance survey of the Jaisalmer area and the first proper thickness measurements were carried out by him. Swaminath *et al.* (1956, 1959) have, in the course of their geological traverses over large parts of the Jaisalmer district, slightly modified Oldham's classification. Oldham had taken the top of his Jaisalmer group at the base of the Bedesir basal grit. Swaminath *et al.* (*ibid.*) distinguished the beds between the top of the Kuldhar oolite (described in another section below) and the base of the Bedesir basal grit as the Baisakhi formation. The old name 'Jaisalmer' was retained by them for the beds above the Lathi up to the top of the Kuldhar oolite.

The detailed mapping (partly on air photographs, scale 1: 31000) of almost the entire Jaisalmer area by the Oil & Natural Gas Commission has not necessitated any serious amendments of the formations already defined by Oldham or Swaminath *et al.*

1. Contribution from the Oil & Natural Gas Commission, Dehra Dun.

2. Dy. Superintending Geologist.

However, many new formations, including the marine Permian Badhaura formation, have been distinguished and mapped.

Geophysical surveys: The torsion balance survey carried out by the Burmah Oil Company (*circa* 1937) was the earliest geophysical activity in the region. A Canadian team (as part of a Colombo Plan Project) carried out airborne magnetometer surveys of the northern parts of Jaisalmer and Jodhpur districts as well as the western part of Bikaner district (Agocs, 1956). In the period 1954 - 1964 over 7000 sq miles of area in Jaisalmer district as well as the northern part of Barmer district have been covered by gravity/magnetic surveys. These were partly by the Geological Survey of India (Negi *et al.*, 1955; and Bose *et al*, 1956) and partly by the Oil & Natural Gas Commission (Awasthi *et al.*, 1957; Sarma *et al.*, 1958; Ramanatham *et al.*, 1959; Bhave *et al.*, Nanda *et al.*, 1963; and Deekshitulu *et al.*, 1964). Experimental seismic (reflection) surveys were carried out in the Jaisalmer district, near Ramgarh, in the 1957-58 season (Awasthi, 1958). Starting from November 1963, a party of the Compagnie Generale de Geophisique (on contract to the Oil & Natural Gas Commission) has been carrying out extensive seismic surveys in the area northwest of Jaisalmer. The results of all these geophisical surveys have been of considerable help in understanding the subsurface geology of the Jaisalmer region.

The extensive seismic work carried out in the plains of the Punjab was extended to the northern parts of western Rajasthan — across the Delhi-Lahore ridge. From information obtained by drilling stratigraphic tests at Adampur (between Jullundur and Hoshiarpur) and at Zira (near (Ferozepur) it is known that successively younger members of the Siwalik group overlap the older members in a southward direction such that at Zira — located very near the 'crest' of the Delhi-Lahore ridge — only the Upper Siwalik is present above the crystalline basement. South of the ridge, in the Ganganagar district, the Siwalik beds were not deposited and the beds immediately overlying the basement belong to the same group as that to which the Jodhpur sandstone belongs.

STRATIGRAPHY

The pre-Mesozoic sediments of West Rajasthan are marine but are unfossiliferous excepting for a very small outcrop of marine Permian. The Mesozoic and Tertiary formations, on the basis of lithological and faunal associations, are interpreted to be sediments deposited in paralic to shallow neritic environment. Only the surface measurement of these formations are presented in this paper but it is obvious that these thickness figures are not expected to hold good in the subsurface as marked basinward thickening, is anticipated for almost all of them. Similarly, the unconformities within the Mesozoic and Tertiary sections are also expected to die out down the dip with insertions of wedges. The stratigraphy of West Rajasthan is summarized in Table 1.

Pre-Cambrian basement: The basement rocks outcropping along the rim of the basin consists of granites and acid volanic rocks of the Malani suite and metamorphic rocks of the Aravalli system.

Birmania formation: This unit consists of over 2000 m of dolomitic limestone, cherty limestone, chert and grey shales with reddish brown medium-grained sandstones at the base. The outcrops of these rocks are about 60 miles south of Jaisalmer and were discovered by the author only in 1959. These rocks appear to be correlatable to the Jodhpur sandstone and the Bilara limestone, which outcrop extensively in the eastern part of Jaisalmer district and in Jodhpur, Bikaner and Nagaur districts of Rajasthan. No fossils have been seen in any of these rocks, and for long the Jodhpur sandstone had been correlated with the Vindhyan system of eastern Rajasthan. However, as the Aravalli Range, which in its pristine form must have been a very prominent chain of mountains, divides these two basins, correlations of unfossiliferous rocks on either side of this great divide is indeed on very tenuous grounds. On the other hand, on account of the presence of thick beds of gypsum, as well as shales with salt pseudomorphs, it would perhaps be better to consider them as coeval and even correlatable with similar beds in the Salt Range sequence. That in the Carboniferous period extensive glaciers spread all over the area west of Aravalli mountains, all the way up to the Salt Range of West Punjab has been inferred on the basis of Malani pebbles in the Salt Range boulder beds. A further point of similarity between western Rajasthan and the Salt Range is the fact that the glacial boulder beds are overlain in both places by marine Permian.

Jodhpur sandstone: The unit is over 100 m thick and consists mainly of reddish, medium to fine-grained, compact sandstone with minor intercalations of purplish clays. Some of the shales have salt pseudomorphs and there are thin gypsum layers in the sandstone. Clear unconformable contacts, sometimes with a conglomerate/boulder bed at the base of the sandstone, have been seen with the underlying rhyolite flows. The best exposures of the basal beds are at the foot of the hill on which the Jodhpur Fort is situated and near Pokaran.

Bilara limestone: Limestones, cherty limestones, dolomitic limestones and bedded chert are seen from Sojat northward to Khinwasar and from there westward to Phalodi and even west of it. The rocks are mostly compact, fine grained, massive, ill-bedded with nodular as well as interbedded chert. The limestone is sometimes fractured and jointed with these voids filled by secondary calcite or chert.

Rol Quazian-Bhakrod series: The cherty dolomitic limestones of Rol-Quazian area have been

TABLE 1

AGE		*FORMATION* *Jaisalmer area*	*Bap-Bikaner area*	*Nagaur area*	*FOSSILS* (*Please see section on 'Previous work' for references to various authorities*)
Plio-Pleistocene		Shumar	Mar		
..........major unconformity..........					
EOCENE	Laki-Kirthar	Bandah	Jogira	—	*Discocyclina* spp. (incl. *D. dispansa*), *Nummulites* sp., *Assillina* sp., lamellibranchs and echinoids
to					
PALEOCENE	Laki	Khuiala	Palana	—	*Nummulites atacicus*, *Assilina granulosa*, *A. daviesi*, *Orbitolites* complanatus; echinoids, corals, pelecypods, etc.; also *Nautilus* sp.
..........major unconformity..........					
LOWER CRETACEOUS	Aptian	Abur	—	—	Ammonites: *Deshaysites bodei* (and re-worked Jaisalmer fauna)
	..........unconformity..........				
	Neocomian ?	Parihar	—	—	Plant remains (not identified)
..........unconformity..........					
UPPER JURASSIC	Tithonian	Bedesir	—	—	Ammonites: *Virgatosphinetes densiolicatus*, *V. communis*, *V.* sp., *Aulacosphinctes occultefurcatus*, *Hibolites* sp. Others: *Belemnites* sp., terebratulids, gasteropods, fish teeth and fossil wood reworked Jaisalmer fauna)
	..........unconformity..........				
	Kimmeridgian ?	Baisakhi	—	—	Ammonites, Belemnites and some forams (Haplophragmines, Trochammines)
..........many diastems..........					
MIDDLE to LOWER ? JURASSIC	to Oxfordian	Jaisalmer	—	—	Ammonites (*Dhosaites* aff. *D. otoitoides*, *Epimayaites* of. *excentricus*, *Obtusicostites* of. *nandi*, *Mayaites* sp., *Kinkeliniceras sp.*, *Indosphinctes* sp., *Reineckeites* of. *wasgeni*, *Reineckeia* sp., *Reineckeia* or *Choffatia* sp.) and Belemnites (*Belemnotis* of. *orientalis*, *B*.sp.) are restricted to the topmost part of the formation only in the Kuldhar member. Brachiopods (*Rhynconella* spp., *Terebratula* spp.) lamellibranchs, gasteropods, echinoids, crinoids and corals are ubiquitous; fossil wood is occasionally present
	..........intertonguing contact..........				
		Lathi	Mayakor	—	Abundant silicified tree trunks; rare broken forams; silicified gasteropods near base; rare leaf impressions near base (*Pterophyllum* sp., *Ptilophyllum acutifolium* and *Equisetites* sp.)
..........major unconformity..........					
PERMIAN		—	Badhaura	—	*Productus* spp., *Spirifer* spp., *Spiriferina* sp., *Derbyia* sp., *Bellerophon* sp., and fossil wood
..........unconformity..........					
UPPER CARBONIFEROUS		—	Bap Boulder Bed	—	
..........major unconformity..........					
LOWER PALAEOZOIC ?		Birmania	Bhilara ls and Jodhpur ss	Nagaur Series / Rol-Qazian-Bhakrod Series	
..........major unconformity..........					
PRE-CAMBRIAN		Acid and basic lava flows, granites, metamorphic rocks of (?) the Aravalli system			

N.B. The formations of the Barmer area are not listed here due to uncertainties of age determination; these problems are fully discussed in the text.

grouped in this series by Roy-Choudhury *et al.* (1959) who have correlated them with the Lower Vindhyan.

Nagaur series: This series, described by Roy-Choudhury *et al.* (*ibid.*) from the boreholes drilled for exploration of gypsum in the Nagaur district, is correlated by the authors with Upper Vindhyan Bhander Series. The series consists of alternations of sandstone, siltstone, clay and limestone with workable gypsum interbeds.

Badhaura formation: The outcrops of this unit are approximately north-west of Bap. The Badhaura consists of only 10-15 m of medium to coarse-grained brownish sand-stone with abundant species of *Productus*, *Spirifer*, *Derbyia* and *Bellerophon*. This assemblage is remarkably similar to the Panjabian of the Salt Range (Misra *et al.*, 1961). The Badhaura overlies the well-known Bap boulder beds. The Badhaura constitutes the only outcrop of fossiliferous Palaeozoic rocks along the eastern marine of the Indus geosyncline and was discovered by Misra, Srivastava, and Jain of the Oil & Natural Gas Commission in 1960.

Lathi formation (*and Mayakor formation*): One of the most important unconformities in the region is at the base of the Lathi. This formation rests at various places on the Permian Badhaura, the supposedly lower Palaeozoic Birmania or its equivalents, as well as pre-Cambrian acid volcanic or granitic rocks. Though the Lathi is poorly exposed a few water wells have been drilled almost through the whole thickness of the formation and most of the information available regarding this formation are from these wells. In outcrop the Lathi mainly consists of medium to coarse-grained sandstone with some red shales. The tubewell drilled near Jaisalmer, however, showed that formation becomes very shaly down the di. Abundant silicified fossil wood, leaf impressions and some silicified gasteropods are the only fossils that have been obtained. Lower Jurassic microflora and some unidentified fragmentary microforams have also been obtained from ditch samples of the water wells. The fossil leaves are referable to the Rajamahal stage of the Gondwana system.

The Lathi is conformably overlain by Jaisalmer formation with which it has an intertonguing contact. The presence of broken foraminifera in the middle and lower parts of the Lathi indicates that the outcropping part of the formation is mainly deltaic and that down the dip marine intercalations become more and more predominant. The maximum thickness of the formation so far drilled through is about 330 m.

Jaisalmer formation: This formation is fully marine and has the marl-limestone-bioclastic limestone-orthoquartzite association characteristic of the shelf. A variety of brachiopods, lamellibranchs. gasteropods, echinoids, crinoids and corals are present all through the section, and many of them have been identified as definitely correlatable with the Middle Jurassic Chari of Kutch. The critical cephalopod assemblage which consists of species of *Reineckeia*, *Reineckeites*, *Indosphinctes*, *Kinkeliniceras*, *Mayaites*, *Obtusicostitis*, *Epimayaitis* and *Dhosaites* appear only at the very top of the formation in what has been mapped as the Kuldhar member. The topmost part of the formation is definitely Upper Jurassic in age. Frequent and rhythmic alternations of the depositional environment at the time when the last few metres of the Jaisalmer formation were being laid down is indicated by alternations of beds with dwarfed giant and fauna. The exposed thickness is about 170 m.

Baisakhi formation: This formation is Upper Jurassic in age and consists of shales with intercalations of sandstone. Minor diastems are indicated by coarse-grained sandstone and conglomerate beds which show evidences of oxidation. The formation is not so rich as the underlying Jaisalmer in fossil content but some layers do contain ammonites and belemnites. The outcropping thickness is about 150 metres.

Bedesir formation: This formation unconformably overlies the Baisakhi. In the area about 30 km west-southwest of Mohangarh the Bedesir overlaps about a third of the thickness of the underlying Baisakhi. A very persistent fossiliferous conglomerate which often contains reworked ammonites from older beds forms the basal bed of the Bedesir. Fossils recovered from this as well as other beds in the Bedesir formation (including the characteristic species of *Virgatosphinctes*) indicate that the formation is uppermost Jurassic in age. The formation mostly consists of medium to coarse-grained sandstone with ferruginous intercalations near the top.

Parihar formation: This formation is very poorly exposed and is mostly under cover of wind-blown sands except for stray outcrops of medium-grained sandstone with bright and variegated weathering colours. The contact of this formation with underlying Bedesir is almost never exposed but there is a suspicion that it partly overlaps the Bedesir, particularly in the area about 35 km due west of Mohangarh. Due to the total lack of palaeontological data it has not been possible to date this formation. However, as it overlies *unconformably* uppermost Jurassic (Tithonian) beds, the Parihar has been tentatively placed in the Lower Cretaceous, and may be equivalent to the Sembar formation of the Indus basin.

Abur formation: This formation consists of sandy bioclastic limestone in the lower part with abundant well-preserved ammonites and belemnites. This formation rests in most of the area on the Parihar but in the area east of Sam it overlaps the Parihar and rests on the Bedesir. The Abur in its turn is overlapped in the area just south of Ramgarh by the Eocene Khuiala formation. The maximum exposed thickness is a little over 60 m. The Abur limestone is an ornamental building stone when polished and has been used in many of the beautiful old buildings of Jaisalmer. In the old days it was probably much more famous and large slabs of Abur limestone have been used on the roof of Akbar's tomb at Sikandra.

The ammonites of the Abur have been identified by Spath as well as Schmidt to be of Aptian. The Argovian *Epimayaites transiens* reported by Krishnan and Jacob (1956) from this formation is most probably derived from erosion, in Lower Cretaceous times, of the upper part of the Jaisalmer formation. The Abur may be the equivalent of the Lower Goru of the Indus basin.

Upper Cretaceous does not outcrop but in the adjoining areas of West Pakistan Upper Cretaceous has been met holes and the total thickness of Cretaceous is many times more than that in the outcrops of Jaisalmer. For example, Pak-Stanvac's Mari 1 drilled through 6900 ft of Cretaceous without crossing over into Jurassic and in Khairpur 2 the Cretaceous section is over 5000 ft thick.

About 25 km SSW of Ramgarh a bed of well-sorted, fine to medium-grained sandstone with well-grounded grains of quartz is present below the basal bed of the Khuiala formation. This sandstone had been tentatively considered part of the Abur formation, even though there are no fossils present. This sandstone may, however, be of Danian age instead.

Khuiala formation : Earlier workers had variously called the Eocene beds of the Jaisalmer area as "Nummulitic limestone", "Eocene limestone", "Foraminiferal limestone", etc. However, the Oil & Natural Gas Commission mapped them as two formations with many members in each of them.

The Khuiala formation, as mentioned in the previous section, unconformably rests on older rocks such as the Abur, Parihar and even Bedesir. The basal beds of this formation consist of greenish or yellowish brown gypseous clays with foraminiferal tests. Some leaf impressions have also been noted in these clays. The rest of the formation consists of chalky limestone, foram test beds and hard compact crystalline limestone. From the presence of *Nummulites atacicus* and *Assilina daviesi* the Khuiala formation is considered to be Laki (Palaeocene) in age. The exposed thickness is about 30 m.

The limestone sequence of the Khuiala formation is probably correlatable to the Sui Main or Dunghan limestone of West Pakistan.

Palana formation: The Lower Palaeocene age of the lignite seams and associated rocks of the Palana area is known for long (Rao and Misra, 1949; Rao and Vimal, 1952). Black and green shales, thin nummulitic limestone beds, thin marl white and pink sandstones, carbonaceous shales and lignite reams constitute the lithological association of this unit. Similar beds of Laki age have been noticed in hand-dug wells and boreholes from Mandal Charan (about 12 miles south-west of Kolayat) to a point about 8 miles east of Palana. Outcrops of these rocks have not been seen as these beds are always overlain either by the Mar formation or by wind-blown sand. Srivastava and Srinivasan (1962), who defined this sequence, have interpreted the Laki beds of the Palana-Deshnok region as having been deposited in a narrow, east-west trending bay, often cut off from the open sea west of Kolayat.

Bandah formation : This formation rests conformably on the Khuiala. The formation consists in the lower part of alternations of bentonitic clays, silts, foram test beds and fragmental limestone. The shales are probably correlatable to the Ghazij shales of West Pakistan and are of Laki age. The upper part of the Bandah formation consists of a bed of hard compact fine-grained crystalline limestone rich in large foraminifera. The upper part of the formation contains species of *Discocyclina*, characteristic of Kirthar, and is correlatable to the Habib Rahi limestone of Mari. The total exposed thickness is of the order of 30 m, with the top never exposed. The total thickness of Eocene in Jaisalmer is less than 100 m whereas Mari 1 drilled through over 300 m of Eocene.

Jogira formation : The outcropping Eocene beds of Kolayat area, consisting of marls, foram test beds, foraminiferal limestones and fuller's earth, were first identified to be in part equivalent to Kirthar by Singh (1951). Earlier workers had mapped all the outcrops exposed from Kolayat along the escarpment for about 12 miles westward as Eocene. However, Srivastava and Srinivasan (1962) have shown that the Eocene (Laki-Kirthar) crops out only in a small area near Kolayat and these beds they defined as the Jogira formation. The rest of the area is covered by the (Plio-Pleistocene ?) Mar formation.

Shumar formation : The Eocene formations north-west and north of Jaisalmer are overlain unconformably by a sequence consisting of conglomerates, sandstones and silty clays which has been termed as the Shumar formation. The topmost bed of the unit consistently shows effects of lateritization. The Shumar as well as the equivalent Mar formation of the Kolayat area have been involved in the major faults of both the areas. Gentle folding has also been noticed in the Jaisalmer area — near Ramgarh.

Mar formation : This formation outcrops in the Kolayat area, resting unconformably on older rocks, and is lithologically similar to the Shumbar of the Jaisalmer area. Both the Shumar as well as the Mar formations are unfossiliferous — apart from derived fossils — and are tentatively correlated to the Plio-Pleistocene upper Siwalik of West Pakistan.

STRUCTURE

Study of the geological map clearly brings out the fact that the most important structural element in the region is a north-west plunging arch in Jaisalmer which, on the basis of gravity data, continues into West Pakistan through Mari to Kandhkot. On the basis of gravity data it had been interpreted that this arch is flanked on the north-east and south-west by tectonic depressions. It is suspected that the Mari-Jaisalmer arch as well as the Shahgarh and Kishengarh basins are structural elements that were active during sedimentation. It is expected that the thickening *along* the arch, and into the two flanking basins would be due to the insertion of wedges at the various unconformities seen in the outcrop. The Palana-Deshnok embayment, in which paralic Laki beds overlying Jodhpur sandstone have been noted, may have faults on either flank.

SOME PROBLEMS OF STRATIGRAPHY

Despite the considerable amount of work done in the last hundred years or more, solutions to certain stratigraphic problems are still obscure. This situation is in most cases due to the paucity or even absence of fossils and in other cases due to the uncertainties of stratigraphic relationships.

The boulder beds of Pokaran, Lowo (Lawan) and Kerawa occur at the base of the Jodhpur sandstone and are similar to the basal conglomerate of the red sandstone near Jodhpur city. At Pokaran and at Jodhpur, the boulders are exclusively of rhyolite. On the other hand, at Lowo (Lawan) and at Kerawa they consist of rhyolite, basalt, granite, as well as of various types of metamorphic rocks. None of the earlier workers such as Blanford and Oldham seems to have had any doubts that the boulder beds are underlying the Jodhpur sandstone or its local equivalents. More detailed work, carried out by Misra *et al.* (1961), has also confirmed this view. They have also mapped similar boulders engulfed in lava flows in the Kerawa area.

The main problem regarding the boulder beds seen at the base of the Jodhpur sandstone at Pokaran, Lowo (Lawan) and Kerawa arises due to their supposed similarity with the Bap boulder ' bed '. The boulders of Bap consist of granite, syenite, pegmatite, rhyolite, various types of basic igneous rocks, biotite schist, calc-granulite, quartzite, phyllite and limestone. These are angular or subangular, only very rarely subrounded and vary in size from $2\frac{1}{2}$ m to 5 cm across. The presence of parallel grooves and striations as well as the poor rounding of the boulders indicate glacial transportation. The occurrence of boulders of foetid limestone, resembling very much the Bilara limestone, is the main difference between the Bap boulders and the boulder beds of Pokaran, Lowo and Kerawa. The Bap boulders are seen lying in a narrow strip between outcrops of the Bhilara limestone to the south and the Permian Badhaura formation to the north. The Pokaran, Lowo and Kerawa boulder beds, on the other hand, are seen celarly underlying the Jodhpur sandstone. The Bap boulders contain material derived from the Bilara limestone whereas the Pokaran, Lowo and Kerawa boulder beds are certainly older than the Bhilara limestone. All these facts have been pointed out by Oldham himself (1886, 1888) and there would have been no confusion had he not raised some doubts regarding the age of the red sandstones of Pokaran. In a case like this, where the order of superposition is fairly well established, it was, therefore, surprising that La Touche correlated the Pokaran boulder beds with the Bap boulder ' beds ' and went on to invoke a faulted contact between the red sandstones of Pokaran and the Pokaran boulder beds. Heron (1932), however, succinctly reviewed the whole question and stated that the Bap boulder " bed " is glacial in origin and is younger than the Jodhpur sandstone (Pokaran sandstone).

The age of the Birmania formation, the Jodhpur formation, the Bilara formation (and equivalent Rol-Quazian/Bhakrod " Series ") and the Nagaur " Series " as well as the correlation of these formations with probably coeval rocks elsewhere are also problems for which answers are difficult to obtain. There is still a doubt that the Nagaur " Series " really underlies the Rol-Quazian/Bhakrod " Series " instead of overlying them as is the present view. Roy-Choudhury *et al.* (1959) who first described these formations have themselves expressed this uncertainty as stratigraphic relationships are invariably obscured by wind-blown sands of the desert. In the absence of any firm evidence which points to the contrary it must be assumed that the structural interpretation, based on which the superposition is inferred, must be correct.

It has already been shown that the term Rol-Quazian/Bhakrod " Series " is the local name given to the very extensive Bhilara formation. Similarly, there is little doubt that the Birmania formation is homotaxial with the Jodhpur and Bhilara formations. The terms Rol-Quazian/Bhakrod " Series " and Nagaur " Series " as well as the term Birmania formation are retained here mainly because they have attained semi-formal status due to priority of publication*, and also because purely objective criteria for revision of nomenclature are lacking in all these three cases.

Blanford (1877), who first studied the " sandstones of Jodhpur ", mentioned only in passing about the similarity of these rocks to the Vindhyan rocks of East Rajasthan. He was, however, careful to add that " the reference to the Vindhyan is little more than a suggestion ". Hacket (1881), Oldham (1886) and La Touche (1902) also studied these beds in various parts of the erstwhile Jodhpur State and consistently referred to them as " equivalents of the Vindhyan Series ". Hacket went on to correlate the " lower white sandstone " to the

*The term " Birmania Formation " has already been used in a map accompanying the brochure on " Oil in India " prepared for the XXII International Geological Congress, New Delhi, December 1964.

Kaimur stage and the "upper red sandstone (with a basal pebble bed)" and the overlying limestone to the Bhander stage. Heron (1932, pp. 462-463) was clearly of the view that these correlations, based as they are on colour and lithological similarities of rocks separated by the Aravalli Range where on too tenuous a ground and concluded that "all that we know definitely regarding their age is that they are younger than the Malani rhyolites (and associated Jalore granite) upon which they rest with a distinct unconformity of erosion". However, more recently, Roy-Choudhury *et al.* (1959) and Krishnan and Swaminath have again correlated these rocks with the Vindhyan system of East Rajathan.

Pascoe (1950, p. 41) has commented, in the manual, that the "Vindhyan rocks of Marwar, to the west of the (Aravalli) range, were deposited in a separate basin which seems to have had no connection with the main basin. Concealment of the deposits beneath the Jurassics of Jaisalmer and the sands of the 'Thar' desert makes it impossible to say how far this second basin extended in a north-westerly direction". Srivastava and Srinivasan (1962) have shown that the Jodhpur sandstone is present in western Rajasthan all the way north to the Ganganagar district — either directly underlying the sub-Recent formations or the Eocene beds of Palana-Bikaner region. Refraction surveys have shown that this formation continues further north at least as far as near Ferozepur. Seismic work carried out recently in the Jaisalmer district indicates the presence of a pre-Lathi sedimentary sequence a few thousand feet thick in the area west and north-west of Jaisalmer. It is, therefore, evident that the Jodhpur and Bilara formations (or their equivalents) are fairly widespread all over western Rajasthan — in the area west of the great Aravalli divide — and are also present in the subsurface below the Mesozoic sediments of the shelf of the Indus geosyncline.

Oldham (1881) and later Pascoe (1950, p. 41) have attempted a correlation with the Saline Series and the Purple Sandstone of the Punjab Salt Range (now part of West Pakistan). The Salt Range outcrops of early Palaeozoic rocks are less than 200 km from the northernmost point where the Jodhpur formation is known to be present. It should be noted that these rocks (or their equivalents) extent for over 500 km from near Barmer to very near Ferozepur. This is an important factor, of course supplemented by the refraction surveys in Jaisalmer and Ganganagar districts, in presuming that the early correlations of Oldham (and later on of Heron) are probably correct. Additional factors such as the presence of salt pseudomorphs in shales, thick evaporite sequences, etc., also indicate that the lithological association of the Jodhpur formation is very similar to that of the Cambrian sequence of the Salt Range. The Bhilara formation is not so extensive as the Jodhpur formation and equivalents of this unit are absent in the Salt Range.

It is not the intention of this author to state that an unequivocal correlation exists between the Jodhpur formation of West Rajasthan and the Saline Series/Purple Sandstone of the Salt Range. Nor is there any clear-cut evidence that the Jodhpur formation (and Bilara formation) are not homotaxial with the Vindhyan system across the Aravalli hills. Actually, the Purple Sandstone of the Salt Range is, according to Pascoe (*op. cit.*, p. 41), "very reminiscent of similar beds in both the Lower Vindhyan (Semri) and Upper Vindhyan of the Peninsula" and it may well be that the Purple Sandstone, Jodhpur and Bilara formations and the Vindhyans are all homotaxial formations. The point that is being stressed here is that there is as yet no evidence to indicate the age of the Jodhpur and Bilara formations (and their equivalents such as the Birmania formation, the Rol-Qazian/Bhakrod "Series" and the Nagaur "Series"). These formations occupy a vast area in West Rajasthan and are totally unconnected with any similar rocks in East Rajasthan. It would be, therefore, incorrect to expect — apart from a general homotaxicity — series and stage-wise correlation with the Vindhyan system. The very term 'Vindhyan' is strictly not applicable to beds in West Rajasthan in much the same way as the terms 'Saline Series' and 'Purple Sandstone' are also not applicable.

The problem of the age of the Bap boulder beds, which was dated purely on the basis of analogy with the Salt Range boulder beds, now appears to have been solved by the find of marine Permian beds resting on them in the area near Bap.

According to Siddiquie (1963, p. 105), Swaminath *et al.* were doubtful about the age of some rocks which have been mapped as Lathi by Daru (1916-17) in the area south of Devikot. It appears that doubts have even been expressed by them that these rocks may be "as old as the Vindhyans". Much more to the south of Devikot, a little beyond Sheo, La Touche had mapped some sandstone outcrops as equivalent to the supposedly Cretaceous Barmer sandstone.

The problem of the correlation of these rocks south of Devikot has been studied by the Oil & Natural Gas Commission. About three miles south-west of Devikot some well-preserved leaf impressions were collected by Mr. B. N. Srivastava of the Oil & Natural Gas Commission from what were mapped as Lathi sandstone. These have been identified as *Pterophyllum* sp., *Ptillophyllum acutifolium* and *Equisetites* sp. (Varma, 1960). Two horizons, with abundant solicified gasteropods, were also mapped by Mr B. N. Srivastava on the ridge about 5 miles south of Fategarh (i.e. about 17 miles south of Devikot). Similar gasteropods were reported earlier from the tube-well at Fategarh (Datta, 1960). Richter-Bernburg and Schott (1957) also noted silicified gasteropods in Lathi sandstone near Dangri. There appears to be no reason, therefore, to doubt that the Lathi sandstone, *sensu stricto*, continues southward up to a few miles south of Fategarh. The Fategarh-Birmania-Sheo-Bhiyar area was studied by Misra *et al.* (1960) and it was seen that the outcrops of Lathi are present at least as far south as Sheo. Stray outcrops of whitish bentonitic clay are present unconformably overlying the Lathi in these areas.

The well-known " Barmer sandstones " were first described by Blanford (1876). La Touche (1902) re-examined these outcrops of " whitish and grey sandstones locally indurated ". La Touche mentions that the outcrops of the " Barmer sandstone " are seen northward from Barmer up to a point six miles south of Sheo. He has collected part of a cast of what appeared to be a shell of Unio (with hinge missing) another " small fragment of a bivalve shell, which may be Cardium " and two impressions of veined leaves which were interpreted by him to be of dicotyledonous angiosperms. No other fossils were seen by the many geologists who worked in the area in later years. The point that needs to be emphasized here is that none of the fossils were identified and the Cretaceous age ascribed to the Barmer sandstone is really based entirely on these very meagre evidences. Actually Blanford himself has stated that the Lathi sandstone contains dicotyledonous fossil wood. Ghosh (1952, p. 106) mentions that a doubt had been expressed by La Touche regarding the possibility of the Lathi being a local development of the Barmer sandstone.

In the absence of critical faunal remains (or even identifiable plant fossils) one could perhaps utilize the heavy mineral suites of these formations in attempting to establish the presence or absence of correlative characteristics. The only data available regarding the heavy mineral contents of the Lathi and the Barmer sandstones are from the works of Swaminath *et al.* (1956, 1957) and Siddiquie (1962, 1963). One of the points on which Siddiquie bases his distinction between the " Jaisalmer basin " and the " Barmer basin " is the absence of staurolite in the latter basin. If it is conceded that the provenances were different for different parts of the West Rajasthan shelf then it is seen that the absence of tourmaline in the so-called Barmer sandstone is what distinguishes it from the Lathi sandstone of the Jaisalmer area. It should, however, be noted that tourmaline is ubiquitous in all the Mesozoic formations of the Jaisalmer area just in the same way as staurolite. Both these minerals, therefore, are not critical for correlation purposes and the absence of either mineral in these sandstones of Barmer does not by itself indicate that they are different in age for the Lathi sandstone. The age of the Lathi is not in doubt, both on account of the fossils recovered from the Lathi sandstone as well as on account of the fact that it underlies the Middle Jurassic Jaisalmer formation. The Lathi formation has been mapped continuously up to Fategarh, 5 miles south of which fossiliferous horizons have been noted. From Fategarh southward, up to Sheo, the regional dips are to south or south-west, and in tubewells drilled at Sheo, Bisu, Bhiyar and Nimla more than a thousand feet of sediments have been drilled through with the wells spudded in on outcrops of Lathi. The only sediments overlying the Lathi in these areas are the whitish bentonitic clays referred to earlier. The Barmer sandstone, in the strict sense of the term, is not present north of latitude 26°N. Whether the sandstones cropping out on either side of the Jaisalmer-Barmer road, south of atitude 26°N up to Barmer, are themselves perhaps only the southern continuation of the Lathi or are on the other hand of Cretaceous age is, of course, not clear at present.

There are, however, two outcrops of sandstone, containing impressions of unidentified angiospermous leaves, twigs and same fossils which have been tentatively identified as fruits, immediately north-west of Barmer. Dips of the order of 30° (to east) have been noted in these outcrops and Mr B. P. Srivastava who mapped these beds is of the opinion that these sandstones may be of Lower Tertiary age. In this context, it would be interesting to know whether any micropalaeontological studies have been carried out of the cuttings obtained from the ETO water well drilled near Barmer. Apart from these two sandstone outcrops one just north-west of Barmer and the other about 6 miles north-west of Barmer — all the other sandstone outcrops in the area north of Barmer appear to be no different from the Lathi sandstone, and the term " Barmer sandstone ", in the sense it is understood at present, should be restricted to the two small outcrops mentioned above. In view of extensive sand cover, outcrops are poor and the field relationships of the Lathi, the Barmer sandstone and the Tertiary bentonitic days are very obscure.

The age of the Parihar formation had been reported for long as Upper Jurassic. In fact Krishnan and Jacob (1956, p. 26) even state that the Abur formation — which overlies unconformably the Parihar — is itself Upper Jurassic. However, Krishnan (1949) places Parihar in Lower Cretaceous. The continued reference to the Abur as " uppermost Jurassic " is, therefore, due to oversight. Spath (1927-33, reported in Arkell, 1956, p. 392) and later Schmidt (in Richter-Bernburg and Schott, 1957, p. 176) have identified *Deshaysites bodie* var. Koenen — a clearly Aptian ammonite. The Bedesir formation, which is overlain unconformably by the Parihar, is uppermost Jurassic (Tithonian) in age on account of the identification of a *Virgatosphinctes Aulacosphinctes* faunal assemblage. In view of the fact that Parihar is unconformably sandwitched between the uppermost Jurassic Bedesir below and Aptian Abur above, this formation should normally be considered as part of Lower Cretaceous. No fossil evidence in support of the above conclusion is, however, available. A general correlation with the unfossiliferous sandstones and shales of the Umia Series of Kutch is possible, where also the unfossiliferous Umia beds are overlain by marine Aptain beds. The Parihar is also correlatable to the Sembar of the Indus basin. In spite of all these arguments, the question will really be decided only after some fossils are recovered in the outcrops or in the subsurface.

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DISCUSSION

P. G. Adyalkar: How does the marine Permian bed reported by the author fit in the palaeogeographic panoroma of the region ?

K. Narayanan: The outcrops of Rajasthan, including those of Mesozoic and pre-Mesozoic sediments, are in the typical shelf facies. Their continuation beneath the younger rocks further west has been confirmed by drilling and seismic work in West Pakistan and by seismic studies in India. To put it in a nutshell, the Indus basin was a sea from early Palaeozoic time with, no doubt, many periods of uplift and erosion. Referring to Permian, in particular, the Badhaura formation of Rajasthan corresponds to the Wulgai formation exposed in the core of an anticline north of Quetta in the folded belt.

K. P. Rode: What is the relation of the Rajsthan basin of sedimentation in geological past with the basin in Sulaiman-Kirthar Range ?

K. Narayanan: The Tertiary sediments of the Rajasthan area represent those of the shelf while those of Sindh, Baluchistan areas are of the deeper part of the basin. Both are part of the Indus geosyncline.

SOIL FERTILITY AND CLASSIFICATION

CLASSIFICATION & FERTILITY OF SOILS OF DESERT & SEMI-DESERTIC REGIONS[1]

by

S. P. RAYCHAUDHURI[2]

INTRODUCTION

THE greater part of north-west Rajasthan and the bordering districts of Punjab consist of desert and semi-desertic regions.

In Rajasthan these soils occupy northern and western parts of the Aravallis. Luni is the only river which crosses south-west of Ajmer and after covering a distance of about 321 km (200 miles) is lost in desert sand, and finally joins the Rann of Cutch. The greater part of north-west Rajasthan is a desert with an annual rainfall of less than 381 mm (15 inches) and reaching as low an average as 51 mm (2 inches). In the desert region the temperature at places rises as high as 52°C. The peaks of high temperatures are followed generally by duststorms, which in turn are succeeded by thunder showers which bring down the temperature considerably. These duststorms are of fair magnitude and they sometimes deposit as much as 5 to 7·5 cm of dust on the floors of residential buildings.

The great desert tract of Rajasthan, known as '*Thar*' of the Rajputana, consists mainly of wind-blown sand. It stretches from the west of the Aravallis to the basin of the Indus in the west and from the Southern confines of the Punjab plains, the basin of Sutlej to the Rann of Cutch as far south as lat. 25. The area is roughly about 643 km (400 miles) long and about 161 km (100 miles) broad, covered not only by sheets of sand but also by rocky projections of low elevation which constitute the older rocks of the country. The great Indian desert of Rajasthan has been spreading towards Agra, Aligarh and Kasganj encroaching upon approximately 130 sq. km (50 sq. miles) of fertile land every year.

Gupta (1958) studied the mineralogical composition of some soils and sands of Rajasthan desert. In the heavy mineral group in all samples hornblende predominates; other minerals, namely garnet, magnetite and limonite, tourmaline, kyanite and epidote, are present in varying proportions but next to hornblende. In the higher fraction quartz predominates with orthoclase and plagioclase coming next. It was further observed that the composition of aeolian sands does not bear any resemblance to the local rocks, wherever they exist. It shows that they are exotic, i.e. brought and deposited.

SURVEY AND CLASSIFICATION OF DESERT AND DESERTIC SOILS BASED ON PROFILE STUDIES

Tamhane, Shome and Raychaudhuri (1953) studied a number of soil profiles from a surveyed area of 81 hectares (200 acres), lying 22 km (14 miles) south-west of Ajmer town. These soils as also the soils of the districts of Jaisalmer, Jodhpur and Bikaner constitute a vast sandy plain including isolated hills and rock outcrops at places. The soils improve in fertility towards east and north-east. Usually the soils are saline or alkaline with unfavourable physical condition and high *p*H value. Water is scarce and occurs at great depths. The phosphate content of the aeolian sands compare favourably with some of the alluvial soils, P_2O_5 ranging from 0·05 to 0·1 per cent. Total nitrogen is low, mostly ranging between 0·02 and 0·07 per cent. The *p*H of the soils and sands varies between 7·2 and 9·2. The salt content is not in toxic doses. The soils and sands are calcareous in nature. Nitrogen occurs in the form of nitrates which contribute to soil fertility.

Depending upon the rainfall conditions, the soils of south and south-eastern Punjab and of western Rajasthan which belong to the arid and semi-arid climate may be classified in the following groups:

1. Pedocal Sierozem of alluvial origin,
2. Pedocal Brown Soil of alluvial origin,
3. Grey Brown (desert) Soil,
4. Desert Soil.

1. Pedocal Sierozem of alluvial origin: These soils have been developed under arid conditions in the alluvium in the districts of Ferozepur and Hissar in the Punjab and in the Pali district in Rajasthan in the rainfall zones of 250 to 500 mm and extend over an area of about 40,5000 sq. km. The soils are sandy loam with large preponderance of fine sand. The open texture and high temperature have resulted in low C/N ratios. The top and bottom layers are more siliceous than the middle ones. There is no indication of illuviation of sesquioxides in any of the lower horizons. Calcium carbonate is present at the surface and there is a marked illuviation of $CaCO_3$ at 92 to 184 cm depth.

1. Contribution from the Planning Commission, New Delhi.
2. Senior Specialist, (Land Resources).

The clay characteristics show montorillonite to be the preponderant clay mineral. Descriptions of two characteristic profiles of this class with analytical data of the soils are given below:

(A) *Pedocal Sierozem of Alluvial Origin**

Location:	Waste virgin land, west of field No. 33 Sirsa Government Agric. Farm. District Hissar, Punjab
Elevation above mean sea level:	220 mm
Annual rainfall:	430 mm
Topography:	Level
Drainage:	Moderately well drained
Parent material:	Alluvium
Depth (cm)	Description
0-10	Light brown, silty, effervescence with HCl; *p*H 7·5
10-30	Same as above
30-91	Colour same as above, calcium carbonate *Kankar* appears at 90 cm depth
91-182	Colour same as above, *Kankar* of irregular shape, very hard and angular; brisk effervescence with HCl; *p*H 7·5-8·0

(B) *Pedocal Sierozem of Alluvial Origin*

Location:	Compartment number 2 of Pali Grassland Farm, Pali District, Rajasthan
Altitude above mean sea level:	218 m
Annual rainfall:	510 mm
Topography:	At the foothills of the Aravallis near Mount Abu
Natural vegetation:	Babul (*Acacia arabica*); Anwal (*Cassia auriculate*); Saris (*Albizzia lebbak*); *khejra* or *kheira* or *Kheiri* (*Prosopis spicegera*)
Parent material:	Coarse grained granites associated with rhyolites
Depth (cm)	Description
0-15	Brown (10 YR 4/3 dry), dark yellowish brown (10 YR 3/4, moist); loam; medium; moderate, tendency to develop subangular blocky structure; loose, weakly cemented; friable, slightly sticky and slightly plastic; slight effervescence with dilute hydrochloric acid; roots common; wavy boundary

(A.1) Percentage constituents (oven-dry basis) of soil

Depth (cm)	*pH* (1:2·5)	SiO_2	Al_2O_3	Fe_2O_3	*CaO*	*MgO*	K_2O	$CaCO_3$	*Org. C*	*N*	*C/N*	*B.E.C.* (*m.e./* 100 *gm*)
0-10	7·5	78·75	12·10	8·4	1·0	0·75	0·68	1·6	0·34	0·05	6·8	10·5
10-30	7·8	76·55	11·30	7·8	1·9	0·62	0·75	1·7	0·30	0·05	6·0	10·9
30-91	7·5	75·80	10·60	8·0	2·1	0·78	0·85	3·0	0·19	0·03	6·6	11·3
91-182	7·5	80·10	10·88	8·2	2·1	1·30	0·80	13·1	0·16	0·03	5·3	11·5

(A.2) Percentage constituents (oven-dry basis) of clay

Depth (cm)	*B.E.C.* (*m.e./* 100 *gm*)	SiO_2	Al_2O_3	Fe_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
0-10	50·4	49·4	22·2	12·8	2·63	3·43
10-30	54·6	50·2	19·1	14·4	2·96	4·37
30-91	59·1	50·5	19·0	15·0	2·89	4·37
91-182	61·7	50·45	16·0	14·0	3·36	5·25

* *Soils of India* by S. P. Raychaudhuri, R. R., Agarwal, N. R. Datta Biswas, S. P. Gupta and P. K. Thomas, (1963).

15-38 Dark grey brown (10 YR 4/2 dry), very dark grey brown (10 YR 3/2 moist); clay loam; medium, moderate, blocky structure; slightly hard; weakly cemented, friable, sticky and plastic; slight effervescence with dilute hydrochloric acid; roots common; wavy boundary

38-61 Light grey brown (10 YR 6/2, dry), brown (10 YR 5/3 moist); loam; medium; weak, blocky structure; loose, weakly cemented, friable, slightly sticky and slightly plastic; violent effervescence with dilute hydrochloric acid; light grey (10 YR 7/2); concretions abundant; roots scanty; sharp boundary

61-122 Light grey (10 YR 7/2, dry), pale brown (10 YR 6/3, moist); sandy loam; medium; weak, blocky structure; loose, weakly cemented, effervescence with dilute hydrochloric acid; concretions abundant; roots absent; diffuse boundary

(B.1) Percentage total constituents (oven-dry basis) of soil

Depth (cm)	*pH*	*Detritus*	*Coarse sand*	*Fine sand*	*Silt*	*Clay*	*Total soluble salts*	*$CaCO_3$*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*Org. C*	*Total N*
0-15	8·20	11·8	21·5	42·2	14·0	19·3	0·029	0·69	72·28	12·56	4·39	0·51	0·055
15-38	8·30	16·6	19·9	31·1	14·4	28·6	0·029	3·96	69·08	14·83	4·52	0·61	0·054
38-61	8·30	53·0	19·6	22·0	14·9	14·9	0·029	28·84	67·22	15·17	2·98	0·51	0·039
61-122	8·25	62·0	36·0	14·9	4·6	11·9	0·029	30·03	67·03	15·41	2·32	0·31	0·028

(B.2) Percentage total constituents (oven-dry basis) of clay fractions

Depth (cm)	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*$\frac{SiO_2}{Al_2O_3}$*	*$\frac{SiO_2}{R_2O_3}$*
0-15	53·87	23·77	10·54	3·84	3·00
15-38	54·19	25·57	11·67	3·60	2·79
38-61	54·64	25·29	10·89	3·66	2·87
61-122	56·21	23·02	11·01	4·15	3·18

Clay Mineral: Montmorillonite is the predominating clay mixed with plenty of illite and some kaolinite.

122+ Compact bed of decomposed granite

This class of soil produces under irrigatigation a wide variety of crops including rice, wheat, cotton, banana and tobacco; sugarcane cultivation is also extensively done.

2. Pedocal Brown Soil of alluvial origin : The brown soils of alluvial origin have developed on alluvium of Indo-Gangetic origin in the region of rainfall varying between 500 and 750 mm and extend over an area of about 34,300 sq. km in the Punjab. They are found in the States of of Punjab and Rajasthan within the above rainfall limits. The description of one characteristic profile of this class with analytical data of the soils is given below:

(C) *Pedocal Brown Soil of Alluvial Origin**

Location:	Agricultural College, Ludhiana
Elevation above mean sea level:	300 m
Annual rainfall:	650 mm
Topography:	Level
Drainage:	Moderately well drained
Parent material:	Alluvium
Depth (cm)	Description
0-15	Brown; sandy loam; dry; no effervescence with HCl
15-38	Same as above
38-75	Brown; sandy loam; blocky; no effervescence with HCl
75-90	Brown; sandy loam; effervescence with HCl; yellow spots of iron found all round the profile
90-135	Brown; sandy loam; effervescence with HCl; blocky
135-180	Same as above

*S. P. Raychaudhuri, R. R. Agarwal, N. R. Datta Biswas, S. P. Gupta and P. K. Thomas (1963).

(C.1) Percentage constituents (oven-dry basis) of soil

Depth (cm)	*pH* (1:2·5)	*HCl insoluble*	R_2O_3	$CaCO_3$	*Org. C*	*N (total)*	*C/N*	*C.E.C.* (*m.e./100 gm*)
0-15	7·3	86·6	10·7	0·53	0·330	0·050	6·6	8·48
15-38	7·3	86·5	10·0	0·46	0·280	0·044	6·4	8·65
38-75	7·2	83·2	12·6	0·45	0·245	0·040	5·1	9·16
75-90	7·0	83·7	12·8	0·17	0·240	0·040	5·9	9·25
90-135	7·1	82·9	10·7	0·18	0·188	0·031	6·0	8·00
135-180	7·0	86·0	11·0	0·20	0·186	0·029	6·0	7·50

This class of soil also produces under irrigation a wide variety of crops as in the case of Pedocal Sierozem of alluvial origin and grows rice, wheat, cotton, banana, tobacco and sugarcane.

3. Grey Brown (desert) Soils: Grey Brown (desert) soils totalling on area of about 36,400 sq· km occur in Rajasthan in the districts of Barmer, Jalore, Jodhpur, Sirohi, Pali, Nagaur, Sikar and Jhunjhunnu. The whole tract is a vast sandy plain including isolated hills and rock outcrops at places. The soils improve in fertility towards east and north-east. Usually the soils are saline and alkaline, with unfavourable physical conditions and high *p*H value. Water is scarce and occurs at greater depth from 100 to 400 ft from ground level. The phosphate content of the aeolian sand compares favourably with some of the alluvial soils, P_2O_5 ranging from 0·05 to 1·0 per cent. Total nitrogen is low, ranging between 0·02 and 0·07 per cent. The *p*H of the soil and sand varies between 7·2 and 9·2. The salt content is not in toxic doses. The soils and sand are calcareous in nature. Nitrogen occurs in the form of nitrates which contribute to soil fertility. The description of one characteristic profile of this class with analytical data of the soils is given below:

(D) *Grey Brown (desert) Soil**

Location:	About 23 km south-west of Ajmer town, Rajasthan*
Elevation above mean sea level:	800 m
Annual rainfall:	625 mm
Topography:	Level.
Drainage:	Excessively drained
Parent material:	Wind-eroded deposit
Depth (cm)	Description
0-30	Sandy and structureless; presence of grass roots
30-60	Sandy; darker and more sticky than the first layer; presence of grass roots; no effervescence with HCl
60-90	Dry, sandy, friable and structureless; occasional presence of grass roots; more compact than above; carbonate detected at some spots

This class of soil also produces under irrigation a wide variety of crops as in case of Pedocal Sierozem of alluvial origin and Pedocal Brown soil of alluvial origin and grows rice, wheat, cotton, banana, tobacco and sugarcane.

4. Desert Soil: A large part of the arid region belonging to Rajputana and South Punjab, lying between the Indus Valley and the Aravallis, is affected by desert conditions of geologically recent origin. This part is covered under a mantle of blown sand which inhibits soil growth. The Rajputana desert proper occupies an area of about 106,000 sq. km. Owing to the physiographic conditions of its situation, the area, though lying in the tract of the south-west monsoon, receives no rain.

The sands with which it is covered are partly derived from the disintegration of subjacent rocks but are largely blown in from the coastal regions and the Indus Valley. Some of these soils contain high percentage ofso luble salts, possess high *p*H, have low loss on ignition, varying percentage of calcium

(D.1) Percentage constituents (oven-dry basis) of soil

Depth (cm)	*pH* (1:2·5)	*Clay*	*Silt*	*Sand*	*T.S.S.*	*Total N*	*Org. C*	SiO_2	Fe_2O_3	Al_2O_3	SiO_2/Al_2O_3
0-30	8·18	4·44	3·84	92·09	0·300	0·016	0·120	45·76	10·74	34·24	3·20
30-60	8·17	4·20	4·16	91·56	0·057	0·013	0·126	46·39	8·57	26·59	3·01
60-90	8·66	5·34	3·54	91·52	0·050	—	—	47·32	10·54	25·41	3·16

*Tamhane, R. V., Shome, K. B., & Raychaudhuri, S. P. (1953).

carbonate and are poor in organic matter. The limiting factor being mainly water, these soils may be reclaimed, if proper facilities of irrigation are available. The description of one characteristic profile of this class with analytical data of the soil is given below:

(E) *Desert Soil*+

Location:	Suratgarh, District Bikaner, Rajasthan*
Elevation above mean sea level:	224 m
Annual rainfall:	290 mm
Topography:	Level
Drainage:	Well drained
Parent material:	Alluvium
Depth (cm)	Description
0-18	D, 7·5 YR 7/4; silty loam; weak blocky; tending to be weakly granular; dry and hard; good effervescence with acid
18-58	D. 7·5 YR 6/4; silty clay loam; weakly laminar developing to blocky and nutty; somewhat porous and dry, easily powdered under light pressure of fingers; good effervescence with acid; existence of some small shells of aquatic nature; a few tabular soil structuree probably in the root holes or animal burrows
54-48	Pinkish to light brown; silty clay loam; compact and hard; somewhat more silty; with a few grains of sand somewhat gritty; medium effervescence with acid; other features as in (2)
84-127	Same as in (3) with slight effervescence with acid

(E.1) Percentage constituents (oven-dry basis) of soil

Depth (cm)	*pH*	*T.S.S.*	$CaCO_3$	*Clay*	*Silt*	*Sand*
0-18	8·25	0·014	2·00	24·9	30·7	44·4
18-58	8·20	0·063	1·50	33·2	48·4	18·4
58-84	8·30	0·032	1·00	29·2	48·4	22·4
84-127	8·20	0·064	0·66	35·2	26·4	38·4

On this class of soil generally coarse millets are grown.

*Satyanarayana, K. V. S. (1956).

QUALITY OF UNDERGROUND WATER

The saline waters of Rajasthan contain mostly sodium sulphate and sodium chloride and in some cases sodium bicarbonates, also. In most cases the Ca/Na ratio is very low and sodium forms 90 per cent of the total cations.

SOIL FERTILITY

Though on the whole the tract is sandy, the soil improves in fertility from west to east and north-east. In many parts the soils are saline or alkaline with unfavourable physical condition and high *p*H value. Water is scarce and occurs at great depths from 30 metres to 122 metres (100 to 400 ft) from ground level. Krishnaswami and Gupta (1952) and Gupta (1953) have found that the desert lands are not waste and infertile but are suitable for growing crops, provided the water scarcity could be overcome. Local informations also revealed that in the years of comparatively good rainfall or in the areas where well water is available, the sandy areas produce bumper crops, particularly bajra. Investigations of Gupta (1953) reveal that (1) salt content of the sands did not prove toxic to plants, (2) nitrogen in the form of nitrates contributed to the fertility and (3) the sands were calcareous in nature.

Over large parts of these stabilized areas (as at Jodhpur and Jaipur) it is seen that CaO content increases downwards resulting in $CaCO_3$ accumulation or *Kankar* bed formation. This confirms the field observation that the profiles in the stabilized sandy areas have developed under comparatively protected condition where rainwater had sufficient time to leach the calcium from top layers down into the subsoil. The Ca content in the subsoil is nearly ten times that of the top soil. Magnesium does not behave similar to calcium. The phosphate contents of the aeolian sands compare favourably with some of the normal alluvial soils. In most of the desert soils P_2O_5 ranges from 0·05 to 0·1 per cent. The total N is low, ranging between 0·02 and 0·07 per cent. This deficiency is, however, made up to a certain extent by the presence of high available N in the form of nitrates. Thus phosphates together with nitrates go a long way to make these desert sands fertile for agricultural crops and other plants whenever nitrate is not deficient. The *p*H of the soils and sands varies between 7·2 and 9·2 with majority falling within the range of 8·1 to 8·8. The salt content is not in the toxic doses. It is further seen that the clay content of the desert sands mostly varies between 2·5 and 8·0 per cent in some soils. Even though the clay content is low in desert sands, there is a tendency to high dispersion on account of sodium-clay formation in the subsoil, which may render it less permeable and, therefore, more retentive of moisture.

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DISCUSSION

I. M. Qureshi: What is the salt content in the heavy soils of the Rann of Kutch and what is the depth of water table ?

S. P. Raychaudhuri: Dr K. V. S. Satyanarayana who has worked on these soils may be able to give reply to your questions.

K. V. S. Satyanarayana: The soils of the Rann area are generally heavy and contain 5 to 15 per cent salt (1:5 soil water extract) most of which is NaCl. The area is waterlogged for a part of the year. During the dry period the water table is at 3-5 ft.

S. P. Chatterjee: You have taken into account mean annual rainfall in the classification of desert soils into four suborders. Don't you think that intensity of rainfall should be taken into account ?

S. P. Raychaudhuri: I agree, but unfortunately data regarding intensity of rainfall at different locations are not available.

R. V. Tamhane: Do you think the data are adequate for classification ?

S. P. Raychaudhuri: This is a broad classification based on the data available from the work of different authors on these soils. The modifications, if any, can be made later on.

P. G. Adyalkar: The surface or ground water influenced by Luni is fresh only to a depth of 4-5 metres. Below this it is saline.

B. B. Roy: A detailed soil survey of arid region should be carried out and different soil phases like eroded phase, salinity phase, etc., demarcated, which may help in planning land development. The main problem in this region is how to carry out detailed soil survey rapidly.

S. P. Raychaudhuri: The rapid detailed soil survey should be carried out at least in the scale 1:15,000 on the basis of important physical properties, e.g. texture of surface soil, permeability and depth of the soil and hazards like salinity and wind erosion.

H. Nath: Exhaustive analysis of water obtained from different areas of Rajasthan, by and large, supports the statement made by Dr Raychaudhuri in his paper, but only surface water obtained from River Luni up to a depth of 1-2 metres has been found to be potable.

N. C. Rawal: What is the depth of subsoil water and the predominant salts present in it ?

P. C. Raheja: Depth of water table varies from 3 to 5 metres and sometimes more. The predominant salt is sodium chloride.

SOME ASPECTS OF SOIL MICROBIOLOGY IN RELATION TO SOIL FERTILITY WITH SPECIAL REFERENCE TO ARID ZONE[1]

by

W. V. B. SUNDARA RAO[2]

INVESTIGATIONS carried out in different parts of the world on the activities of microorganisms in the soil established beyond doubt that the microorganisms take part in the decomposition of organic residues added to the soil and build up soil humus. In the process mineral nutrients like phosphorus, calcium, magnesium and potassium which are in the bound form in the organic matter are released in available form to the growing crop. Work conducted in this country showed that the rate of evolution of carbon dioxide from the soil is a measure of the activity of the heterotrophic microflora and reflects in general the fertility levels of differently fertilized plots (Table 1). The conditions for proper microbiological activities are similar to those for proper crop growth like aeration, optimum moisture and temperature regimes, availability of adequate amounts of mineral nutrients and nitrogen. Therefore, the supply of a mineral deficient in the soil leads to enhanced microbial activity and as such results in greater availability of this mineral as well as other mineral nutrients and nitrogen to the crop (Table 2). The Indian work involving the use of radioisotope P^{23} corroborates the work done in other places with respect to positive action of microflora in releasing phosphorus in available form to growing crop (Table 3).

TABLE 1: CO_2 evolution and yields in wheat crop*

Plot No.	Treatment	CO_2 evolved in mgm per 100 gm of soil (spring sample)	Yield of wheat in lb (1941-42)	Av. yield in lb (1930-31 to 1941-42)
3A	F.Y.M.	43	867	922
7A	K_2SO_4	31	233	419
10A	N.P.K.	38	689	945
12A	G.M.	34	367	500
13A	Check	28	223	365
16A	G.M. and Super	51	1350	1386
	Coefficient of correlation		+0·98992	+0·96605

1. Contribution from Indian Agricultural Research Institute, New Delhi.
2. Head of the Division of Microbiology at the Institute.
*Desai, S. V. and Sundara Rao, W V B. (1948).

Usually under restricted moisture regimes actinomycetes dominate the microbial population in the soil while other organisms die off or sporulate and remain in a very dormant condition. Further, actinomycetes play an important role in decomposing the more resistant forms of organic matter like lignin, hemicelluloses and complex hydrocarbons. Actinomycetes also play an important role in the synthesis of antibiotics which influence the microbial balance in the soil. Streptomycin synthesized by *Streptomycetes* has been effectively used in the control of some plant pathogens. In view of the importance of the actinomycetes it will be of interest to examine the nature and dominance of this group among soil microflora in the arid zones.

It will be of advantage if strains of microflora which can thrive under low moisture regimes in the arid regions can be isolated or evolved through exposure of normal microflora to radiation. The introduction of such organisms in the arid-region soils may lead to better microbial activity resulting in the establishment of better soil fertility.

However, as more and more areas in the arid zones are irrigated and brought under cultivation there will naturally be fluctuations in the counts of bacteria and fungi and the nature of such fluctuations will be of interest both from the applied and fundamental aspects.

The isolation and propagation of rhizobial strains that will increase the yield and nitrogen content of leguminous food and fodder crops in the area will be another line which needs to be studied in detail. Microorganisms play an important role in the building up of soil structure and the possibility of establishing a suitable soil structure in the arid region by the use of such microflora may be studied.

Work carried out in UK and USSR on the control of plant pathogens through the proliferation of saprophytic microflora by manurial amendments is attracting world-wide attention. King, Hope and Eaton (1934) obtained considerable amount of success in controlling the cotton root rot caused by *Phymatotrichum omnivorum* by adding alfalfa hay or cereal manure to infested soil. Millard (1921) reported a striking control of potato scab caused by *Streptomyces scabies* by means of heavy green manuring of the soils with grass cuttings and suggested that the actinomycetes preferred a saprophytic existence on the dead or dry grass material to a parasitic life upon living potato tubers, if the choice

TABLE 2: Effect of mineral application on barley (1943-44)*

Plot No.	Treatment	Yield per acre	Total in the grain		Increase over unmanured in total recoveries by grain	
			N	P_2O	N	P_2O_5
		lb	lb	lb	per cent	per cent
3	F.Y.M.	813·9	12·45	4·61	683·0	1407·0
6	$(NH_4)_2SO_4$	98·3	2·31	0·37	45·3	19·3
7	K_2SO_4	98·3	1·92	0·38	20·8	23·0
8	Super	402·6	6·01	2·85	278·0	800·0
9	K_2SO_4 and super	330·9	4·96	2·34	211·9	665·0
10	Amm. sulphate, super and potassium sulphate	295·2	4·2	2·79	164·1	812·8
11	$(NH_4)_2SO_4$ and super	697·8	10·4	2·8	554·1	817·3
12	Unmanured	80·4	1·59	0·31	—	—
13	$(NH_4)_2SO_4$ and K_2SO_4	62·6	1·55	0·26	−2·5	−13·3

TABLE 3: Mean yields of tomato (tops) and total fertilizer and native phosphorus uptake by plants in pot culture experiment (mean of 4 replications)†

Treatment	Dry wt of tops (g/pot)	Percentage composition (P)	Total phosphorus uptake (mg/pot)	Percentage of phosphorus in plant derived from fertilizer	Fertilizer phosphorus uptake (mg/pot)	Native phosphorus uptake (mg/pot)
1. Soil+F.Y.M.+superphosphate (tagged)	7·65	0·258	19·77	36·46	7·06	12·71
2. (1)+phosphobacterin	8·86	0·288	25·51	38·48	9·51	16·00
3. (1)+Indian strain	8·86	0·271	24·00	35·48	8·55	15·45
4. Soil+FYM+hydroxyapatite (tagged)	7·59	0·238	18·09	23·19	4·12	13·97
5. (4)+phosphobacterin	9·46	0·267	25·27	31·42	7·45	17·82
6. (4)+Indian strain	9·50	0·219	20·84	30·80	6·37	14·47
'F' test	Significant		Significant		Significant	Not significant
SEm	±0·185		±1·874		±0·672	
C.D. at 5%	0·55		5·52		2·002	

were open to it. But Sanford (1926) suggested that the control of scab was a biological control due to increase in the population of certain saprophytic bacteria that multiplied upon the decomposing grass material. The general hypothesis proposed is that the other microorganisms of the soil exert through their competitive assimmilation and resulting exertion a natural biological control of the pathogenic organisms and that this natural biological control could be enhanced by organic manuring. The work of Weindling (1932, 34, 37, 41) and of Weindling and Fawcett (1936) resulted in the eventual isolation of antifungal antibiotics, gliotoxin and viridin (Brian and McGowan, 1945). Stover (1954) and Stover *et al.* (1953) have obtained some degree of control of panama disease of bananas by flooding, thereby reducing the population of *Fusarium oxysporums* var. *cubense* in the soil. Russian workers were active in investigation on the control of seed-borne diseases and showed that the inoculation of flax seed carrying the pathogen *F. lini* with certain soil bacteria capable of lysing this fungus caused an increase in the number of healthy seedlings of certain varieties, although not of others (Novogrudski, 1937).

Davey and Papavizas (1959) showed that the application to the soil of various organic amendments reduces the pathogenicity of *Rhizoctonia solani* to snapbeans. The incorporation of crop residues leads to a marked increase in the abundance and activities of non-pathogenic microorganisms and often a decrease in the number of the pathogens. The rapid rise of the former population may make conditions unfavourable for the latter through competition for nutrients or oxygen by building up the carbon dioxide concentration to deleterious level

*Desai, S. V. and Sundara Rao, W. V. B. (1948).
†Sundara Rao, W. V. B., Bajpai, P. D., Sharma, J. P. and Subbiah, B. V. (1963).

or by antibiotic synthesis. This aspect shouid constitute an important item of study in the arid regions.

The rhizosphere microflora play an important role in influencing the crop growth. Broadly the results obtained at IARI with respect to the study of the rhizosphere microflora are indicated in the papers by Sundara Rao, W. V. B. and Chayanulu, M. V. (1961), Sankaram, A. and Sundara Rao, W. V. B. (1961), Sundara Rao, W. V. B. and Venkataraman, K. V. (1963). These results show that the rhizosphere of the plants supports a high bacterial count as well as a large population of microflora that need aminoacids for their nutrients. Some of the rhizosphere microflora synthesize vitamins that accelerate plant growth and also increase the activities of microflora that play important role in the development of soil fertility. Nitrogen fixation and nitrification were found to be accelerated by vitamin B_{12}. This vitamin was found to be synthesized by the microflora that belong to the aminoacids requiring group and flourish near the rhizosphere of the plants. Further the microorganisms near the rhizosphere were shown to have a power of solubilizing mineral nutrients like phosphorus and supply the same to the growing crop.

Success has been achieved in increasing the yields of the leguminous food and fodder crops through seed inoculation with efficient strains of *Rhizobium* (Table 4). The method of preparation of mass cultures of the *Rhizobium* cultures has been perfected at other places and it is necessary that a wide use of the rhizobial cultures be encouraged in the arid zones. The selection of the strains should be based not only on their efficiency in forming nodules and in fixing nitrogen but also by its capacity to establish itself in the root zones against the competitive action of other microflora. Seed bacterization with azotobacterin and phosphobacterin was found to increase crop yields under specific condition from 5 to 15 per cent (Tables 5 and 6). The amount of bacterial fertilizers required is about 500 gm of soil cultures enriched with *Rhizobium* in the case of the cultures intended to increase the yields of leguminous food and fodder crops. In the case of *Azotobacter* the growth on agar slants made from 250 ml of the agar medium specific for these organisms and in the case of phosphobacterin about 2 to 10 gm of the bacterial fertilizers depending upon the size of the seeds are required for an acre of land. Considering that the cost of these bacterial fertilizers is considerably low (about Rs 2), quantity required for an acre, the possibility of their use in the arid regions together with the organic manures and artificial fertilizers need be explored. The process of increasing nitrogen in the soil either by growing leguminous crop or by adding readily decomposing organic matter low in nitrogen content or by leaving the soil wet, where facilities for irrigation exist, for nitrogen-fixing blue-green algae to develop, needs to be examined as to their suitability under different conditions. Efficient strains of *Rhizobium* or *Azotobacter* or blue-green algae can be supplied from the IARI for this purpose.

How far manuring and crop rotation could establish the proper microbial balance in the soil as to benefit crop growth should constitute the subject-matter of intensive investigation in the arid zone areas where the soils will be gradually brought under cultivation after ensuring adequate supply of water.

TABLE 4: Increase of yield by application of *Rhizobium* (unpublished)

Pulse	*% increase in yields*	*% increase in nitrogen content*
Gram (*Cicer arietinum*)	58	47
Rahar (*Cajanus cajan*)	79	—
Urid (*Phaseolus mungo*)	46-530	26-419
Pea (*Pisum sativum*)	39	26
Soybean (*Glycine max*)	45	60
Sem (*Egyptian bean*)	133	100
Cowpea (*Vigna sinensis*)	23	33
Guar bean (*Cyamopsis tetragonoloba*)	100	90

TABLE 5: Green and dry fodder yields of jowar in kg per acre as influenced by some bacterial cultures in association with nitrogen, P_2O_5 and F.Y.M. for the summer and monsoon seasons of the year 1962-63* (unpublished)

Treatments	*Summer season*		*Monsoon season*	
	Green fodder	*Dry fodder*	*Green fodder*	*Dry fodder*
1	5790	3576	2637	1175
2	5358	3283	2896	1286
3	6115	3775	2722	1216
4	7216	4403	2938	1307
5	7367	4679	2938	1307
6	5704	3480	2982	1338
7	5164	3202	2852	1270
8	6223	3967	3197	1431
9	6654	4044	2334	1040
10	7043	4368	4104	1831
11	7043	4244	3804	1691
12	6503	4131	3845	1714
13	—	—	3241	1452
14	—	—	3111	1390
15	—	—	3389	1740
L.S.D. at 5%	996	626	778	350
C.V.%	9·15	9·30	15·00	15·00

*In collaboration with Agril. Chemist and Agronomist, Agricultural Research Institute, Anand.

TABLE 6: Phosphobacterin inoculation* (unpublished)

	Field trials	Number of experiments showing significant increase
Delhi Alluvial soil	Berseem — 4	3
	Maize — 1	1
Karnal Alluvial impregnated with salt	Wheat — 3	2
	Maize — 2	1
	Paddy — 3	nil
*Pusa** Calcareous soil	Urid — 3	1
	Gram — 1	nil
	Maize — 1	nil
	Wheat — 3	nil
*Wellington** Acid soil	Potato — 1	nil
Nagpur Black cotton soil	Rahar — 1	nil
Indore Black cotton soil	Paddy — 1	1
*Simla** Acid soil	Wheat — 1	nil
Hyderabad	Paddy — 2	1
Bapatla	Paddy — 1	nil
	28	10
Experiment in calcareous* or acid soil	9	1
	19	9

*In collaboration with the Division of Agronomy at IARI and State Agricultural Departments.

TREATMENTS

1. No manure and no inoculation (control)
2. 2·5 tons of F.Y.M. per acre
3. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 per acre as superphosphate
4. Azotobacter 1 (Indian culture)
5. Azotobacter R (Russian culture)
6. 2·5 tons of F.Y.M. + Azotobacter 1 per acre
7. 2·5 tons of F.Y.M. + Azotobacter R per acre
8. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 + Azotobacter 1 per acre
9. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 + Azotobacter R per acre
10. 40 lb of N per acre as sulphate of ammonia
11. 20 lb of N + Azotobacter 1 per acre
12. 20 lb of N + Azotobacter R per acre

The above twelve treatments were studied for their effect during summer season of the year 1962-63. On studying the results of this season, it was thought worthwhile to include the following three treatments in the experiments conducted in the monsoon of the year 1962-63.

13. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 + 20 lb of N/acre
14. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 + 20 lb of N + Azotobacter 1 per acre
15. 2·5 tons of F.Y.M. + 20 lb of P_2O_5 + 20 lb of N + Azotobacter R per acre

INFERENCE

Treatments 11 and 12 which include 20 lb of nitrogen as sulphate of ammonia and *Azotobacter* treatment gave yields which did not significantly differ from that obtained from treatment 10 containing 40 lb of nitrogen as sulphate of ammonia per acre which is a locally recommended dose, thus showing the advantage of using *Azotobacter* to conserve nitrogenous fertilizers.

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DISCUSSION

C. T. Abichandani: Some years back it was reported from Arizona desert that a strain of blue green algae was isolated from the soil crust. Has any work on these lines been done in India ?

W. V. B. Sundara Rao: The work in Arizona indicated that algae in desert do not fix much nitrogen and as such are not of much importance in nitrogen economy of soil.

A. R. Zafar: Is it possible in your opinion to introduce algae to the soils to improve their fertility ?

W. V. B. Sundara Rao: Work carried out at Calcutta, Hyderabad and Banaras suggests that it is possible to introduce algae.

H. Nath: Has any work been carried out on the microbial population of soils of different parts of the arid zone, their seasonal variation and the tolerance limits with respect to temperature and humidity ?

W. V. B. Sundara Rao: Not much work on this aspect has been done in India. It has been planned to start this work at the Indian Agricultural Research Institute, New Delhi.

M. R. Narayanan: Since the present trend of research is to use more and more saline water for irrigation purposes, may I know the level of salinity of irrigation water that affects seriously the microbial population of the soils ?

W. V. B. Sundara Rao: In general for most of the micro-organisms the level of tolerance of salinity is higher than that of higher plants. However, strains that tolerate high level of salinity can be developed for specific needs.

FOREST SOILS OF THE ARID AND SEMI-ARID REGIONS OF INDIA[1]

by

I. M. Qureshi[2] & J. S. P. Yadav[3]

INTRODUCTION

The dry zone covers about two-fifths of the entire country and comprises the whole of Rajasthan and Delhi States, plains of Punjab, plain districts of Uttar Pradesh towards the west of the Ganges river, north-western portion of Madhya Pradesh, parts of Gujarat, Maharashtra, Andhra Pradesh, Mysore and Madras. The rainfall in this zone is very scanty, irregular and erratic and concentrated in a short period. The average annual rainfall in parts of Rajasthan remains below 375 mm and is at places as low as 50 mm. According to the All India Dry Zone Afforestation Symposium (1959) the areas having rainfall below 875 mm (35 in.) were included in the dry zone. Tamhane *et al.* (1959) included the community project areas having NSQ less than 200 in semi-arid and arid regions. Thornthwaite's (1948) two types (1) 'Dd' (semi-arid) and (2) 'Ed' (arid) with little or no water surplus cover most of the dry zone, while Shanbhag (1958) suggested that 'effective growth indices' between 0 and 20 indicate arid and those between 20 and 40 indicate semi-arid climate.

Geology and soils: The soils of arid zone have been developed from a variety of geological rocks under different topographic, hydrological and climatic variations and thus differ significantly in their physical and chemical properties. The geological formations vary from trap in the Deccan plateau to alluvium in the Indo-Gangetic plain in addition to metamorphic rcok like gneiss. According to the Report of the Committee on Natural Resources, Planning Commission (1963), the approximate area covered by important soils in the arid zone is as follows:

		Million acres
1.	Highly calcareous alluvial soils	22
2.	Alluvial soils affected by salinity and alkalinity	17
3.	Desert soils	36
4.	Black soils affected by salinity and alkalinity.	17
5.	Mixed red and black soils	26
6.	Red and yellow soils	44
7.	Grey and brown soils	9
8.	Skeletal soils	6

The characteristics of a few important soil groups were described in detail by Yadav (1960).

In general, the soils of dry zone have higher *p*H values, greater concentration of bases, lower amount of organic matter and nitrogen, incomplete leaching, ill-defined profile development and accumulation of lime at some depth in the profile. Many soils are affected by salinity and alkali which are injurious to plant life. In parts of Saurashtra and Kutch salty winds aggravate the adverse effect of prevalent aridity. In several areas the sand dunes cover the alluvial soils, thereby making the ground undulating. Topographically, the soils vary from being coarse, *murrumy*, stony, poor and shallow on the hill tops and slopes to deep, fine-textured and fertile alluvial soils in the sheltered valleys, flat low lands and river basins. The menace of runoff and erosion is conspicuously accelerated on account of deficient humus in soil, short duration of rainfall, sparse vegetation, uncontrolled grazing and burning, faulty cultivation and such other factors. There are vast stretches of land where the top soil has been washed away almost completely and the residual mass either consists of dry loose stones and gravels with partly disintegrated blocks of rock or is dominated by the solid rock outcrops and exposed lateritic or other hard pans. Also, wind erosion assumes high magnitude especially in Rajasthan.

Vegetation: Wide variations occur in the nature and composition of natural vegetation from one region to another. The scanty rainfall, extremes of temperature, hot winds, low relative humidity, unfavourable soil conditions and severe biotic influences are important factors which limit plant growth. Biotic factors bring about retrogerssion resulting in several degraded types of vegetation. In general, the forest growth is very sparse, stunted, malformed and xeric in character. According to Champion's classification (1936) the following forest types are of common occurrence in the dry zone:

1. Southern tropical dry deciduous forests including dry teak and dry mixed deciduous forests.
2. Northern tropical dry deciduous forests including dry mixed deciduous forests.
3. Southern tropical thorn forests.
4. Northern tropical thorn forests including *Acacia* scrub.

Besides, certain edaphic types of *Hardwickia binata, Boswellia serrata, Butea monosperma, Anogeissus pendula, Babul* and Gangetic saline scrub are also found

1. Contribution from the Forest Research Institute, Dehra Dun.
2. Director of Forestry Research.
3. Senior Research Officer (Soils).

on extensive areas. The edaphic conditions appear to play an important role in governing the flora of different localities. *Hardwickia binata* is a characteristic species of some of the arid tracts in Maharashtra, Madhya Pradesh, Madras, Mysore, Andhra Pradesh and is confined mostly to the Deccan peninsula on shallow, poor, *murrumy* and dry soils derived from trap where it is gregarious. It attains best growth on sandstone, conglomerate, quartzite, granite and schist, with an overlying soil of sandy loam texture. The capacity to subsist on dry soils is due to the characteristically long tap-root through which the species is able to penetrate even deep fissures in rocks, etc. The seedlings may continue to die back for a number of years before a vigorous shoot is put up by the growing tap-root. *Boswellia serrata* is another typical species which thrives in dry climate, on poor rocky substrata and dry hill ridges. In Maharashtra, Madhya Pradesh, and other parts of peninsular India, it is found on hotter slopes and ridges of hills, usually on trap, and sometimes on gneiss and schist, in association with *Sterculia urens, Anogeissus latifolia, Odina wodier, Acacia catechu,* and some other species, and sometimes with *Hardwickia binata* or stunted teak. *Butea monosperma* mainly occurs on stiff ill-drained clayey soils and black cotton soils. Saline alkali soils bear widely scattered growth of *Acacia arabica, Butea monosperma, Capparis* spp., *Prosopis* spp., *Salvadora oleoides* etc., while the ravines have *Acacia* spp., *Azadirachta indica, Adhatoda vasica, Capparis* spp., *Prosopis spicigera, Zizyphus* spp., etc.

Other characteristic species of the arid zone are: *Trees: Acacia senegal* (Kutch and Rajasthan), *Prosopis spicigera, Buchanania latifolia, Albizzia amara, Acacia leucophloea, A. jacquemontii, A. latronum, Melia azadirachta, Salvadora oleoides, S. persica, Tamarix articulata* (syn. *T. aphylla*), *Tecomella undulata, Zizyphus* spp., *Balanites roxburghii, Chloroxylon swietenia* (Badami Bijapur), *Ficus asperrima, Acacia modesta* (Punjab.)

Herbs and shrubs: Aerva tomentosa, Adhatoda vesica, Calotropis procera, Capparis aphylla, C. horrida, Carissa spinarum, Dodonaea viscosa, Euphorbia nivulia, Grewia populifolia, Indigofera spp., *Suaeda fructicosa, Tamarix dioica, Tephrosia purpurea, Zizyphus rotundifolia, Z. nummularia, Nyctanthes arbortristis, Balsamodendron mukul, Ipomoea biloba, Cassia auriculata, Dichrostachys cinerea, Gymnosporia montanna, Salsola* (saline soils), *Calligonum polygonoides* (sandy soils).

Grasses: Aristida spp., *Cenchrus ciliaris, Chloris, montana, Chrysopogon montanus, Cymbopogon* spp., *Desmostachya bipinnata, Dichanthium annulatum, Elionurus hirsutus, Eragrostis* spp., *Heteropogon contortus, Panicum antidotale, Saccharum munja, S. spontaneum, Sporobolus* spp.

A proper understanding of the nature and properties of the different soils found in the arid zone is, therefore, essential for a precise appraisal of their fertility status and for deciding the measures which should be adopted for their amelioration and greater production. Studies on some important forest soils occurring in the dry zone are reported in the present paper.

Methods: A large number of soil profiles occurring in the dry regions of India were examined during the Dry Zone Afforestation Study Tour and were classified on the twin basis of surface topography and underlying rock formation (Seth, 1960). These classes were further characterized by the morphological features of the soil profile including the nature and depth of top and subsoils, absence or presence of concretions or pans, occurrence of fine clay, etc. The analytical data of a few saline alkali soils of these profiles were discussed earlier by Khan and Yadav (1962).

An assortment of ten important profiles, from those taken in the Dry Zone Afforestation Study Tour, covering a wide range of conditions of topography, geology, rainfall, water-table, drainage, soil and vegetation was made for the present investigation. The soils were analysed for different physical and chemical properties employing the standard methods described by Wright (1934) and Piper (1944). Available phosphorus and exchangeable manganese were estimated colorimetrically by the use of stannous chloride-ammonium molybdate blue method and periodate method respectively. Cation exchange capacity was determined by normal neutral ammonium acetate method; whereas exchangeable calcium and magnesium were estimated in the leachates of ammonium acetate solution in the case of non-calcareous soils and in the leachates of normal sodium chloride solution in the case of calcareous soils.

RESULTS AND DISCUSSION

Information about the location and site features of the soil profiles studied are given in Table 1.

It will be seen that the profiles are widely distributed covering several states of the country and are developed from a variety of geological formations under low annual rainfall ranging from approximately 300 mm to 820 mm with varying drainage status. Profile 9 of Chaugaon (Uttar Pradesh) is characterized by the occurrence of hard impervious *Kankar pan* at a depth of 60 cm which interferes seriously with internal drainage and acts as physical barrier to the root development. The soils occupy different topographic situations varying from alluvial plain to plateau and hilly areas. The ground water-table varies considerably being shallow to very deep. These significant differences have resulted in the formation of divergent soils of varying depth and represent several soil groups encountered in the country. Broadly speaking, deciduous and thorn forests in many degraded forms are of major occurrence and comprise the following flora in different localities.

1. Sahibnagar (A.P.): Mainly open grassland with sporadic *Acacia leucophloea, Anona squamosa, Butea monosperma, Calotropis gigantea, Cassia auriculata, C. fistula, Cymbopogon martini,*

TABLE 1: Location and site features of soil profiles

Profile No.	*State*	*Forest Division*	*Locality*	*Altitude (metres) approx.*	*Topography*	*Rainfall (mm) approx.*	*Water-table (metres)*	*Geology*	*Drainage*	*Soil group*	*Soil depth (cm)*	*Forest vegetation*
1	A.P.	Hyderabad	Sahib-nagar	518	Plateau, un-dulating	766	21	Granitic gneiss	Rapid	Bouldery red	15	Dry deciduous
2	A.P.	Tandur	Shamshul-lapur	670	Plateau, flat	800	13	Gneissic granite	Medium	Lateritic	23	Dry deciduous
3	Mysore	Chitaldrug	Anaboor	701	Plateau, low	460	22	Gneiss	Rapid	Red	45	Scrub forest
4	Maharashtra	Poona	Yadasi	671	Flat upland	550	16	Trap	Medium	Black	60	Thorn forest
5	Gujarat	Banas-kantha	Veraghanta	305	Plateau	500	Shallow	Sandstone	Slow	Red	48	Degraded scrub
6	Rajasthan	Jodhpur	Johr-Bir	223	Flat, low land	300	85	Aeolian sand	Rapid	Desert	Deep	Dry deciduous
7	Rajasthan	Jaipur	Digota	320	Flat, undulating	600	Shallow	Alluvium	Medium	Saline alkali	Deep	Dry deciduous
8	Punjab	Hissar	Nimbi-Dalaut	250	Plain, undulating	300	30	Aeolian sand	Rapid	Desert	Deep	Dry deciduous
9	U.P.	Vrajbhumi	Chaugaon	169	Plain, upland	795	20	Alluvium	Slow	Alluvial with *kankar* pan	Deep	Thorn forest
10	M.P.	Gwalior	Nurabad	153	Gullied	820	7	Sandstone shale	Excessive	Ravine with *kankar* nodules	Deep	Thorn forest

Eragrostis flexuosa, Euphorbia spp., *Heteropogon contortus, Jatropha glandulifera, Randia dumetorum,* etc.

2. Shamshullapur (A.P.): *Acacia sundra, A. concinna, Azadirachta indica, Cassia siamea, Dodonea* spp., *Diospyros melanoxylon, Randia* spp., *Santalum album, Zizyphus* spp. and grasses.
3. Anaboor (Mysore): *Acacia catechu, Cassia auriculata, Dodonea, Hardwickia binata, Melia* spp., *Tamarindus indica, Zizyphus* spp. and spear grass.
4. Yadasi (Maharashtra): *Azadirachta indica, Andropogon* spp., *Bridelia stipularis, Zizyphus jujuba,* etc.
5. Veraghanta (Gujarat): *Acacia catechu, A. arabica, Anogeissus latifolia, Butea monosperma, Cassia auriculata, C. tora, Mitrogyna parvifolia, Prosopis juliflora, Zizyphys jujuba* and low quality grasses.
6. Johr-Bir (Rajasthan): *Aristida* spp., *Cenchrus ciliaris, Prosopis juliflora, Salvadora* spp., *Zizyphus nummularia,* etc.
7. Digota (Rajasthan): *Acacia leucophloea, A. senegal, Anogeissus latifolia, A. pendula, Boswellia serrata, Euphorbia* spp., *Holoptelea integrifolia, Zizyphus* spp., etc.
8. Nimbi-Dalaut (Punjab): *Artemisia* spp., *Azadirachta indica, Calotropis procera, Capparis aphylla, Calligonum polygonoides, Leptadenia spartium, Prosopis spicigera, Saccharum munja, S. spontoneum, Zizyphus* spp., etc.
9. Chaugaon (U.P.): *Acacia arabica, A. leucophloea, Capparis aphylla, Cenchrus ciliaris, Dichanthium annulatum, Prosopis spicigera,* etc.
10. Nurabad (M.P.): *Acacia catechu, A. leucophloea, Balanites roxburghii, Capparis horrida, C. aphylla, Cassia tora, Clerodendron phlomoides, Dichanthium annulatum, Desmostachya bipinnata, Dichrostachys cinerea, Eragrostis tenella, Indigofera* spp., *Lantana* spp., *Prosopis spicigera, Salvadora oleoides, Zizyphus rotundifolia.*

Mechanical and physical properties of soils: A perusal of Table 2 indicates that the soils vary in texture from sand to clay, in maximum water-holding capacity from 27·7 to 83·3 per cent and in moisture equivalent from 6·7 to 45·4 per cent and are able to retain 0·1 - 10·6 per cent moisture at air-dry condition. With the exception of lateritic and black soils, sand appears to be the predominant fraction of the soil mass. The black soil of profile 4 has the highest moisture retentive capacity owing to greater fine fraction and preponderance of montmorillonite clay mineral, but high values of wilting coefficient will reduce the range of its available moisture. Relatively higher moisture constants in the lateritic soil of profile 2 are due to greater amounts of both clay and organic matter. The desert sands show the lowest values of moisture constants. In general, these soils possess fair to moderate water-holding power, but the situation is worsened on account of appreciable quantities of gravels, stones, etc., (>2 mm mass) present in moist soils. Besides, low rainfall coupled with high temperature further restricts moisture availability. The soils of profiles 1, 2, 3 and 8 are non-calcareous, while those of the remaining profiles display varying intensity of calcareousness. Out of the latter only profiles 6, 7 and 9 are calcareous throughout the depth.

Chemical characteristics of soils: The general chemical characteristics of the profiles are assembled in Table 3.

A critical study of which reveals that although the *p*H values lie in a wide range from 4·8 to 9·5, most soils have alkaline reaction due to the presence of either free calcium carbonate or exchangeable sodium in the colloidal complex. Fairly strong acidic values are noticeable only in the red and lateritic soils which are subjected to greater leaching. Majority of the soils have poor status of organic matter and nitrogen excepting the lateritic soil of profile 2. The organic matter content is generally below 0·5 per cent, but it has gone as high as 4·026 per cent at the surface of profile 2. Usually the amount of nitrogen decreases with the depth. A low level of organic matter and nitrogen in the soils of arid and semi-arid regions of India was also noted by Mutatkar and Raychaudhuri (1959). Though the individual values of organic matter and nitrogen are generally low, C/N ratio varies considerably ranging from 1·9 to 34·6 and does not follow any consistent trend with the depth. The amount of available P & K is in general low and is particularly deficient in the calcareous and alkaline soils, desert sands and ravine lands. In calcareous and alkaline soils a major portion of phosphorus exists in the form of hydroxy apatite, chlorapatite and the like (Hibbard, 1931). Low P-availability in alkaline soils was also observed by Raychaudhuri and Landey (1960) and Yadav and Pathak (1963). Comparatively, the lateritic and red soils with acidic *p*H values have manifested greater availability. This observation is in conformity with the findings of Yadav and Pathak (1963). The studies of Tamhane *et al.* (1959) showed that the community project areas in the arid and semi-arid areas have low to medium available nitrogen, medium available phosphorus and potassium and low organic carbon status.

The cation exchange capacity is low to moderate except in black soil which has distinctly greater value (61 m.e. per cent) due mainly to the abundance of montmorillonite clay mineral. Despite the maximum content of clay the lateritic soil of profile 2 has only moderate capacity like other profiles which possess much less clay. This differential behaviour may be attributed to the predominance of kaolinite clay mineral in the lateritic soil. Relatively lower cation exchange capacity of the remaining soils is due to greater proportion of sand, deficient organic matter and possible occurrence of kaolinite or illite type of clay mineral. Kanwar (1961) observed that illite and chlorite are the two dominant clay minerals in

TABLE 2 : Mechanical composition and physical properties of soil profiles

Profile No.	State	Depth (cm)	Fractions of soil mass		Mechanical composition of 2 mm soil mass				Textural class *	Air-oven dry moisture %	Water-holding capacity %	Moisture equivalent %	Calcareousness **
			>2 mm %	<2 mm %	CS %	FS %	Silt %	Clay %					
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Andhra Pradesh	0-13	12·3	87·7	64·0	24·0	2·5	7·5	S	0·3	28·9	6·7	0
		13-127	18·9	81·1	46·8	17·9	2·5	25·0	SCL	1·2	50·0	17·9	0
		127-183	15·1	84·9	54·7	22·9	7·5	7·5	LS	0·6	37·0	12·2	0
2	Andhra Pradesh	0-13	32·8	67·2	27·0	9·9	10·0	45·0	C	1·9	54·4	22·4	0
		13-23	19·6	80·4	27·7	7·9	7·5	50·0	C	2·2	59·0	26·8	0
		23-61	26·2	73·8	25·3	6·3	5·0	57·5	C	2·0	64·2	27·1	0
		61-122	31·5	68·5	24·5	3·9	7·5	60·0	C	4·6	63·9	28·7	0
		122-183	55·9	44·1	23·3	7·3	7·5	57·5	C	2·0	65·0	30·8	0
		183-213	34·2	65·8	26·1	12·3	7·5	45·0	C	6·7	61·4	30·2	0
3	Mysore	0-46	7·5	92·5	31·7	30·2	17·5	15·0	SL	2·6	37·9	22·4	0
		46-97	23·8	76·2	23·6	23·8	17·5	27·5	SCL	3·6	44·5	15·1	0
		97-168	18·5	81·5	34·7	43·5	10·0	11·8	SL	2·8	34·6	21·2	0
4	Maharashtra	0-20	11·0	89·0	8·9	31·1	30·0	25·0	L	6·9	58·0	41·0	0
		20-61	10·2	89·8	14·7	19·7	22·5	30·0	CL	8·3	66·4	43·7	+
		61-183	24·3	75·7	12·0	14·7	12·5	47·5	C	10·6	83·3	45·4	++
5	Gujarat	0-8	8·8	91·2	15·8	55·4	15·0	12·5	SL	0·5	34·5	19·6	0
		8-48	32·0	68·0	35·8	44·7	5·0	12·5	SL	0·6	36·8	21·7	0
		48-91	32·7	67·3	40·5	44·1	5·0	10·0	LS	0·7	33·9	12·2	0
		91-147	21·9	78·1	31·5	52·5	2·5	10·0	LS	0·8	35·0	15·9	0
		147-183	19·7	80·3	33·4	46·7	2·5	10·0	LS	0·7	37·5	23·4	+++
6	Rajasthan	0-10	0·0	100·0	34·4	52·0	5·0	7·5	LS	0·9	27·7	20·1	+
		10-91	1·0	99·0	25·0	53·9	7·5	10·0	LS	1·7	35·5	19·3	+
		91-132	18·3	81·7	21·5	52·2	2·5	10·0	LS	1·9	37·9	11·7	++
		132-183	11·3	88·7	23·2	49·7	2·5	10·0	LS	1·6	37·3	17·2	+
7	Rajasthan	0-10	3·3	96·7	25·8	47·8	5·0	10·0	LS	2·3	35·8	16·4	+
		10-41	11·1	88·9	14·4	43·9	5·0	15·0	SL	2·4	63·2	28·2	++
		41-76	0·8	99·2	15·2	24·3	5·0	12·5	SL	1·9	50·6	27·3	+++
		76+	58·1	41·9	18·5	18·3	5·0	10·0	LS	0·9	74·9	22·1	+++
8	Punjab	0-8	0·0	100·0	8·8	83·5	2·5	5·0	S	0·1	28·8	17·9	0
		8-23	0·0	100·0	8·6	80·5	2·5	7·5	S	0·3	31·5	9·8	0
		23-183	0·0	100·0	9·3	81·2	2·5	5·0	S	0·2	29·9	9·0	0
9	Uttar Pradesh	0-15	20·5	79·5	0·7	62·7	12·5	10·0	SL	0·8	39·7	23·5	++
		15-61	17·6	82·4	0·2	65·7	10·0	10·0	SL	1·4	43·6	16·3	++
		61-130	14·7	85·3	0·5	33·3	20·0	20·0	SCL	1·5	52·1	30·8	+++
		130-183	0·0	100·0	0·6	70·1	5·0	5·0	S	0·1	34·1	23·5	++
10	Madhya Pradesh	0-18	1·5	98·5	9·7	65·4	7·5	15·0	SL	0·5	41·6	16·9	0
		18-76	0·0	100·0	2·5	51·0	20·0	20·0	SCL	1·7	51·5	23·6	0
		76-122	23·5	76·5	1·0	48·0	12·5	20·0	SL	1·5	52·7	25·6	++
		122-183	25·7	74·3	1·0	48·6	10·0	17·5	SL	1·7	49·9	22·3	+++

*S=sand, LS=loamy sand, SL=sandy loam, SCL=sandy clay loam, L=loam, CL=clay loam, C=clay.
**0=nil, +=slight, ++=moderate, +++=high.

TABLE 3 : General chemical characteristics of soil profiles

Pro-file No.	State	Depth (cm)	pH	Organic matter %	Nitrogen %	C/N ratio	Cation ex-change capacity m.e. %	Exchangeable cations			Available	
								Ca m.e. %	Mg m.e. %	Mn p.p.m. %	P_2O_5 %	K_2O %
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Andhra Pradesh	0-13	5·6	0·896	0·025	20·8	12·4	7·2	0·4	10	0·0074	0·037
		13-127	5·3	0·931	0·021	25·7	13·7	11·6	0·4	14	0·0074	0·022
		127-183	6·0	0·207	0·015	8·0	15·5	13·6	0·6	6	0·0099	0·014
2	Andhra Pradesh	0-13	5·2	4·206	0·123	19·8	15·4	10·4	0·6	192	0·0099	0·014
		13-23	4·8	3·482	0·005	19·2	15·9	11·0	0·8	210	0·0075	0·034
		23-61	5·3	1·483	0·068	12·6	16·6	11·8	0·8	42	0·0099	0·019
		61-122	5·1	2·310	0·098	13·7	21·6	15·8	0·6	98	0·0099	0·014
		122-183	5·5	0·896	0·056	9·3	14·4	10·6	1·0	40	0·0087	0·024
		183-213	6·3	0·655	0·043	8·8	14·3	11·8	1·2	12	0·0060	0·003
3	Mysore	0-46	6·5	1·370	0·039	20·2	31·9	7·6	0·6	11	0·0111	0·011
		46-97	6·9	1·485	0·056	15·3	22·2	10·5	1·0	12	0·0124	0·011
		97-168	7·2	0·517	0·009	34·6	16·2	12·8	1·2	10	0·0099	0·009
4	Maharashtra	0-20	7·0	2·184	0·074	17·1	44·7	38·2	0·4	14	0·0010	0·048
		20-61	7·6	1·561	0·049	19·1	52·3	29·0	2·2	4	0·0049	0·023
		61-183	7·7	0·827	0·038	12·7	61·0	33·4	2·6	2	0·0049	0·034
5	Gujarat	0-8	6·8	0·517	0·043	7·1	11·0	6·8	0·6	6	0·0012	0·020
		8-48	7·0	0·246	0·061	1·9	12·3	8·6	1·2	6	0·0015	0·026
		48-91	7·2	0·172	0·046	2·2	12·0	9·0	1·4	6	0·0015	0·011
		91-147	7·4	0·138	0·006	5·0	13·0	8·4	1·8	8	0·0017	0·023
		147-183	7·7	0·138	0·023	3·5	6·7	4·8	0·8	11	0·0040	0·028
6	Rajasthan	0-10	7·8	0·138	0·018	4·4	12·6	7·6	1·8	14	0·0098	0·014
		10-91	7·9	0·378	0·022	10·0	17·5	5·8	0·8	6	0·0057	0·014
		91-132	7·9	0·069	0·099	2·1	17·1	5·0	1·2	6	0·0042	0·039
		132-183	7·9	0·137	0·015	5·3	16·7	3·6	0·6	6	0·0016	0·045
7	Rajasthan	0-10	9·5	0·206	0·028	4·3	11·0	3·4	0·4	10	0·0042	0·008
		10-41	9·3	0·068	0·014	2·8	19·2	3·4	0·2	11	0·0009	0·011
		41-76	9·2	0·215	0·011	14·5	16·8	3·8	0·4	8	0·0006	0·017
		76+	9·1	0·206	0·014	8·5	15·1	5·0	1·0	10	0·0003	0·011
8	Punjab	0-8	6·9	0·206	0·017	7·1	13·4	5·0	0·2	6	0·0022	0·017
		8-23	6·8	0·206	0·019	6·3	10·3	5·6	0·4	10	0·0004	0·006
		23-183	6·8	0·206	0·009	13·3	9·0	4·4	0·2	6	0·0009	0·011
9	Uttar Pradesh	0-15	7·8	0·412	0·055	4·0	16·3	7·2	0·6	18	0·0023	0·014
		15-61	8·1	0·172	0·022	4·5	15·4	7·2	0·6	16	0·0015	0·014
		61-130	8·3	0·137	0·032	2·5	14·2	8·0	0·8	16	0·0019	0·011
		130-183	8·5	0·069	0·005	8·0	12·1	3·8	0·6	16	0·0038	0·008
10	Madhya Pradesh	0-18	6·9	0·310	0·050	3·6	21·9	8·4	0·6	6	0·0018	0·028
		18-76	7·4	0·241	0·038	3·7	40·6	21·8	1·2	10	0·0001	0·034
		76-122	8·3	0·172	0·025	4·0	15·0	11·4	1·0	6	0·0001	0·020
		122-183	7·9	0·172	0·037	2·7	14·2	9·8	1·0	6	0·0004	0·016

Punjab soils, but illite is more prominent in saline-alkali soils. The amount of exchangeable calcium varies from 3·4 to 38·2 m.e. per cent and occupies on the whole more than 50 per cent of cation exchange capacity. The black soil contains the highest amount of this cation about 85 per cent of the exchange capacity. The concentration of exchangeable magnesium is comparatively lower lying in the range of 0·2 - 2·6 m.e. per cent. Almost all soils are poorly supplied with exchangeable manganese excepting the lateritic soil where an amount of about 200 p.p.m. was recorded in the top layers presumably due to its ferruginous nature, acidic reaction and better vegetative cover. The calcareous and alkaline nature of most soils seems to be responsible for their lower manganese status (Yadav and Kalra, 1964).

As profiles 1 and 2 have negligible salt content, analytical data of water extracts of only eight profiles (3-10) are set out in Table 4 which demonstrates that the hightest concentration of soluble salts is present in profile 7 (Rajasthan), giving a value of 1·162 per cent in the surface layer. Profile 6 of Rajasthan also possesses soluble salts in toxic quantities. Profile 5 (Gujarat) contains soluble salts below the injurious limit in the upper 91 cm zone but is heavily infested in the lower depths. Similarly, the lowest depth of profile 8 (Punjab) also contains excessive amount of soluble salts. The high salinity in the subsoil may have a detrimental effect on the growth of deep-rooted species. The soluble salt content in the remaining soils is at or approaching closely the level of harmful limit (0·15 per cent) and may create problem of salinity in future if suitable measures are not adopted to prevent further accumulation. The carbonate ions are almost absent except in profile 7, which shows high soil alkalinity. The quantity of sulphate ions is appreciably high throughout the depth in profile 6 of Rajasthan. However, in general, the salts consist of biocarbonate, chloride and sulphate anions. Agarwal and Yadav (1954) had reported

TABLE 4: Analysis of water extracts of soil profiles

Profile No.	*State*	*Depth (cm)*	*Total salts %*	*CO_3 %*	*HCO_3 %*	*Cl %*	*SO_4 %*
3	Mysore	0-46	0·078	Nil	0·026	0·018	0·011
		46-97	0·270	Nil	0·076	0·014	0·080
		97-168	0·127	Nil	0·025	0·024	0·017
4	Maharashtra	0-20	0·122	Nil	0·051	0·031	0·016
		20-61	0·162	Nil	0·050	0·045	0·047
		61-183	0·169	Tr.	0·057	0·009	0·012
5	Gujarat	0-8	0·11	Nil	0·045	0·015	0·012
		8-48	0·094	Nil	0·038	0·031	0·009
		48-91	0·140	Nil	0·034	0·014	0·066
		91-147	0·423	Tr.	0·018	0·019	0·120
		147-183	0·523	Tr.	0·036	0·020	0·128
6	Rajasthan	0-10	0·464	Tr.	0·038	0·177	0·178
		10-91	0·756	Tr.	0·040	0·009	0·170
		91-132	0·404	Tr.	0·036	0·006	0·251
		132-183	0·480	Tr.	0·038	0·006	0·112
7	Rajasthan	0-10	1·162	0·022	0·275	0·334	0·254
		10-41	0·598	0·041	0·131	0·162	0·051
		41-76	0·296	0·012	0·156	0·048	0·066
		>76	0·246	0·008	0·043	0·176	0·021
8	Punjab	0-8	0·110	Nil	0·023	0·018	0·024
		8-23	0·116	Nil	0·045	0·014	0·006
		23-183	0·580	Nil	0·036	0·013	0·240
9	Uttar Pradesh	0-15	0·154	Tr.	0·055	0·017	0·021
		15-61	0·128	Tr.	0·046	0·011	0·024
		61-130	0·114	Tr.	0·050	0·017	0·021
		130-183	0·130	Tr.	0·038	0·017	0·060
10	Madhya Pradesh	0-18	0·130	Nil	0·030	0·011	0·065
		18-76	0·150	Nil	0·059	0·014	0·012
		76-122	0·110	Tr.	0·052	0·010	0·002
		122-183	0·200	Tr.	0·053	0·015	0·054

Tr.= traces.

that the salts in the saline alkali soils of Uttar Pradesh are dominated by carbonate and chloride anions.

The analytical data of HCl extracts are presented in Table 5 which indicates appreciably high amount of HCl insoluble except in lateritic and black soils. The amount of HCl soluble iron oxide is somewhat low except in the lateritic soil where a value of 14·5 per cent was observed. On an average, the concentration of aluminium oxide is relatively higher except in profiles 1 and 8 which are readily prone to leaching. The quantities of calcium are in general high especially in the calcareous soils where the value has gone as high as 12·9 per cent, while the content of magnesium is variable. The status of HCl soluble phosphorus is moderate, but the lateritic soil has relatively higher amount owing to greater retention of the element by iron. Gupta (1958) and Yadav and Pathak (1963) found that the quantities of phosphorus in the desert soils compare favourably with some of the normal alluvial soils. Almost all soils are adequately supplied with potassium reserve. No definite trend in the distribution of the elements with the depth of the profile is discernible. The data reveal that despite fair native reserve of phosphorus and

TABLE 5: Analysis of HCl extracts of soil profiles

Profile No.	*State*	*Depth (cm)*	*HCl insolubles* %	*HCl solubles*					
				Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	P_2O_5 %	K_2O %
1	Andhra Pradesh	0-13	93·2	1·8	2·9	0·588	0·061	0·040	0·107
		13-127	82·6	2·6	3·3	0·280	0·020	0·043	0·307
		127-183	80·2	4·0	0·6	0·784	0·061	0·055	0·415
2	Andhra Pradesh	0-13	70·1	9·3	7·7	0·336	0·141	0·123	0·315
		13-23	72·2	5·0	2·8	0·672	0·040	0·250	0·324
		23-61	72·6	7·7	8·3	0·336	0·040	0·102	0·307
		61-122	73·5	10·1	5·1	0·532	0·020	0·090	0·373
		122-183	73·7	14·5	7·2	0·644	0·020	0·096	0·332
		183-213	75·2	9·3	2·9	0·644	0·081	0·121	0·224
3	Mysore	0-46	82·6	3·0	10·6	0·196	0·202	0·050	0·271
		46-97	78·8	5·4	12·3	0·252	0·121	0·053	0·242
		97-168	82·5	6·7	5·9	0·420	0·101	0·034	0·185
4	Maharashtra	0-20	69·0	7·8	12·6	0·840	0·184	0·058	0·350
		20-61	62·6	9·7	16·3	1·372	0·202	0·049	0·185
		61-183	61·7	6·2	18·6	1·120	0·061	0·065	0·285
5	Gujarat	0-8	89·6	2·7	7·6	1·120	0·121	0·104	0·114
		8-48	90·5	2·6	3·7	1·428	0·222	0·077	0·156
		48-91	92·2	2·2	3·2	1·428	0·081	0·110	0·118
		91-147	90·5	2·5	10·2	1·456	0·675	0·065	0·085
		147-183	75·6	2·5	3·3	5·384	0·514	0·074	0·092
6	Rajasthan	0-10	93·2	2·7	1·3	0·756	0·040	0·049	0·293
		10-91	86·3	3·5	5·3	2·240	0·020	0·046	0·207
		91-132	86·7	2·4	3·7	4·228	0·020	0·065	0·257
		132-183	83·3	3·8	2·2	5·068	0·061	0·040	0·495
7	Rajasthan	0-10	86·9	2·7	3·5	1·960	0·141	0·031	0·357
		10-14	77·5	4·2	6·1	5·292	0·161	0·034	0·386
		41-76	62·2	3·2	18·2	9·660	0·504	0·049	0·350
		>76	44·9	4·0	26·9	12·908	0·282	0·056	0·214
8	Punjab	0-8	94·7	1·8	2·3	0·616	0·040	0·083	0·350
		8-23	92·9	2·1	3·3	0·672	0·020	0·071	0·300
		23-183	94·1	1·4	3·6	0·476	0·020	0·056	0·293
9	Uttar Pradesh	0-15	84·7	3·5	5·5	4·536	0·061	0·071	0·648
		15-61	80·7	3·2	11·9	2·212	0·020	0·077	1·616
		61-130	72·4	2·7	18·9	4·976	0·020	0·090	1·647
		130-183	84·5	2·6	10·7	3·752	0·040	0·065	0·854
10	Madhya Pradesh	0-18	90·0	4·3	7·1	0·031	0·363	0·046	0·379
		18-76	83·0	3·7	6·6	0·757	0·887	0·195	0·350
		76-122	75·0	4·2	9·5	0·393	0·544	0·151	0·466
		122-183	88·0	3·5	7·4	5·684	0·423	0·207	0·258

potassium, their percentage availability is rather low. The lesser percentage of K-availability may be due to the presence of unweathered primary minerals. Kanwar and Grewal (1960) ascribed low availability of phosphorus to its greater fixation and observed positive response to fertilizer application in the alkaline and calcareous soil of Punjab.

CONCLUSION

The results of the investigation show that the soils of dry regions differ considerably in their properties and present varied problems of immense economic value from both agricultural and forestry stand-points in view of their poor physical condition, unfavourable morphological features including indurated pans, calcareous nature, deficient moisture supply, alkaline reaction, high salt concentration, low level of organic matter and nitrogen, decreased availability of phosphorus and potassium, etc. Suitable and effective measures to conserve maximum amount of rainfall, to protect the soil, to eliminate the deleterious influence of salinity and alkali, to improve fertility status, improve the existing vegetation and to afforest the barren and degraded lands are the essential prerequisites for achieving greater production.

The saline alkali soils are the most problematic and need special measures for reclamation as outlined by Khan and Yadav (1962). Adequate provision for leaching and drainage to reduce the salt content below the danger limit and addition of organic matter to improve the fertility status are necessary in saline soils. In case of alkali soils dominated by exchangeable sodium, application of suitable calcareous amendment like gypsum will be an additional requirement. Since adoption of these measures may prove costly in forestry, greater attention should be given to the use of suitable planting techniques and correct choice of species. The soils which are not affected by salinity and alkali are comparatively easier to reclaim. The chief problem in such areas is of soil and water conservation. Terracing, bunding, gully plugging, etc., may be used for checking erosion, whereas continuous or staggered trench mounds and sunken beds in undulating tracts, contour trenches on gentle slopes, pits on steep slopes, sunken mounds on deposition plain, saucer pits on flat ground and ridge-ditch or ridge-trench in saline soils may be adopted for conserving moisture. The technique of continuous contour trenching has been found to be efficient in several dry areas. The various soil working techniques for the soils of the dry zone have been suggested by Seth (1960). Besides, hardy and tolerant species with long and spreading root system should be used for planting, so that they can obtain moisture from deeper layers. Certain species like *Acacia tortilis*, *A. sieberriana*, and of Eucalyptus like *E. camaldulensis*, *E. terminalis*, *E. tesselleris*, *E. papuana*, *E. melonophloia*, *E. tereticornis* (syn. Mysore Gum or *E.* hybrid of Chickbalapur origion), *E. populnia* (syn *E. popalifolia*), *E. oleosa* and *E. rudis* have been found suitable for afforestation work.

In areas where there is indurated *kankar* or clay pan close to the surface, it may be necessary to break it by subsoiling. Certain soils containing fine clay form hard crust at the surface and need destruction of this clay seal. Stabilization of sand-dunes is another problem in the desert areas which requires large-scale concerted efforts. Moreover, addition of organic manures and inorganic fertilizers will assist in improving the physical condition and enhancing the fertility status of most soils in arid zone. Attempts should also be made to increase the availability of native reserve of potassium and phosphorus. As our existing knowledge about the characteristics, rational utilization and economic management of the soils of dry zone is very limited, further systematic research is called for on the following aspects:

1. Conduct soil surveys in the different areas for defining the various soil types and for suggesting corrective measures for each type.
2. Develop economic methods of stabilizing sands, reducing salinity and alkali, preventing erosion and improving soil structure.
3. Find out suitable species, soil working techniques and planting methods for different soils.
4. Determine nutritional requirements of tolerant species and work out fertilizer schedule for different soils.
5. Evolve methods to conserve moisture and to ensure maximum utilization of available moisture.
6. Carry out studies on trace element deficiencies, mineralogical composition and biological characteristics.

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DISCUSSION

B. B. Roy: Soil samples have been collected from areas where rainfall is up to 35 inches. All these areas cannot be considered to belong to arid climate!

J. S. P. Yadav: In connection with All India Dry Zone Afforestation Study Tour and Symposium held in 1959, areas having rainfall less than 35 inches were included in the dry zone. As such some of the soils reported in the present paper will fall in the category of semi-arid zone.

T. N. Srivastava: As a forester my experience in the arid and semi-arid areas of Rajasthan has been that if adequate water is available, these soils are very fertile though there is no organic matter in most of these soils. Is this observation correct and if so what is the reason ?

J. S. P. Yadav: There is no doubt that water is the first limiting factor. Our experience is that soils of arid areas are not as poor as they had been considered so far. Nutritional requirements of different tree species differ a great deal. Moreover, trees are capable of growth because of their deep root system.

U. S. Madan: Have soils of high level deserts in Ladakh and Spiti tracts been studied ?

D. R. Bhumbla: Some work on these soils has been done in Soils Section of the Punjab Agricultural University, Hissar.

U. S. Madan: Althouth deep-rooted plants are affected by high salinity in the subsoil but, actually, *Prosopis spicigera* does well! What is the explanation ?

J. S. P. Yadav: Salinity tolerance of different species differs. The areas where this species is doing well may not necessarily have high salinity in the subsoil or the salinity present may be below the toxic limit for this species.

R. V. Tamhane: How far are the soil classification and fertility studies useful in forestry? Has any work been done on these aspects ?

J. S. P. Yadav: Soil classification is important in forestry but so far no systematic work has been done. Soil fertility studies are in progress at the Forest Research Institute, Dehra Dun.

S. P. Chatterjee: You have given averages of different soils ? What is the basis of your classification ?

J. S. P. Yadav: The data have been taken from a report published by the Planning Commission.

T. N. Srivastava: Can the plants grow only on inorganic constituents if adequate water is supplied ? The experience in Hanumangarh, where rainfall is only about 5″ and there is no organic material in the soil, is that plants grow very well if adequate irrigation is available.

J. J. Chinoy: Yes, it is known that plants can be grown in sand culture as well as water culture in a perfectly healthy condition by providing only inorganic nutrients.

N. C. Rawal: Analysis of soil profiles for total salts, CO_3, HCO_3, Cl and SO_4 only have been reported, why other soluble salts like Ca, Mg, Na, K have not been estimated ?

J. S. P. Yadav: They have not been analysed. The analysis of acid extracts of soil profiles has been done and presented in Table 5.

GENESIS, MORPHOLOGY AND MANAGEMENT OF ARID ZONE SOILS[1]

by

C. T. ABICHANDANI[2]

INTRODUCTION

SOILS of arid zone of western Rajasthan, comprising an area of about 175,000 sq km in the west and north-west of Aravallis, have been broadly classified as desert soils (ICAR, 1953; and Yadav, 1959). Tamhane (1952) and Wadia (1960) described these soils as belonging to the whole complex of Indo-Gangetic alluvium extending from Assam to Sind. Gupta (1958) examined a large number of soils from desert area of western Rajasthan and reported that the minerological composition of the heavy residue showed a predominance of hornblende with other minerals like garnet, magnetite and limonite, tourmaline, kyanite and epidote. The lighter fraction showed predominance of quartz and some orthoclase and plagioclase. This suggests the origin of soil parent material predominently from igneous and metamorphic deposits. The geological formations in western Rajasthan consist mainly of calc-gneisses, calciphyres, limestones, mica schists, phylites, shales and quartzites on the Aravallis' slopes and rocky prominences of rhyolite, granites and sandstones outcropping in the desert region. These geological formations of different ages have been weathered, eroded, transported and deposited giving rise to different soils according to topographic situation. Abichandani and Ghose (1968) described the geomorphic evolution of land surface in western Rajasthan, predominantly due to fluvial action during the Pleistocene and Recent times. This fluvial action eroded and weathered the various geological formations, transported and deposited them over a large area giving rise to extensive alluvial plain extending from foot of Aravallis to the Rann of Kutch. Aridity set in later on and initiated the aeolian erosion cycle particularly in the west and north-west, resulting in the deposition of extensive sand-dune chains and sand sheets over the alluvial deposits.

SOIL PARENT MATERIAL

The predominant soil parent material in the arid zone of western Rajasthan is, therefore, the alluvial deposits of the Pleistocene and Recent times often reworked by later aeolian cycle, which deposited the sand-dunes and sand sheets. The aeolian cycle, however, was not continuous, but has been interrupted by fluvial action, depositing agraded stream washes over the finely graded aeolian sands. On the piedmont apron, skirting the hills, on 1-3 per cent slope coarse sediments have been deposited by sheet wash flows mostly during the recent times. The dead stream channels (Ghose, 1964) of the fluvial cycle, which later became disorganized due to onset of aridity, and depressions in old flood plain have later served as back, water-ponded areas and accumulated finer sediments. Some of these have again been covered with low dunes of recent aeolian cycle. The main river channels which continued to be active with periodic monsoon flows even after the onset of aridity, have deposited fresh alluvium deposits on river banks forming flat levee tops mostly of coarse sediments.

The main soil-forming materials in the region can thus be classed as under:

(1) Aeolian sands of recent aeolian cycle.
(2) Older alluvium deposits of Pleistocene and Recent times on less than one per cent slope.
(3) Prolluvial sheet wash deposits on piedmont apron on 1-3 per cent slope.
(4) Younger alluvium deposits along stream channels.
(5) Calcareous clays deposited in the depressions in the older alluvium deposits and in the dead river channels.

The origin of sand in the arid zone of western Rajasthan has been a subject of discussions by various workers. Wadia (1961) considered Rajasthan sands indistinguishable from the sands of seashore and remarked that these have been transported in a great measure from Rann of Kutch and in part from basin of Lower Indus. Ghosh (1952) found the sands of Rajasthan rather fine-grained and more rounded than average beach sands. Gupta (1958) considered that, although origin of desert sands may be similar, e.g. from older sea existing in the area, the sands could not have been transported from over long distances from the Arabian Sea. Ghose, 1964 (private communication) has done the microscopic examination of sands from various locations of western Rajasthan and observed that about 80-90 per cent fraction of the dune sand was sub-rounded to rounded. In the sand fractions collected from the old flood plain also about 80 per cent of the sand fraction was sub-rounded, and rounded and of similar nature as dune sand. It was only in the piedmont apron areas that 70-80 per cent of the sand fraction was angular to sub-angular. In

1. Contribution from the Central Arid Zone Research Institute, Jodhpur (Rajasthan).
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the latter case the material has been transported for a short distance only under sheet wash flows. He, therefore, considered the origin of sands of western Rajasthan mainly due to local re-working by aeolian cycle of earlier alluvial deposits.

SOILS IN RELATION TO CLIMATE

Soil is regarded as a product of interplay of environmental condition of climate, topography and vegetation on parent material. The soil cover of arid zone of western Rajasthan exhibits a strong xeromorphic character and an extremely low humus content. There is also a lack of illuvial horizon indicating the absence of any strong leaching effect. The soil thus belongs to a broad pedo-geographic unit of moderately to weakly leached soils with calcareous horizons.

The older alluvium deposits in western Rajasthan are characterized by the presence of *kankar* pans of different degrees of induration. Thick layers of powdery deposits of limestone or gypsum and pans in concretionary nodule forms are both met with at different locations. The occurrence of these pans in soils of arid and semi-arid regions of the world have been reported from various places. Gile (1961) observed the occurrence of calcareous layers as filaments or indurated horizons several feet thick in alluvial fans and desert blosoms of Dona-Ana country, New Maxico. Occurrence of lime *kankar* nodules has also been reported in the older alluvium (Kumar *et al.*, 1961) and in *Dankar* grey hydromorphic soil (Gupta *et al.*, 1957) of Indio-Gangetic alluvium. Kulik (1959) noted pea size calcareous concretions in bare hollows eroded by winds in the semi-desert zone of northern Caspian.

The occurrence of the calcareous pans and crusts show little relation to the present climate of the region, but give some evidence of the past climate after the deposition of the parent material in the Pleistocene and Recent times. Durand (1956) discussed the significance of various calcareous deposits in relation to biostasis and palaeo-climate. He considered the occurrence of thick layers of powdery deposits of limestone, gypsum and salts due to influence of forest vegetation and prevalence of hot and humid climate. The presence of concretionary form of deposit is due to onset of drier climate and breakdown of biostasis indicating a humid climate alternating with drought and promoting erosion. In western Rajasthan the concretionary type of deposits are more common in the drier and arid areas which at present have less than 300 mm of rainfall. Powdery form of deposits of limestone are met with in the semi-arid region bordering the Aravalli foot hills. Powdery forms of gypsum crusts about 10-15 cm thick indicating long dry periods are also found in depressional areas in western Rajasthan. The evidence of these crusts suggest a past hot and humid climate alternating with dry weather and followed by increasing dry weather leading to an arid cycle.

Evidence of past humid climate alternating with drought and promoting erosion is also surmised from certain buried soil profile near Siwana which possesses the following characteristics:

0-120 cm Brown to dark brown sandy loam soil, very slightly calcareous, subangular blocky structure.

120-140 cm Yellowish brown gravelly sandy loam with copious light grey mottling of calcium carbonate concretions, highly calcareous indurated zone of carbonate accumulation.

140-230 cm Brown gravelly loamy sands, very slightly calcareous; structureless.

>230 cm Highly cemented zone of carbonate accumulation with calcium carbonate concretion embedded in loamy sands.

Particle size distribution in the non-clay fraction of soil in the various horizons also suggests a complex pattern (Table 1).

TABLE 1 : Particle size distribution

Soil depth	*Percentage*				
	Clay	*Silt*	*Fine sand*	*Coarse sand*	*$CaCO_3$ %*
0-120 cm	18·0	5·5	50·0	29·3	1·2
120-140 cm	7·3	7·1	17·8	65·2	9·5
140-230 cm	6·3	3·6	6·2	83·8	1·0
>230 cm	7·4	7·1	19·2	57·5	8·0

The normal zone of carbonate deposition and accumulation in powder or in nodule form in the soils of western Rajasthan occur generally at 50 cm depth and below. The presence of two zones of carbonate accumulation in the above profile, one at 120-140 cm depth and the other below 230 cm, coupled with distribution of particle size down the depth shows a non-uniformity of the profile and also suggests the influence of the wet climate alternating with a dry climate, permitting development of two zones of carbonate accumulation at the different depths.

The present xeromorphic character of the soil in the arid zone of western Rajasthan, however, shows that the soil formation appears to have been by and large promoted under the comparatively dry climatic condition. The soils are, therefore, of recent origin, immature or with very weakly developed horizon. Because of long dry, arid spell the vegetation is very sparse and the population subsist on erratic monsoon showers for growing *Bajra*, a monsoon millet. Year round cultivation of crops exists only along the banks of main river channels, where some good quality ground water is available for irrigation. Progress in aridity in the region has thus transformed the lands into barren areas and the increase in the xeromorphic character of soil in most of the areas of the arid zone has led to a considerable depletion of the soil productivity.

MORPHOLOGICAL CHARACTERS

Aubert (1962) has described certain morphological characters of desert soils, desert steppe soils, sierozem and sub-arid brown soil of arid zone. Counterparts of some of these groups are found in the arid zone of western Rajasthan. Deposited desert soil comprising *Nebkhas* and dune chain (Durand, 1954; and Le Houerou, 1960) are widespread. Grey brown desert soils termed as desert steppe soil by Aubert are also found in the old flood plains. Morphological characters of soils found on different parent material are as under.

1. Soils formed on wind-deposited sands: In western Rajasthan sand deposits occur mainly as transverse, longitudinal and parabolic dune and sand sheets. The soils formed on the sand sheet deposits do not show any differentiating morphological characters, except for the darkish colour of the top soil and the presence of a few and scattered calcium carbonate nest and filaments along root channels at lower depths. The darkish colour of the top soil is mainly due to the accumulation of organic matter, which sometimes reaches 1·0 per cent in well-vegetated sand sheet deposits. In the comparatively dune-free area of Barmer-Bikaner tract and other similar places, the sand sheet deposits are 50-100 cm deep overlying older alluvium gritty sands and a concretionary zone of calcium carbonate accumulation. A profile from Barmer on flat to undulating topography showed the following characters:

0-23 cm Sands yellowish brown (10 YR 5/4 dry); structureless; plentiful roots; calcareous.

23-46 cm Sands yellowish brown (10 YR 5/3 dry); structureless; slightly compact layer; few roots; calcareous, lime increasing with depth.

46-66 cm Sands pale brown (10 YR 6/3 dry); structureless; few roots, calcareous; abrupt boundary.

66-110 cm Hard concretionery zone of calcium carbonate accumulation.

The sand layer up to 66 mm depth had practically the same particle size distribution with 6-7 per cent clay, 3-4 per cent silt, 75-80 per cent fine sand and 4-6 per cent coarse sand, showing a large component of wind-deposited material.

The soils formed on the sand-dunes also show almost the same characters as on the sand sheets, except that the dune profile is very deep and the material contains over 90 per cent fine sand. In a dune profile sampled up to 7 m depth, the clay content varied from 3·5 to 4·0, silt from 1 to 2, fine sand from 90 to 92 and coarses and from 3 to 7 per cent. The dune topography may be divided into the dune swale, dune flank and the dune crest. The dune swale is invariably the depositional phase and the dune flank and dune crest erosional phases.

2. Soils formed on older alluvium: These are the oldest soils of arid zone of western Rajasthan and are in many respects comparable to older soils of Indo-Gangetic alluvium. The older alluvium soils, particularly in the older flood plains of Luni and Mitri rivers, are characterized by the presence of calcareous *kankar* pans at various depths from 40 to 150 cm. Soils in the older flood plain of Jawai, however, do not show the presence of *kankar* up to 200-250 cm depth. Such soils also have comparatively more clay and silt fraction than the Luni flood plain soils and are comparable to desert steppe soil. The soil texture in the Luni flood plain varies from loamy sands to sandy clay loam, but the profile consists predominantly of loamy sand top horizon overlying sandy loam soil with *kankar* pan at 40-100 cm depth. A typical profile north of river Luni has the following characters:

0-23 cm Brown (10 YR 5/3 when dry), loamy sands, structureless, loose, very slightly calcareous, plentiful roots.

23-38 cm Brown (10 YR 5/3) sandy loam soil with tendency to form weakly sub-blocky structure, few root calcareous.

38-152 cm Concretionary zone, highly calcareous *kankar* pan, indurated.

Variations of this profile occur with a thin veneer of loamy sands over sandy loam or sandy clay loam horizon of 20-40 cm thick, the top loamy sand horizon is 50-70 cm thick and such lands give a hummocky appearance with intensity and depth of hummocks increasing with depth of loamy sand horizon. In the south of river Luni at many places, the zone of calcium carbonate accumulation is not concretionary in character but massive which is not very highly cemented.

Soils in the older flood plain of Jawai river have, however, different profile characters as shown below:

0-30 cm Dark brown (10 YR 4/3); sandy loam; single grained and loose; structure; many roots; well-drained calcareous ($CaCO_3$ 6·3 per cent).

30-130 cm Dark yellow brown (10 YR 4/4); sandy clay loam; medium sub-angular blocky structure; few root ($CaCO_3$ 8·3 per cent).

130-150 cm Dark brown; loamy sands; loose single-grained structure; no roots; slightly calcareous ($CaCO_3$ 3·6 per cent).

150-200 cm Dark brown; sandy loam with a few siliceous concretions; loose single-grained structure; but compact zone; calcareous ($CaCO_3$ 5·5 per cent).

These soils are the continuation of a large Takhatgarh flood plain of Jawai and Old Mitri rivers. Therefore, there are several similarities in the profile characters of these soils of arid zone and that of the semi-arid zone in Jawai canal command area. Mehta (1960) has described a number of soil profiles of Jawai project area with similar characteristics.

3. Soils formed on prolluvial sheet wash deposits on 1-3 per cent slope: These soils have been formed during the Recent times on material transported over

short distances by sheet wash flows on the piedmont areas skirting the rhyolite, granite and sandstone hills. Near the foothills, the soils are very shallow and gravelly. Away from the foothills, the soils are deep to very deep loamy sand with no differentiating horizons. Below the sandy mantle occur angular to sub-angular gravel coated with lime and mixed with highly calcareous loamy sand soil. The soils have a strong component of aeolian sands and the soil surface gives appearance of hummocky and over blown phases. These soils like the aeolian sands of sand sheet deposits have a large component of 60-70 per cent of fine sands particularly in the top 25-30 cm depth.

4. Soils formed on younger alluvium: This is the most important soil group of the region formed on younger alluvium deposit on the levees of the existing river channels of Jawai, Luni and their tributaries. The soils have good water potential for irrigation. Two to three crops are raised on these soils under irrigation. The younger alluvium soils are largely loamy sands to sandy loams, very deep, uniformly layered with no definite zone of calcium carbonate accumulation. The soils have clay 5-15 per cent, silt 5-7 per cent, fine sand about 50 per cent and coarse sand 30-35 per cent. The soils on the levee tops are very deep on flat land surface. The soils on the levee back slopes tend to be deep to moderately deep with older alluvium deposits at 70-100 cm depth. The levee front slopes often represent a strongly over-blown phase, with small dune and high fence-line hummocks.

5. Grey to grey brown hydromorphic soils: These are the medium to fine-textured soils formed under hydromorphic conditions on calcareous clays in the depressions in older alluvium deposits and also in the recently abandoned and dead stream channels. These soils also have very little profile differentiations and consist mainly of clay or clay loam alluvial deposits. Heavy clay soils in the depressions show evidence of gley layers at 100-200 cm depth. Hydromorphic soils formed in depression in the older alluvium are generally loamy to clay loam in texture. A characteristic profile formed on the fringe of arid and semi-arid zone area near Chhenda in Pali district had the following characters:

0-8 cm	Dark grey brown; sandy clay loam; non-calcareous; *p*H 7·5; medium crumb structure; plenty of roots.
8-60 cm	Dark grey brown; sandy clay loam; calcareous; *p*H 8·0; dry hard, medium angular blocky structure; $CaCO_3$ 0·7 per cent.
60-100 cm	Greyish brown loam; highly calcareous with white mottling of calcium carbonate; dry hard, medium angular blocky structure; *p*H 8·4; $CaCO_3$ 14 per cent.
100-180 cm	Pale brown; highly calcareous loam with copious white mottling of amorphous calcium carbonate; dry hard, angular blocky structure; *p*H 8·4; $CaCO_3$ 27 per cent.

Variations of this occur in Jalore-Sonpara area, where 60 cm of dark grey brown clay loam soils occur over grey brown clay with zone of concretionary calcium carbonate accumulation at 105 cm. In these soils the illuvial horizon of clay accumulation (clay content about 30 per cent) occurs at 20-60 cm depth, with clay content decreasing to 5-15 per cent below this zone. These soils in certain respects are comparable to ***Dankar*** soils of Indo-Gangetic alluvium (Gupta *et al.*, 1957) and hydromorphic soils described by Aubert (1962).

Hydromorphic soils formed in abandoned stream channels, however, show a uniformly layered deposit of clay loam or clay soil with saline substratum. A profile studied west of Jalore contains clay 42, silt 27, fine sand 20, coarse sand 7 per cent and $CaCO_3$ 4·0 per cent right up to 180 cm depth overlying less calcareous sandy clay loam containing a large proportion of river washed coarse sand.

6. Saline soils: These soils in arid zone are of two categories: (1) naturally saline soils formed due to capillary rise of underground saline waters and (2) soils salinized by secondary salinization due to irrigation with saline underground waters.

Naturally occurring saline soils or the solanchaks are scattered in the arid zone of Rajasthan in the depressional areas, which serve as drainage basins for underground waters or where there is rise in saline underground water due to hydrostatic pressure of recharge from surrounding hills. Sanwarla ka Rann, Pachbhadra basin, Khutani and Nilkanth depressional areas in the Central Luni basin are examples of depressional areas which serve as underground drainage basins for surrounding areas and where salts rise due to capillary action and render the soil saline and unfit for cultivation.

In the recent times, rise in underground water-table is taking place in certain area, south and north of River Jawai in Jalore district. This rise of saline underground waters in Nimb-lana, Reothra, west of Komtan and near Bagra has brought the saline water within capillary fringe of top soil and has led to the development of saline patches in earlier non-saline lands.

Secondary salinization of soils by the use of saline irrigation waters is a common site in the older alluvium areas. Here, saline ground waters of 2 - 7 grams per litre salinity are used for growing a salt tolerant variety of wheat. The crop on the same land is taken in alternate years or every 2-3 years. In sands and loamy sands, the use of these waters has not produced any serious problem, as rainfall of 200-350 mm for two years suffices to reclaim the land. In the sandy loam soils, however, residual salinity is not washed down and some of the lands are showing signs of accumulation of salts in the upper horizon. Evidence of high sodium saturation (over 50 per cent) is invariably present in saline water-irrigated lands, at lower depths ranging from 20 to 100 cm. In the south of river Jawai in Saila block, where saline irrigation waters of 4-5 grams/litre salinity and SAR of 30-50 are used for irrigation, salinity ranging from 4 to 11 millimhos/cm at 25°C of saturation extract and exchangeable sodium percentage ranging from 30 to 55 has developed at many locations.

FERTILITY STATUS

Soils of western Rajasthan are generally low in fertility status. Due to arid conditions prevailing in the region the organic matter in the soil rapidly decomposes reaching a low equilibrium value. The rapid decomposition due to high temperature also results in end products, chiefly consisting of lignins and resistant proteins, which undergo little further change in the soils. The organic matter content of these soils is, therefore, low.

Seth and Mehta (1963) have summarized the fertility status of soils of various districts falling in the arid zone. They consider these soils generally low in nitrogen, low to medium in available phosphate and medium to high in available potash. Dune soils generally have the lowest fertility level. Organic matter in these soils rarely exceeds 0·25 per cent except in sand sheets and sandy plains, where it is about 0·8 per cent. In the older alluvium soils the organic matter is about 0·5 per cent in the coarse-textured soils and 0·8 per cent in the medium-textured soils. The hydromorphic soils have generally higher organic matter content ranging from 0·7 to 1·0 per cent. The younger alluvium soils are naturally poor in organic matter content, but due to intensive cultivation in the area and continued addition of compost, the organic matter status of these soils on the levee tops is about 0·8 per cent. C/N ratio in all the arid zone soils generally ranges from 10 to 14.

The available phosphorus (extractable by bicarbonate) generally ranges from 7 to 20 kg/ha in the coarse-textured soils. In medium-textured soils, particularly on the younger alluvium, the available phosphorus ranges from 20 to 40 kg/ha. The available potash status (extractable by Morgan's reagent) is generally medium to high being 150-350 kg/ha.

Extensive and detailed work on determination of fertility status of some of the soils in Panchayat Samities has been carried out by Department of Agriculture, Rajasthan (Fertility Survey Series, 1 and 2, 1961, 1962). The doses of fertilizers recommended are based on soil tests carried out in these areas.

MANAGEMENT OF ARID ZONE SOILS

The soils of the Arid zone of Rajasthan, when classified on the basis of USDA land use capability classification fall largely under classes VI and VII, lands fit for pasture development only. Detailed reconnaissance survey of the soils in the Central Luni basin have, however, shown that better class lands exist in the region and are used for cultivation of various crops. Misra (1959) reported that in the various districts of the arid region of western Rajasthan percentage of land under cultivation was as follows: Bikaner 21·6, Jodhpur 32·7, Barmer 24·4, Nagaur 48·3 and Jaisalmer 0·24 per cent. Irrigated area in the region is, however, very small and mostly concentrated along river banks.

The percentage of land utilization in West Rajasthan is mainly conditioned by the factors of land relief, soil, climate and economic and social conditions. Climate and soil are the most important factors limiting the land use and land management in the area. The climate of the tract is characterized by low ill distribution rainfall and extremes of temperature. About 90-95 per cent of the total rainfall of 100-350 mm falls during the monsoon season from end of June to mid-September. During hot months of May and June temperatures as high as 45-47° are recorded, while during winter months temperatures below zero occur at certain places. The diurnal variation in temperatures is also fairly high, about 8-10°C during monsoon month and 14-16°C during the other period. There is, therefore, large soil moisture deficit in the area. High wind velocities also occur during the months of April, May and June and create a severe wind erosion hazard in the sandy terrain. Thus the two important aspects of soil management in the region are the anti-wind erosion measures to protect the soil from blowing and the conservation of moisture and its utilization to best advantage.

The large areas in the region are covered by sand-dune chains and sand sheets, where the wind erosion hazard is severe. At present these are extensively used for cultivation of *Bajra* (*Pennisetum typhoideum*) during monsoon and left fallow for 2-4 years before the next crop is taken. This bare dune soil without vegetation and due to large biotic influences of grazing livestock proves a hazard for adjoining good lands and leads to extension of desert conditions. Soils on the older alluvium, prolluvial sheet wash deposits on piedmont apron and on the younger alluvium also have a large wind erosion hazard. Being dry, loose and uncultivated lands for most part of the year, these are prone to blowing with strong wind. Management in these lands will, therefore, include practices like preparatory tillage for quick penetration and conservation of moisture, wind strip cropping and stubble mulching. Provision of wind breaks and shelter belts in the area will greatly check the wind erosion hazard, conserve moisture and assure better crop growth.

Livestock population of the arid zone tract is very high. Even in the Jaisalmer area, where rainfall is less than 200 mm, livestock population reaches nearly one million. Uncontrolled grazing by livestock decreases the plant cover and depletes fertility of land and thus increases erosion hazards resulting in formation of hummocks and low dunes. This has been occurring in the past in the sandy sheet plain and in the piedmont apron of prolluvial sheet wash deposits. It is, therefore, essential to have protective covering of vegetation on the soil in addition to the shelter belts. Prakash (1957) and Bhimaya *et al.* (1961) have suggested trees and shrubs suitable for rainfall condition ranging from 150 to 400 mm, for rehabilitation of arid zone soils susceptible to wind erosion. Raheja (1963) has suggested growing species like *Prosopis juliflora*, *Albizzia lebbeck*, *Temarix articulata* and *A. indica* on sand-dunes with shelter belt width of 13 m interspersed with 60 m grass strips. For flat range lands the species suggested are *Albizzia lebbeck*, *Prosopis spicigera*, *Ailanthus excela*, *A. indica* and *Z. nummularia*, as these provide fodder loppings for cattle and also serve as shelter belts. Ganguli and Chitnis (1963) consider *Z. nummularia* thrifty both on soil fertility and soil moisture and it does well even in shallow soils of the arid zone.

Wind strip cropping trials conducted at Central Arid Zone Research Institute (Misra, 1963) have shown the efficiency of protective strips of *Lasiurus sindicus* and *Ricinus communis* in soil moisture conservation and increasing crop yield of *Phaseolus radiatus* and *Phaseolus aconitifolius*. Stubble mulching has also shown advantage in checking wind erosion hazard and increasing crop yield.

Many of the village grazing areas on the older alluvium flood plains are on hydromorphic soils of medium to heavy texture with low permeability. The dominant tree vegetation on these lands consists of *Salvadora oleoides*, *S. persica*, and *Caparis decidua*. Because of over-grazing very little ground cover persists in these areas, with the result that rainwater easily runs off the ground creating water erosion hazard. These lands need periodic deep ploughing to increase permeability and water intake. Controlled grazing is essential to maintain vegetation cover on the soil. Seeding of land with palatable grasses like *Dicanthium annulatum* and *Cenchrus ciliaris* will allow grazing of more livestock on these lands. These areas of medium to heavy soils also serve as good water storage points for stock drinking.

Considerable areas of good lands on the fringe of younger and older alluvium where saline underground waters of salinity 2-7 grams per litre are used for growing irrigated wheat are getting spoiled due to faulty management. There is both increase in salinity and in exchangeable sodium percentage in the soil. Periodic application of gypsum and preparatory tillage during monsoon will serve to correct the solonetz effect and also leach down the salts in the profile.

The soils of the arid zone are, by and large, of low fertility. Nitrogen deficiency is one of the most important factors, which needs attention. In the irrigated areas in the younger alluvium soils, this can be attained by introducing crop rotations with symbiotic nitrogen fixing leguminous plants. Application of fertilizer nitrogen on all soils, particularly in the irrigated areas, will help increase production. Trace element deficiencies are also likely to be present. Misra (1963) reported that grain yield of *Bajra* increased due to application of iron, zinc and managenese. Application of magnesium and sulphur also showed advantage.

Raychaudhuri (1952) and Kanitkar (1952) have suggested means of conserving soil moisture by soil working and dry farming methods. In loamy sand soils of western Rajasthan 10 mm of rainfall penetrates to a depth of 8-9 mm of soil. The field capacity of these sand soils does not exceed 11-12 per cent by volume. The soil thus holds only about 110-120 mm of water per metre depth of soil. In sandy loams and heavier soils this reaches to 120-150 mm, while in sand-dune soil only about 70-80 mm of water is held in one metre depth. Moisture movement in desert soils, when below field capacity, is restricted. Abichandani *et al.* (1967) have shown that in a bare fallow in sandy loam soil in the arid zone, evaporation front due to surface evaporation after rains reaches only 45-50 cm depth and below this the soil is naturally moist with over 5 per cent moisture. The hidden condensation plays an important part in enriching the sub-surface layers particularly during the hot months of April, May and June. Fallowing, in arid zone, therefore, conserves nearly 50-80 mm of available water per metre depth of soil at lower depths below 40 cm. The long bare fallow in sandy soil may, however, encourage wind erosion hazard. This practice will, therefore, have to be applied judiciously with shelter belt protection, wind strip cropping and other practices like bunding, preparatory tillage, etc. It is encouraging to note that bunding, locally known as *mer-bundi*, is a common practice in villages in the arid zone. Its popularization in the distant areas away for village will greatly increase the water intake by soil and give better yield of crop and pasture.

ACKNOWLEDGEMENT

The author is grateful to Dr P. C. Raheja, Director, Central Arid Zone Research Institute, Jodhpur, for his valuable suggestions in improving the text of the paper.

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DISCUSSION

J. S. P. Yadav: Has the effect of differential distribution of free $CaCO_3$ in the amorphous form in the soil profile, on the moisture availability of the soil, been studied in these areas ?

C. T. Abichandani: The effect of indurated lime pan has been examined to some extent, but the relationship of free $CaCO_3$ in the amorphous form on the moisture availability has not yet been studied.

R. Vaidyanadhan: What are the criteria employed by the author to fix the age of fluvial action in western Rajasthan ? Does the author refer to interfingering of older and younger alluvia ?

C. T. Abichanadani: No attempt has been made to fix the age. There is no interfingering but laying of one alluvium over the other.

R. V. Tamhane: In what form was calcium found ? Was there any deposit of calcium sulphate ?

C. T. Abichandani: Calcium was in the form of calcium carbonate. No calcium sulphate was found in the profiles studied.

G. B. Maxey: The very practical approach of this paper is to be commended and represents a highly useful function of the Institute.

S. P. Raychaudhuri: Whether the buried soils were transported by water or by wind?

C. T. Abichandani: These soils were buried by water-transported material.

A. R. Subramaniam: Has any work been done on water holding capacity of soils of arid zone ?

C. T. Abichandani: Some work has been done but detailed investigations have not been carried out.

P. Ranganathan: The author has presented a multi-modal vertical profile in regard to soils, fine sand and $CaCO_3$ distribution — associating this feature to variation in rainfall. Could the author give an idea of the periodicity of such variations in rainfall ?

C. T. Abichandani: As a point of information I may mention that in a recent study I have found that the heavier type of precipitation has shown a decrease during the last 30-40 years. Usually such intensive precipitations are associated with atmospheric depressions. It has also been observed that depressions after crossing the Madhya Pradesh have in recent past a great tendency to skirt Rajasthan to the south.

A. R. Zafar: If we base the classification on $CaCO_3$ content will it not be more useful if we take into account the trace element also, particularly molybdenum ?

C. T. Abichandani: You are right. However, I have not taken this into account as such data are not yet available.

LAND CLASSIFICATION AND LAND USE IN THE ARID ZONE OF INDIA[1]

by

K. V. S. SATYANARAYANA[2]

IT is estimated that about 25 million sq km in the world are not favoured with good rainfall and receive less than 250 mm of rain in any given year. This great area, because of its low rainfall, is known as the arid zone. The desert and semi-arid areas of India form roughly about one-third of the country's total area and approximate to 3 million sq km. The desert area largely consists of western Rajasthan, south-eastern Punjab, some parts of Gujarat, principally Kutch and Jamnagar districts. The cold desert areas are in the north, mainly in Jammu and Kashmir State. In south India there is an area of roughly about 52,000 sq km although not strictly a desert but agriculturally suffers from drought year after year. This area is spread out in the States of Andhra Pradesh, Maharashtra and Mysore.

The problems in all the arid and semi-arid areas can be broadly grouped in the ultimate under two major divisions: (1) exploitation of the area for its mineral resources and (2) exploitation of the land resources for production of food and animal products. The latter problem is discussed here.

SOME CHARACTERISTICS AND PROBLEMS

The soils of the arid region fall under the category pedocals and are understood by the few characteristics such as their low content of organic matter, their usually alkaline nature, poor permeability, and usually high content of soluble salts. The other chief features in the arid regions are susceptibility of soils to wind erosion and the occurrence of sand-dunes. These soils are inherently productive once water is made available and are potential sources for supporting large animal and human populations under proper land management.

The arid and semi-arid zones of India include different kinds of tracts each with its own problem. In southern Punjab and western Rajasthan, the problem is one of extreme aridity. A reconnaissance survey of Rajasthan Canal areas carried out by the Central Water & Power Commission showed the whole area (3·93 million hectares) could be divided into six classes as follows:

(a) Class I Flat area presently under cultivation (0·25 million hectares)
(b) Class II Flat area with high *p*H and excessive salts (0·27 million hectares)
(c) Class III Areas intercepted by sand-dunes (1·78 million hectares)
(d) Class IV Sand-dune area (0·80 million hectares)
(e) Class V Flat area with gypsum pan after 3′-4′ (0·65 million hectares)
(f) Class VI *Kankar* area (0·18 million hectares)

Surveys in Suratgarh, including Ghaggar plains, showed the soils are heavy and up to a quarter of the area is likely to be saline-alkali in nature. There is also occasional flooding in these areas. In the mainland of Kutch the problem again is one of aridity and lack of water for agricultural uses. In the Rann of Kutch the problem is both of salinity and water-logging which require large-scale reclamation measures (Satyanarayana, 1954). On the coastal tracts of Saurashtra and Gujarat the problem is one of reclamation of the saline soils (Satyanarayana, 1962).

A rational soil productivity survey is needed for remunerative agriculture and animal rearing. Surveys have to be broadly planned first to obtain information of areas suitable for growing vegetation followed by an assessment of the limitations to growing periods of vegetation. This type of study will also take into account climatic factors as rainfall and humidity on the one hand and the nature of soil and subsoil on the other. A broad classification of the areas will be developed on the following lines:

(1) Areas unsuitable for production of vegetation.
(2) Areas fit for vegetation but with a limited growing season.
(3) Areas with salt and alkali requiring large-scale reclamation.
(4) Areas of highly permeable soils which require improving of structure and water-holding capacity of the soil.
(5) Areas likely to be irrigated.

The above type of broad information can be utilized to tackle areas on priority basis for developing land use methods.

LONG-RANGE LAND USE PROBLEMS

The problems of arid and semi-arid areas are identified as one of human ecology. To this may be added the animal population as well. There is ample evidence to show that there is over-exploitation of the resources in the desert region of northern and western

1. Contribution from Indian Agricultural Research Institute, New Delhi.
2. Soil Correlator, Alluvial Soil Region.

India dating back to 40-50 centuries. Archaeological evidence suggests that the western and northern Rajputana areas were habitable and continued to be so until early centuries of Christian era. From the literary evidence it may be inferred that western Rajputana was already a desert by at least the third century B.C.

The exploitation of the limited resources of soils beyond their capability and capacity, such as over-grazing and over-population, has tended to aggravate the problems in the areas. This is both a warning and guide for future planning. The future plans should envisage long-range aspects instead of immediate concern. One important phase of this programme should be to exploit the land resources under large-scale mechanized agriculture rather than peasant farming. Mechanization limits the demand of human beings and also at the same time reduces the number of cattle that may be maintained on a farm or ranch. Further, when large areas have to be cultivated within the short period of time then mechanization is the only answer. The arid areas in other parts of the world are exploited by growing crops like grapes, dates, which may also find resources to produce animals and animal products, milk, milk products, wools, skins, poultry and poultry products.

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DISCUSSION

A. R. Subramaniam : Was any work done on the maximum water-holding capacity of soils of arid zone ?

C. T. Abichandani : Some work was done on sandy and sandy loam soils. The former yielded values from 20 to 24% and latter about 27 to 32%. However, the work has not been published anywhere.

N. C. Rawal : The reconnaissance survey of Rajasthan Canal area carried out by the CW & PC for the whole area was 9·43 million acres against 3·81 m acres as actually done. May I know from where these figures and classification of the area in six groups were obtained ?

K. V. S. Satyanarayana : This was obtained from Rajasthan Canal Board and classification of soil was broad-based.

V. P. Subramanyam : May I know the criteria you have used to consider the areas in S. India as semi-desert zones ?

P. C. Raheja : After trying all schemes Thornthwaite's criterion was found to be consistent with vegetational distribution. Dr K. V. S. Satyanarayana adopted this criterion supplied by the CAZRI.

S. P. Chatterjee : In the absence of detailed land capabilty survey is it not the fact that the statement " over-exploitation of the resources has occurred " is open to question ?

P. C. Raheja : Vegetation has definitely deteriorated.

SOIL-PLANT-WATER RELATIONSHIPS

EFFECT OF ATMOSPHERIC AND SOIL DROUGHTS ON GROWTH AND YIELD OF CROP PLANTS[1]

by

J. J. CHINOY[2]

REVIEW of work on drought resistance (Maximov, 1929, 1952; Levitt, 1951; Stocker, 1956; Iljin, 1957; Chinoy, 1960) shows that attempts have been made to evaluate the degree of resistance to drought mainly in terms of isolated morphological, anatomical or biochemical properties of the plant without taking into consideration the influence of growth and development as well as that of the environmental factors upon the characteristics under study. It is on account of this deficiency in the study of resistance physiology that different workers have interpreted the results in different ways and often times arrived at diametrically opposite conclusions.

Considering these facts and the great importance of plant hardiness to drought and salinity of the soil only a comprehensive programme of research in resistance physiology can lead to conclusions of theoretical and practical values.

The work initiated by the writer in 1941 at the IARI, New Delhi, and continued till today comprised of the following main lines of study: (1) Direct agrobiological test of large number of varieties of crop plants grown under irrigated and ' dry ' conditions; (2) Determination of varietal resistance to wilting at different stages of growth; (3) Determination of varietal resistance to wilting after synchronization of growth and developmental stages by giving different vernalization and photoperiodic treatments; (4) Presowing hardening treatment of seeds; and (5) Study of protoplasmic factors determining drought resistance.

1. Some illustrative data are given in Fig. 1 for a large number of wheat varieties classified according to their time of flowering from 100 to 170 days. It will be seen that in these agrobiological tests temperature of the ripening period was found to be the paramount factor in determining the grain yield and 1000 kernel weight of wheat, barley, oat, linseed, gram, wheat-rye hybrid (Triticale of Arne Muntzing), both under irrigation as well as ' dry ' conditions. As late flowering varieties ripened their grain at an appreciably higher temperature compared to the early flowering one, their 1000 kernel weight as well as yield were considerably lower compared to those of the latter. This conclusion was confirmed by growing

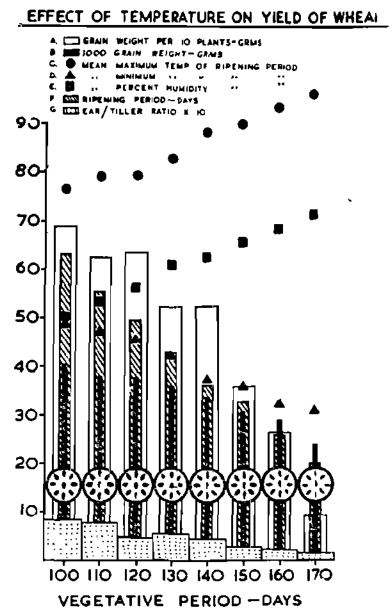

Fig. 1 — Grain yield, 1000 kernel weight, ripening period and ear/tiller ratio of 260 varieties of wheat belonging to eight classes of flowering

varieties of different crop plants under varying photoperiods with and without vernalization so as to synchronize the ripening period with higher and lower ranges of temperature (Fig. 2). The yield and 1000 kernel weight were found to be inversely correlated with the temperature of the ripening period.

All these experiments have conclusively proved that the yield of all the crop varieties grown during the Rabi season (October to April) is mainly controlled by the temperature of the ripening period. Early flowering varieties give better yield because temperature during their ripening period is conducive to grain filling processes; while the yields of the late flowering ones are low because of the adverse effect of high temperature prevalent during the ripening period of these late varieties on their grain filling processes.

2. According to Maximov (1929, 1952) the basis of drought resistance in plants is their capacity to endure wilting. Tumanov's method of drought resistance in plants is based on this conception. In the work under review a modified Tumanov's method of

1. Contribution from the University School of Sciences, Gujarat University, Ahmedabad 9.
2. Head of the School of Sciences.

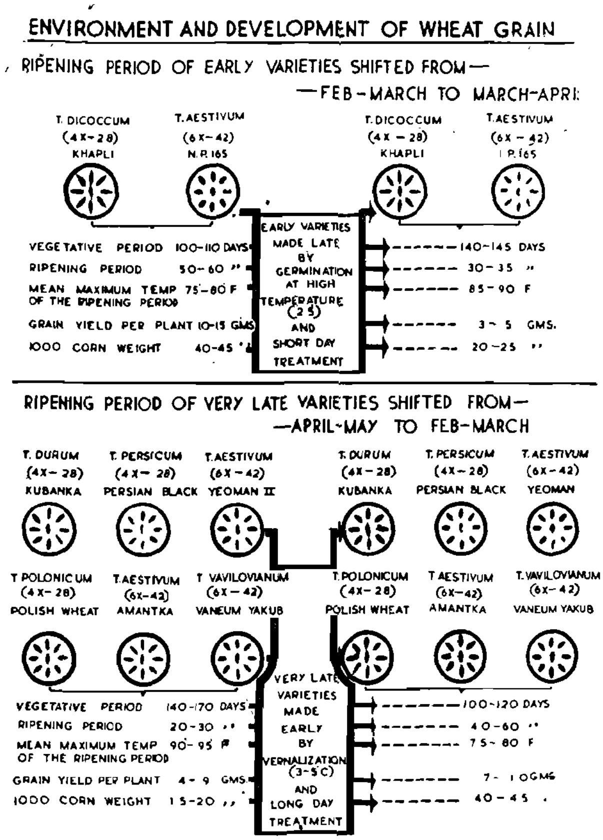

Fig. 2 — Change in various characters brought about by vernalization and photoperiodic treatments

permanent wilting depending not only upon the survival values of plants after wilting, but also on the determination of growth and yield responses was used. Drought was given at three stages of growth: (1) tiller initiation; (2) shooting; and (3) flowering. Results of six experiments out of the many carried out during the last 23 years are summarized in the following figures.

The linear regression of mean soil moisture during the wilting period on mean temperature of the wilting period showed an inverse relation. "Drought intensity" to which the plants were subjected during the wilting period was determined from the equation

$$I = K.\frac{t}{m}$$

where I is the drought intensity, t is the mean temperature, and m is the mean per cent moisture of the soil during the wilting period; K is a constant which in this case represents the number of days in wilting period.

(i) When survival values of plants subjected to wilting at tiller initiation, shooting and flowering stages were plotted against the corresponding values of drought intensity to which the plants were subjected, it was seen that these values progressively decreased with increasing lateness in flowering of a variety. This was because drought intensity was greater in the case of late varieties. On the other hand, plants of all the varieties not only survived but also made good growth when subjected to wilting at the tiller initiation stage because they were all wilted at the same time and at a lower temperature.

(ii) Determination of drought resistance was also undertaken on the basis of stem elongation, tiller production, stem and leaf dry weights as well as yield characters such as grain number, 1000 kernel weight, grain yield, and others.

Retardation in tiller production and leaf dry weight of plants wilted at the tiller initiation and the shooting stages is overcome during the recovery period to such an extent that they surpass even the normally watered plants in these growth characters. Wilting at the shooting stage also causes retardation in stem elongation and stem dry weight. This disadvantage is, however, quickly overcome by the plants of early flowering varieties. On the other hand, retardation in these growth characters in late flowering varieties increased with progressive lateness and was permanent.

(iii) Grain number, 1000 kernel weight and grain yield progressively declined with increasing lateness of flowering under all wilting treatments and in normally watered plants. Wilting at the shooting and the flowering stages further reduced considerably the values of these yield characters in late varieties.

(iv) An index was used for evaluating drought resistance designated as Coefficient of Drought Resistance. It is determined for different growth or yield characters as follows:

$$Q_D = 100\,\frac{\text{Value of growth or yield character under wilting treatment}}{\text{Value of the same character under normal watering}}$$

Thus, for instance, Q_D, for grain weight of plants wilted at the shooting stage, is determined by dividing the grain yield of 10 plants of a variety under wilting treatment at the shooting stage by the corresponding grain yield of 10 plants of the same variety receiving normal watering and multiplying by 100.

Drought coefficients of tiller production as well as for leaf dry weight show a stimulating effect of wilting at the tiller initiation and the shooting stages on these growth characters in almost all the varieties (Fig. 3). Again drought

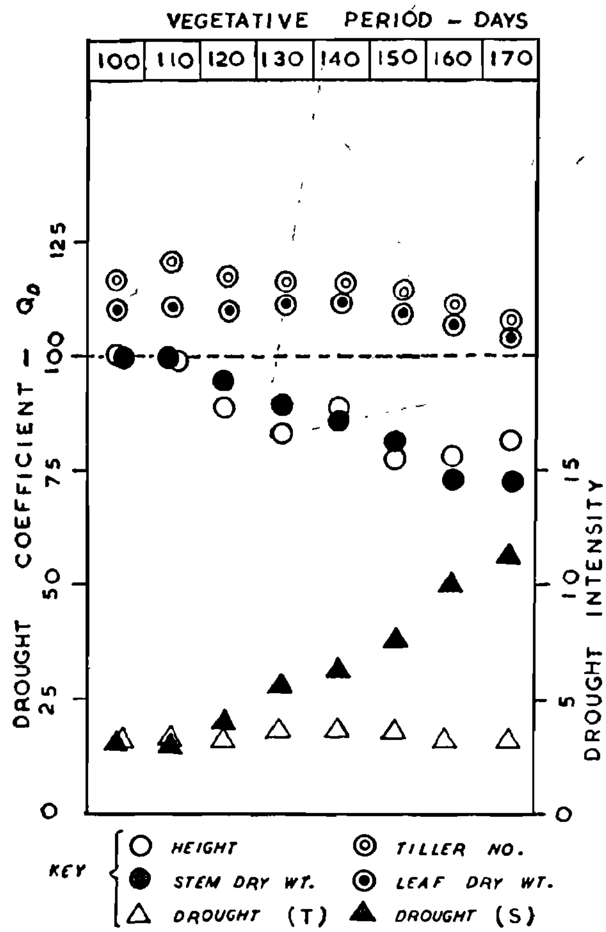

Fig. 3 — **Drought coefficients of height, stem and leaf dry weights, as well as tiller number of different wheat varieties belonging to eight classes of flowering**

coefficients for height and stem dry weights of plants subjected to wilting at tiller initiation stage show that these growth characters are not affected by drought at this growth stage; whereas drought coefficients for the same growth characters of plants undergoing wilting at the shooting stage show a progressively greater decline with increasing lateness of flowering in a variety.

(v) Drought coefficients for grain number, 1000 kernel weight and grain yield of plants wilted at the shooting and the flowering stages showed progressive decline with increasing lateness in flowering. Drought coefficients for spikelet and ear number, and ear length showed reduction only for plants wilted at the shooting stages. This reduction too increased progressively with lateness in flowering (Fig. 4).

All these results taken together leave no doubt that environmental factors determine the response of a variety to drought. Varieties falling in the same or a close flowering class do not show significant differences in response to drought. The response to drought becomes significant only when appreciable increase in temperature during the wilting period enhances drought intensity.

The general conclusions derived from the above-mentioned work are: (1) Drought resistance in crop plants is inseparably bound with its major growth and developmental processes as well as with environmental conditions which are prevalent during its growth period and, therefore, it cannot be considered as a separate unrelated heritable characteristic; (2) For the proper elucidation of the complex phenomenon of drought resistance in plants a comprehensive study of their major physiological processes in relation to environmental conditions is absolutely essential.

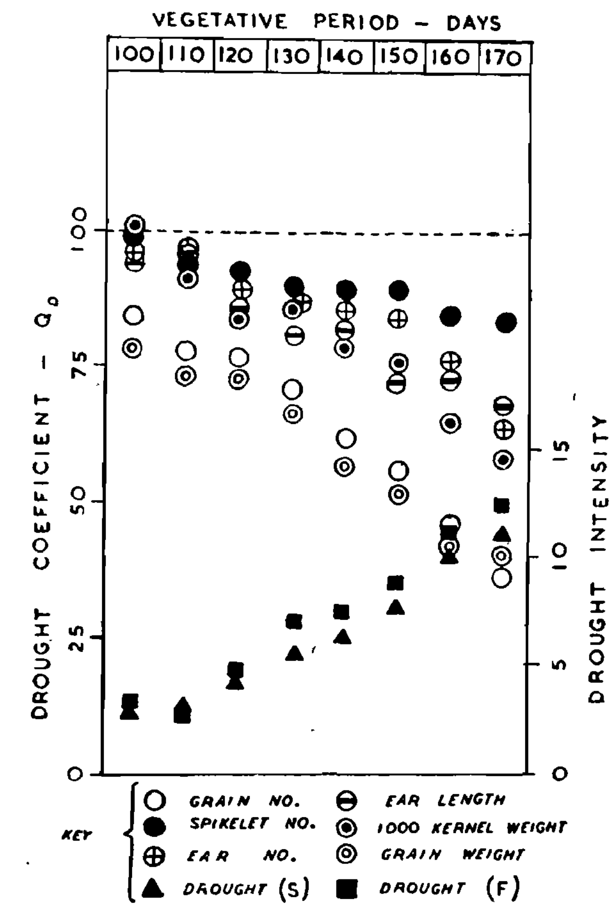

Fig. 4 — **Drought coefficients of grain, spikelet and ear number; also of ear length, 1000 kernel weight and grain weight of wheat varieties belonging to eight different classes of flowering**

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DISCUSSION

J. P. Hrabouszky: What is the effect of late seeding on short growing period varieties ?

J. J. Chinoy: When the short growth period varieties are sown late in the season their growth period is still further shortened on account of lengthening day due to the advancing summer and their yield and 1000 kernel weight are adversely affected on account of the higher temperature range obtained during their ripening period.

C. S. Christian: When you take different varieties and induce them to flower by differential treatments how do you know it is the temperature which is having the effect ?

J. J. Chinoy: Different photo-periodic and vernalization treatments can hasten or delay the flowering and thus ripening period may be brought to higher or lower range of temperature. This shift in the ripening period with respect to temperature produces higher or lower 1000 kernel weight and yield. Very significant inverse correlation between yield and mean maximum temperature as well as between 1000 kernel weight and mean maximum temperature of the ripening period have been obtained. When the early and late flowering varieties of wheat were transferred to a green house at 85°F and 65-70 per cent relative humidity just at the time of anthesis, all varieties took the same number of days to ripen their grain and their 1000 kernel weight and yields were also of the same order of magnitude.

S. P. Chatterjee: Have you studied in detail the phenology of the crops, such as, flowering time, harvesting time, etc.?

J. J. Chinoy: Yes. A very detailed programme of periodic measurements of growth and harvest has been carried out following the methods of F. G. Gregory. Over the last 20 years we have collected the phenological data of a large number of wheat varieties, and also on varieties of other crop plants like barley, oat, rye, wheat-rye hybrid, linseed, gram, etc.

C. S. Christian: Do you interpret the effects of temperature mainly as an effect on the rate of photosynthesis or respiration?

J. J. Chinoy: High temperature during the ripening of grain affects both the processes. The optimum temperature for photosynthesis lies in a comparatively lower range of temperature. On the other hand, optimum range of temperature for respiration is in the higher range. With the lowering of photosynthetic activity and enhancing of the respiratory activity grain filling processes are adversely affected leading to lowering of 1000 kernel weight and yield in late flowering variety.

P. Jagannathan: How has it been ensured that factors other than those considered in your study have not altered the yield ?

J. J. Chinoy: The relationship between yield, 1000 kernel weight and other growth characteristics on the one hand and the temperature of the ripening period on the other is based on the data of experiments carried out over 20 years, in pots and in field. Proper care was taken to see that variables other than these were kept at the optimum levels.

A. R. Subramaniam: Does the drought intensity indicate "physiological drought" in relation to plants ? What is the basis of the equation for drought intensity ?

J. J. Chinoy: The drought referred to is physical drought. The equation is derived from the curve of temperature changes in relation to reduction in soil moisture.

ECO-PHYSIOLOGICAL STUDIES ON THE GERMINATION OF SEEDS OF CERTAIN ARID ZONE PLANTS: PART I — GERMINATION EXPERIMENTS WITH THE SEEDS OF *PARKINSONIA ACULEATA* LINN.

by

U. N. CHATTERJI & KAMAL MOHNOT*

INTRODUCTION

FOR the purpose of afforestation of the arid and semi-arid zones of Rajasthan desert, attempts are being made to find out the plants that could be acclimatized to the natural conditions prevailing in these regions. With this point in view, germination studies on seeds of *Parkinsonia aculeata* L., a native of tropical America (Hooker, 1879) introduced in this region, were carried out. The utility of this plant lies in its being a hedge plant, a soil binder and a fodder plant (Badhwar, Dey and Griffith, 1946). It belongs to the family Leguminosae and sub-family Caesalpinoidae. It is both a shady and an ornamental tree.

MATERIALS AND METHODS

The *Parkinsonia* tree fruits twice a year, once in spring and again in autumn. So the seeds of the respective seasons have been designated in this paper as ' spring seeds ' and ' autumn seeds '. Spring seeds of the year 1963 were collected in May and autumn seeds of the same year in March 1964. Seeds were cleaned and stored in glass bottles in the laboratory at room temperature.

Seeds are compressed, oblong and albuminous with a crusty brown, hard and smooth mosaic testa. It is thicker in the middle and becomes gradually thinner towards both the ends. Its length measures 1 cm and breadth 0·5 cm in middle part and 0·1-0·2 cm at both the ends. Autumn seeds are somewhat bigger and heavier than spring seeds. Average weight of autumn seeds was 0·1728 gm and of spring seeds 0·1138 gm.

The germination as measured by the emergence of radicle was studied by the usual petridish method, under different conditions of light and temperature. The seeds were placed for germination in petridishes on moist filter paper or in soil. The filter papers were constantly moistened with sterilized distilled water. Both seeds and petridishes were sterilized prior to the use. Imbibition was studied by increase in weight and volume of the seeds. The germination tests were replicated three times.

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The germination studies were carried out at various temperatures including room temperature. Any change of temperature was secured by transferring the petridishes from incubator to refrigerator and vice versa, and from room temperature to incubator, or to refrigerator and vice versa.

For pre-chilling, the seeds were placed on the moist substratum in petridishes and held at 3°C for different intervals of time.

Hot water pre-treatment was effected by placing the seeds in hot water at boiling point which was allowed to cool down gradually with the seeds in it. The seeds were kept in this water for the next 24 hours. Dry heat was given by: (i) keeping the seeds at high temperatures in petridishes, and (ii) placing them in soil in incubators adjusted at different degrees. Seeds were also sown in hot soil (at 90-100°C) and in soil at room temperature, supplied with water, in the following four combinations, viz. (i) soil and boiling water, (ii) hot soil and water at room temperature, (iii) soil and water both at room temperature, (iv) hot soil and boiling water.

Shaking treatment was also given by shaking dry seeds in a glass bottle for 20 minutes for mechanical rubbing of the mutual seed surfaces.

Seeds imbibed with water by hot water treatment were subjected to different conditions of light and darkness for germination study.

RESULTS AND DISCUSSION

Seeds, collected in May 1963, did not imbibe water even after one month's, continuous soaking in ordinary and distilled water separately at room temperature. Imbibition of water is generally accepted as the first stage (Toole *et al*., 1956; Mayer and Mayber, 1963; Kamal Mohnot, 1965) in the germination sequence; and if the process is arrested at the initial stage, it may be taken to be a suggestive of seed coat dormancy. It was, therefore, felt that there was thus the necessity of bringing about an increase in the seed coat permeability by different pre-germination treatments.

The seeds from the same sample (i.e. those collected in May 1963) were subjected to the pre-treatment of hot water once in June and then in October 1963. Imbibition was found to be 100 per cent both the times, while germination was 100 per cent in June and 94 per cent in October. Imbibition percentages obtained as indicated by the number of seeds which exhibited swelling with different pre-treatments have been presented in Table 1. The change in permeability has been expressed as the percentage of seeds which underwent swelling.

Spring seeds soaked in distilled water and kept for germination at laboratory conditions were taken as control in all the cases. There was no response in case of fresh spring seeds which were placed for germination soon after the collection.

TABLE 1: Changes in permeability of spring seeds of *P. aculeata* to water caused by various pre-treatments

Pre-treatments	*Imbibition percentage*	*Details of pre-treatments*
1. No treatment (control)	0 to 4	Control in distilled water at room conditions of light and temperature
2. Chilling	0 to 3	Seeds placed in refrigerator at 3°C for 15 days to 3 months
3. Low temperature	0 to 4	Seeds kept at 10° and 13°C for seven days
4. Shaking	8	Shaking in glass bottle for 20 minutes
5. High temperature	90	Seeds placed at 100°C in distilled water for 30 minutes
6. Boiling hot water	100	Seeds placed in boiling hot water and allowed to cool down to room temperature

The increase in the weight of seeds due to imbibition has been indicated in Table 2. The increase in weight is expressed as percentage of original weight of seeds.

TABLE 2: Increase in weight due to the imbibition of water by seeds

Seeds	*a*	*b*	*c=(b−a)*
	Original weight of the seeds	*Weight of imbibed seeds*	*Weight of water imbibed*
Spring seeds	100 gm	214·28 gm	114·28 gm
Autumn seeds	100 gm	227·64 gm	127·64 gm

Seeds were allowed to germinate after pre-treatment with hot water and also after shaking and chilling. The percentages of germination in each case have been incorporated in Table 3.

TABLE 3: Percentage of germination after various pre-treatment

Days after placing for germination	*Control*	*Hot water treatment*	*Shaking treatment*	*Chilling treatment*			
				15 days	*30 days*	*60 days*	*90 days*
6	0	95	8	0	2	3	3

HOT WATER PRE-TREATMENT

Spring seeds were subjected to hot water pre-treatment, and the seeds that imbibed water were then removed and placed on moist filter paper in petridishes for germination. Those that failed to imbibe on the first treatment were subjected to hot water treatment for a second time and even for a third time in order to ensure 100 per cent imbibition. The data relating to the imbibition and germination of spring (one year old) and autumn (fresh) seeds have been shown in Table 4.

TABLE 4: Imbibition and germination of seeds

	Days	*Imbibition percentage*		*Germination percentage*	
		Control	*Hot water*	*Control*	*Hot water*
Spring seeds	2	2	100	2	94
Autumn seeds	2	4	100	—	70

Evidence in the literature is lacking so far as the effect of hot water treatment on *P. aculeata* seeds is concerned. This study has, however, shown that hot water treatment, acting as moist heat, brings about a change in permeability of seed coat to water from 0-3 per cent to 95-100 per cent and it is effected by a change in structure of seed coat. The water in which seeds were kept became acidic (*p*H 4-5).

SHAKING PRE-TREATMENT

After shaking treatment the seeds were soaked in distilled water for 1-3 days. The percentage of swelling attained in this case conforms with the results reported by Crocker and Barton (1957), viz. 8 per cent (Table 1). The percentage of germination was also 8 per cent (Table 3).

CHILLING PRE-TREATMENT

Petridishes containing seeds with distilled water were placed at 3°C for 1-10 days (not shown in table), 15, 30, 60 and 90 days separately. These pre-chilled seeds were soaked in distilled water and placed for germination at room temperature. The results were very insignificant showing that chilling did not help in germination (Table 3). The autumn seeds were not tested for chilling responses.

TEMPERATURE EFFECTS

There was no germination at lower temperature, i.e. 3°, 10°, and 13C°. Among higher temperatures, 35°C seems to be the optimum temperature for spring seeds where germination results were 28 per cent For autumn seeds optimum temperature was found to be 40°C in which 32 per cent germination was obtained (Figure 1). The difference might be due to the age

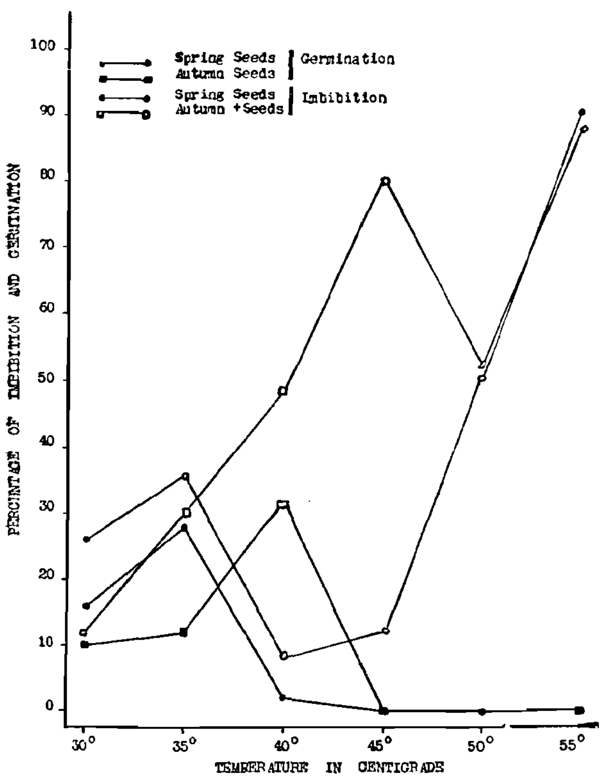

Fig. 1 — Effect of temperature on germination and imbibition of seeds of *Parkinsonia aculeata*

of the seeds, as the spring seeds were nearly a year old, whereas the autumn seeds were fresh. At the constant temperature of 45°C only 12 per cent of spring seeds continued to imbibe water as observed for 15 days while in the case of autumn seeds the same condition was indicated by 80 per cent of them. But at the constant temperatures of 50° and 55°C, the imbibition results were almost equal to the spring and autumn seeds. At 50°C, results were 50 and 52 per cent, and at 55°C, they happened to be 90 and 88 per cent. However, no germination could be recorded at these temperatures in either case.

Seeds kept in water at constant high temperatures, viz. 58°, 68° and 100°C, for 18-24 hours apparently became injured and appeared to be killed. When seeds were kept in water at the same temperatures for short duration of 20 minutes (at 100°C) to 2 hours (at 68°C) and then transferred to room temperature (32-36°C) and kept there for a further period of 24 hours in water, imbibition was recorded to be 80-95 per cent and germination 50-90 per cent (Table 5).

TABLE 5: Relation between alternating temperatures and germination of spring seeds of *Parkinsonia aculeata*

Sl. No.	*Variation of temperature*	*Kept at high temperature (time)*	*Kept at room temperature (33° to 36°) (time)*	*Percentage of imbibition*	*Percentage of germination*
1a	58°C and room temperature	4 hours	48 hours	55	35
b	do	24 hours	48 hours	90	—
2a	68°C and room temperature	2 hours	48 hours	80	50
b	do	4 hours	48 hours	80	—
3a	100°C and room temperature	10 minutes	48 hours	12	8
b	do	20 minutes	48 hours	95	90
c	do	30 minutes	48 hours	90	70
d	do	60 minutes	48 hours	100	60
e	do	90 minutes	48 hours	100	4

To study the effect of alternating temperature, seeds were first kept at lower temperatures and then transferred to higher temperatures, and vice versa. This was achieved by keeping petridishes in a refrigerator for low temperatures and in an incubator for high temperatures. Results have been tabulated in Table 5 and 5(a).

TABLE 5(a): Imbibition percentage and germination percentage at varying temperatures

Sl. No.	*Variation of temperature*	*Low temperature (time)*	*High temperature (time)*	*Imbibition percentage*	*Germination percentage*
1	3°C and room temperature (33°-36°C)	15 days	4 days	4	4
2	3° and 40°C	15 days	4 days	5	2
3	3° and 45°C	15 days	4 days	5	—
4	3° and boiling water treatment and then kept at room temperature	15 days	2 days	100	95

Like hot water pre-treatment, high temperature pre-treatment also helps in removing impermeability of seed coat.

EFFECT OF LIGHT

Seeds soaked in distilled water at room temperature were subjected to different light conditions, but there was neither imbibition nor subsequent germination. Seeds which imbibed water by hot water pre-treatment were subjected to different intensities of light, viz. (i) direct sunlight; (ii) diffused light; (iii) total darkness. The difference in germination percentage as brought about by different light conditions was not very appreciable. Results have been illustrated in Table 6.

TABLE 6: Germination in different intensities of light

Light conditions	*Percentage of germination*
Complete darkness	94
Diffused light	94
Direct sunlight	97

It appears that different light intensities do not play any important role in the germination of *Parkinsonia* seeds.

SEEDS IN SOIL

Spring seeds and autumn seeds were separately placed in soil at room temperature and in hot soil (at 90-100°C) and water at room temperature and boiling water was supplied to the soil separately. The four combinations of soil and water are shown, along with the results, in Table 7.

TABLE 7: Relation between germination of *Parkinsonia* seeds and different temperatures of soil and water

Combination of water and soil	*Days*	*Percentage of sprouting*	
		Spring seeds	*Autumn seeds*
Soil and boiling water	1	44	52
Hot soil and water at room temperature	4	70	65
Soil and water both at room temperature	5	—	—
Hot soil and boiling water	3	60	60

The maximum germination was obtained in case of hot soil and water at room temperature. These results were comparable with those obtained with hot soil and hot water. No response was obtained in the case of soil and water both at room temperature which served as control.

The observations indicated in the preceeding pages appear to correspond with what prevails in nature. The autumn seeds ripe in October-March and the spring seeds in May when it becomes very hot in the desert. The seeds are generally dispersed in late May-June. The seeds would thus remain buried in hot soil and get a supply of water by rains in July-August. Water remaining in the soil is utilized by the seeds for imbibition followed by germination. When the first rains precipitate, soil is always hot here, and the initial rain-water falling on the soil also becomes warm. Heat treatment, as has been indicated in the preceeding pages, thus appears to be a possibility in nature in these regions.

This study leads to the conclusion that the hard seed coat in *Parkinsonia aculeata* seeds needs heat treatment for breaking its dormancy. It is the application of heat that is responsible for making the seed coat permeable to water. A diurnal alternation of temperature does not appear helpful in this case though in the case of a great variety of seeds alteration of day and night temperatures brings about germination as indicated by Harrington (1923).

SUMMARY

Parkinsonia tree fruits twice a year, in spring and in autumn. The seed has a hard seed coat which is impervious to water in ordinary conditions. The seed coat dormancy is removed by heat treatment, and heat brings about imbibition of water and germination of these seeds. Hot water pre-treatment gives 100 per cent imbibition and 95 per cent germination in the case of spring seeds.

The effect of different temperatures was also studied in this connection. Imbibition was found to be nil at low temperatures (viz. 3°, 10°, and 13°C). The maximum germination results were obtained at 35°C for spring seeds and 40°C for autumn seeds, the respective figures being 28 and 32 per cent. Normally a continuity of high temperature was found to be injurious, but exposures of short durations to high temperatures (20 minutes at 100°C and two hours at 68°C) followed by exposure to room temperature (32-36°C) gave 80-95 per cent imbibition and 50-90 per cent germination.

Pre-treatments with low temperatures of the range indicated above and mechanical shaking did not give any appreciable imbibition or germination, the results being 3 per cent in the former case and 8 per cent in the latter.

Light did not seem to play any significant role in imbibition and germination of these seeds.

Soil at the room temperature and at 90-100°C (i.e. hot soil) was supplied with water in the following combinations, viz. (i) soil and boiling water, (ii) hot soil and water at room temperature, (iii) soil and water both at room temperature, and (iv) hot soil and boiling water. Of these treatments, it was observed that hot soil with water at room temperature induced appreciably greater germination, the respective values being 70 per cent for spring seeds and 65 per cent for autumn seeds.

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DISCUSSION

S. Chattopadhyay: I would like to know about the effects of growth regulators on the germination of seeds ?

U. N. Chatterjee: We are still doing this work and as such I am not in a position to make any comments on this subject.

ECO-PHYSIOLOGICAL STUDIES ON THE GERMINATION OF SEED OF CERTAIN ARID ZONE PLANTS. II—A PRELIMINARY AND COMPARATIVE STUDY OF GERMINATION BEHAVIOUR OF SEEDS OF FIVE SPECIES OF *INDIGOFERA* LINN.[1]

by

U. N. CHATTERJI & DAKSHA BAXI[2]

INTRODUCTION

Indigofera Linn. is well represented by a number of species occurring in different ecological habitats of Rajasthan (Nair & Koshy, 1963). The prevelance of various species with differing habits and suitable adaptations to a variety of ecological conditions lead to this comparative study of the germination behaviour of the seeds of these species. *Indigofera cordifolia* Heyne is the most common, widely distributed, prostrate annual, appearing after rains on sandy wastes. The plant is known as a good sand binder and sometimes predominates the fresh and bare sand dunes. Pigeons and ants have special liking for their pods. *Indigofera hochstetteri* Baker and *Indigofera linnaei* Ali are prostrate, annual and perennial, respectively, growing on stable sandy soil and are grazed by domestic animals. *Indigofera oblongifolia* Frosk., a woody perennial not exceeding three feet in height, grows both on rocky land and stable soil. The seeds are eaten by the insects and the leaves by goats. *Indigofera tinctoria* Linn., the original source of the dye indigo, often forms pure associations in stable soil as well as on hill slopes.

MATERIALS AND METHODS

The seeds of the species named above were collected from and around the city of Jodhpur during the month of October and November, 1963. The seeds were soaked in distilled water and distributed in petri dishes, containing soaked filter papers, at the prevailing room temperature (25°C) for germination under aseptic conditions. The seeds of *I. oblongifolia* and *I. tinctoria* failed to germinate, whereas the percentage germination of remaining three species ranged from 2 to 6 per cent only. Therefore, efforts were made to overcome the failure of germination of the seeds by various treatments. The treatment given were as indicated below:

Impaction: The vigorous shaking of the seeds resulting in their mutual impaction was brought about by placing the corked seed containers (Pyrex flasks) on an electric shaker for 15 to 30 minutes at 25°C and subsequently the seeds were placed for germination.

Hot water treatment: The water was allowed to boil and seed were added to it after removing the water from the heater. The temperature of the water was 70°C when seeds were added.

Alcohol treatment: The seeds were soaked in 95 per cent alcohol for 2, 24 and 48 hours and were subsequently placed for germination after thorough washing.

Acid treatment: In preliminary experiments the seeds were treated with conc. H_2SO_4 for 30, 60 and 120 minutes but with the latter two time-periods the acid proved injurious to the seeds. Thereafter, the seeds were treated for 10, 20, 30 and 40 minutes and subsequently placed for germination under laboratory conditions (25°C).

Temperature treatment: The seeds were kept continuously under three different temperatures viz., 25°C (room temperature) 30° and 40°C.

EXPERIMENTAL RESULTS

Intact seeds of *I. cordifolia, I. linnaei* and *I hochstetteri* at 25°C indicated 2-6 per cent germination, whereas those of the other two species did not germinate. At 30°C there was an appreciable increase to 12-17 per cent germination, of the seeds of *I. cordifolia, I. linnaei* and *I. hochstetteri* and even those of *I. oblongifolia* showed 5 per cent germination. But again at 40°C the percentage of germination of the seeds of all the species named above except *I. cordifolia* decreased from 12-27 to 2-4 per cent whereas in *I. cordifolia* percentage germination was 26 but the seedlings could not stand the high temperature and died within 48 hours. *I. tinctoria* remained uneffected by the various changes of temperatures, the germination percentage being nil in all the cases.

The impaction treatment made little or no difference in improving the percentage of germination of seeds as compared to that at ordinarily prevailing conditions in the laboratory at room temperature

1. Contribution from the Botany Department, University of Jodhpur, Jodhpur, Rajasthan.
2. Head of Botany Department and Research Scholar, respectively.

(25°C). Boiling hot water treatment gave variation of 2 to 16 per cent in water imbibition and 0 to 16 per cent in germination. The highest germination percentage of 16 per cent was obtained in case of *I. cordifolia.*

The soaking for 2 hours in alcohol raised the germination percentage of *I. cordifolia* to 16 per cent as compared to that under ordinary laboratory conditions. *I. hochstetteri*, *I. linnaei* and *I. tinctoria* did not respond favourably when soaking period extended from 2 to 24 hours, but 2-4 per cent germination was obtained when soaked for 48 hours. In *I. oblongifolia* the percentage of germination increased from 2 to 12 per cent with increase in duration of treatment as is evident from data in Table I.

capability of the seeds to germinate at different times because an advantageous change in the degree of permeability of the seed-coats would probably lead to quicker germination; this might also explain the persistent survival of the seeds possibly extending to several years.

Hemly (1932), Barton (1947) and Koller and Cohen (1949) found impaction to be a safe and effective measure for improving germination in *Papilionaceous* seeds and seeds of *Convolvulus* Spp. respectively. In the cases dealt with in the present paper the respond of impaction on germination percentage was, on the other hand, negligible as compared with the results obtained by them, even when the duration of impaction given was longer.

TABLE 1: Effect of various treatments on germination of five species of *Indigofera linn.*

Name	*Percentage germination*									
	Impacted at 25°C		*Hot water*	*Alcohol treatment*			*Conc.* H_2SO_4			
	30 *mt*	60 *mt*		2 *hr*	24 *hr*	48 *hr*	10 *mt*	20 *mt*	30 *mt*	40 *mt*
I. cordifolia	8(8)	8(12)	16(16)	14(14)	12(12)	6(6)	0(100)	90(100)	90(100)	10
I. hochstetteri	4(4)	4(4)	4(6)	0	0	2(2)	0(100)	100(100)	50(100)	90(100)
I. linnaei	4(8)	12(12)	0(2)	0	0	4(4)	0(90)	81·8(100)	90(100)	100(100)
I. oblongifolia	4(4)	0(4)	0(4)	2(2)	10(10)	12(12)	20(90)	100(100)	100(100)	100(100)
I. tinctoria	0	0	0(2)	0	0	2(4)	30(30)	100(100)	100(100)	100(100)

The percentage of imbibed seeds are shown in brackets.

The seeds of *I. cordifolia*, *I. linnaei* and *I. hochstetteri* when treated with conc. H_2SO_4 for 10 minutes showed 90 per cent germination and the imbibition of water was as high as 90-100 per cent as indicated by the changes in their volumes. In the case of the seeds of *I. oblongifolia* and *I. tinctoria* 20 to 30 per cent germination took place after this treatment. Germination to the extent of 100 per cent was obtained with seeds of *I. cordifolia*, *I. oblongifolia* and *I. tinctoria* when treated for 20 minutes. In respect of the seeds of *I. linnaei* and *I. hochstetteri* the percentage of germination increased from 50 to 90 per cent, respectively with the increase in the time of the treatment given, and 100 per cent results were obtained when the treatment was continued for 40 minutes.

In all the cases and with all the treatments dealt with above, five days were required to obtain the maximum percentage germination.

DISCUSSION

The percentage germination of 2 to 6 obtained with untereated intact seeds indicate a variability in the degree of hardness of seed-coats within and among the various species. The variability in the degree of hardness of seed-coat might possibly explain the

Boiling hot water acts as wet heat and increased the permeability of the seeds, as encountered in the species of *Parkinsonia aculeata* (Chatterji and Mohnot, unpublished) resulting in increased germination percentage from 3-4 to 70-80 per cent. The seeds of *Indigofera* did not show stricking result, when compared to those under ordinary conditions, except for *I. cordifolia* which showed increase from 4 per cent to 16 per cent germination.

The optimum period for the maximum germination of all the species with conc. H_2SO_4 treatment varied between 20 to 40 minutes in contrast to the results obtained by treatments of duration of one hour or more reported in case of leguminous seeds by various workers. The prolonged treatment with conc. H_2SO_4 adversely effected the embryo, thus bringing about a lowering in percentage germination. Therefore, the relative hardness of seed coats of various species might seem to indicate that germination in the last analysis depends on the changes in the hardness of the coats brought about by the acid treatment. Because the larger seeds would naturally expose comparatively larger surfaces for absorption, it would, therefore, be safe to infer that size would also play a part in bringing about changes in the seed coats by treatment with the acid and hence favourably influence the germination percentage.

SUMMARY

Studies on the comparative germination behaviour of five species of *Indigofera*, *viz.*, *I. cordifolia* Heyne, *I. hochstetteri* Baker, *I. linnaei* Ali, *I. oblongifolia* Frosk, and *I. tinctoria* Linn. were carried out. The germination of all the species varied between 0 to 6 per cent, under ordinary laboratory conditions at room temperature of 25°C. Therefore, the seeds were subjected to various pre-treatment as, high temperature, impaction, boiling hot water treatment, alcohol (95 per cent) and acid treatment to overcome failure of germination. Maximum germination results (12-27 per cent) for *I. cordifolia*, *I. hochstetteri*, *I. linnaei* were obtained at 30°C. Exposure to high temperatures for longer duration were found to be injurious. *I. oblongifolia* gave only 5 per cent germination at 30°C. *I. tinctoria* remained uneffected by the variation in temperature within the range 25°-40°C. Boiling hot water treatment gave variations of 2-16 per cent in imbibition of water and 0-16 per cent germination. Impaction or mechanical shaking given for 30-60 minutes brought about germination which varied between 4 to 12 per cent for *I. cordifolia*, *I. hochstetteri*, and *I. linnaei* and *I. oblongifolia*, *I. tinctoria* again remained uneffected. *I. cordifolia* gave 14 per cent germination when soaked only for two hours. *I. hochstetteri*, *I. linnaei* and *I. tinctoria* did not respond even when soaking was extended from 2 to 24 hours; but 2-4 per cent germination was obtained when soaking was prolonged to 48 hours. In *I. obolingifolia* the percentage of germination increased from 2 to 12 per cent with increase in duration of treatment up to 48 hours. The optimum period for the maximum germination (100 per cent) of seeds of all the species treated with conc. H_2SO_4 varied between 20 to 40 minutes. The prolonged treatment with conc. H_2SO_4 adversely affected the embryo thus bringing about a lowering in percentage of germination.

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DISCUSSION

A. K. Chakravarty: A distinction has been made between the autumn and spring seeds about their ability to germinate. May I know the causes of this different behaviour of autumn and spring seeds ?

U. N. Chatterji: One set of seeds has to pass through the winter while the other has to pass through the summer. As such, the physiological conditions for maturation of seed are different which affect germination.

Dalbir Singh: You have shown that the maximum inhibition and germination of the seeds of *Parkinsonia aculeata* took place after pre-treatment with boiling water. You attribute this to moist heat and further you have mentioned that the moist heat brings about a change in the structure of seed. Will you let me know, how you define moist heat and what type of changes take place in the seed coat-physical or chemical ?

U. N. Chatterji: In the dry heat the seeds will desiccate. With moist heat this difficulty is overcome and metabolic processes are permitted to continue. Permeability or the degree of absorption, in this case, indicated the changes in the seed-coat.

L. D. Ahuja: Why is the germination of the seeds of *Indigofera* species poor on petri-dishes while in nature profuse germination is observed ? Do you relate this loss of germination in storage or due to germination inhibitors ?

U. N. Chatterji: We have not carried out any studies on germination inhibitors. If the conditions are same in both cases, there should be equal germination. However, the physiological processes related to germination may be altered if the conditions are different.

MANAGEMENT OF SOIL-WATER-PLANT-CLIMATE COMPLEX WITH SPECIAL REFERENCE TO SALINE AND SODIC SOILS IN THE ARID ZONE[1]

by

B. RAMAMOORTHY[2]

INTRODUCTION

IT HAS been estimated that as much as 39 per cent of the total land area of the world comprises of the arid and semi arid regions and that a good part of this is of the saline nature. Quite a large proportion of this land surface is capable of producing high crop yields with irrigation. According to the committee on Natural Resources of the Planning Commission in India (1963) the ground water sources in northern India have not been fully exploited in some areas due to the highly saline nature of water, deep aquifers and non-availability of cheap power. Correct use of irrigation is more important in the long run than making it available because millions of acres of land in northern India which were once productive had to be abandoned on account of the development of soil salinity and alkalinity. Parks (1951) reported that over one million acres of land in the eleven Western States of the U.S.A. were abandoned during 1930-40 alone for this reason. Similarly Uppal (1962) reports that 1 lakh acres of productive land of the Indus-basin per year is going out of cultivation as it is rapidly becoming salinized. Chief amongst the characteristic agricultural management problems in this region (besides water conservation methods) are (I) recognition of the different kinds of problem soils (saline, sodic and saline-sodic) requiring different management practices and (II) the management (a) of non-saline non-sodic soils dependent on irrigation with ground waters, (b) of non-saline non-sodic soils dependent on major irrigation works from the rivers, (c) of sodic soils, (d) of saline soils and (e) of saline-sodic soils.

CHARACTERISTICS OF SALINE, SODIC AND SALINE-SODIC SOILS

The excessively saline or saline sodic soils is recognized by the appearance of salt incrustration on the soil surface during the summer season. The excessively sodic soils have the appearance of characteristic soil structure which has been described by Vilenski (1924). In the black soils of India, the *Chopan* (alkali) soils can be distinguished from the normal from the standing of water for longer periods even after a small amount of rain and the stickiness of the the soil as compared to normal soils. In the red soils, there is usually the development of columnar structure in the sub-soil. In the saline-alkali soils especially of the Recent alluvium subject to flooding, profile differentiation is not reported (Raychaudhuri and Sankaran, 1952).

In the course of lysimeter studies on the effect of irrigation with waters of different quality, it was found that in June after 20 irrigations on the alluvial loamy soil of Delhi, at the rate of 5 irrigations per year, the soils developed a smooth surface broken by small cracks into a mosaic like pattern. The width of the fissures as well as the number per unit area increased with the extent of alkali development as shown in Figs. 1, 2 and 3. Fig. 1 shows least cracking. The soil was treated with water of salinity of 2·5 m.e./litre, S.A.R. value of 8·27 and Residual Soluble Carbonate (R.S.C.) value of 1·01. The soil now has a *p*H value from 8·35 to 8·37, conductivity of saturation extract from 0·65 to 0·80 m mhos/cm, the degree of sodium saturation (D.S.S.) from 6·5 to 8·15, the equi-

Fig. 1

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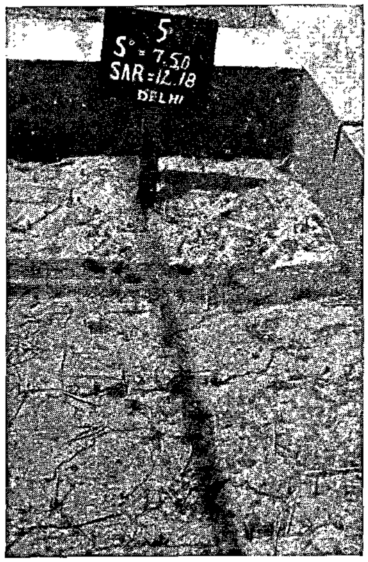

Fig. 2

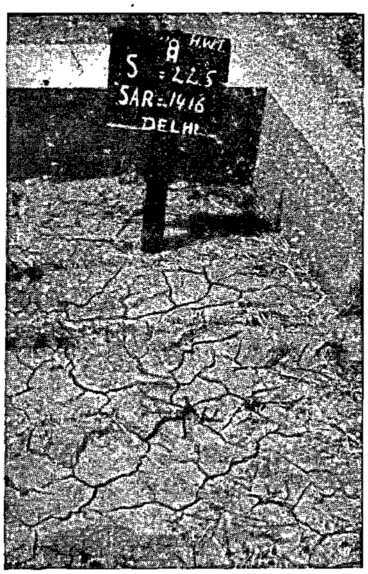

Fig. 3

librium S.A.R. value from 5·05 to 6·0. Figure 2 showing this symptom to a medium extent is of a soil irrigated with water of salinity 7·5 m.e./litre, S.A.R. value 12·18 and R.S.C. value 2·79. The soil has *p*H value ranging from 8·4 to 8·6, E.C. value from 1·10 to 1·40, D.S.S. from 7·2 to 13·5 and D. D. from 5·27 to 6·4. Figure 3 showing this very severely was irrigated with water of salinity of 22·5 m.e./litre, S.A.R. value of 14·16 and R.S.C. of 5·88. The water table in this soil was at about 2 ft. depth. The soil now has *p*H of 8·78, E.C. value from 2·15 to 2·00, D.S.S. from 18·0 to 21·0, equilibrium S.A.R. from 23·0 to 29·0 and D.D. from 14·8 to 18·0. The highly calcareous-grey sandy loam soil of Pusa also shows the same symptoms but at a slightly higher level of alkali development as compared to the Delhi soil. These symptoms may, therefore, be useful in recognizing mild alkali development in the alluvial soils.

As pointed out by the U.S. Salinity Laboratory Staff (1954), even in milder cases of salinity, the extent and frequency of bare spots in many areas may be taken as an index of the concentration of the salts in the surface soil especially during the period of germination. This is accompanied by the stunted growth of plants with considerable variation in size and a deep green foliage. But these have to be distinguished from other causes like faulty levelling of the soil and nutritional deficiencies. But if this great variability in size is also accompanied by characteristic symptoms at different spots in the field, it can generally be attributed to saline or alkali development in the soil.

The U.S. Salinity laboratory staff (1954) have examined the use of a vegetation survey of uncultivated lands for appraising the saline and sodic conditions in the soil and concluded that precautions should be taken in its interpretation. As Russell (1961) points out, there is a loss in the yield of crops due to salts without the salt damage being apparent to the farmer. There is need, therefore, for a sensitive indicator cultivated crop plant that is usually grown in the arid zone of this country.

Miglani (1964), has shown from both from sand culture and field analysis that gram (*Cicer aretinum*) developes characteristic symptoms to distinguish saline, sodic and saline-sodic conditions. In sand culture with nutrient solution having the same K.A.R., same levels of all nutrients except Ca and also excepting Na which were used to adjust S.A.R. and salinity of the growing medium to varying value, he obtained symptoms of non-availability with 45 m.e. of P/100 gm of dry matter in plants growing under moderate salinity of (8 m mhos/cm & S.A.R. value of 6) as against 58 m.e./100 gm d.m. of P in the normal plants in the seventh week of growth. The symptoms were purple tinge on the margins of leaflets, especially of the older leaves, increasing towards the mid-rib, darkening and drying with age till it proved fatal for 75 per cent of the plants in the 17th week.

Symptoms of Ca-deficiency like yellowing of new leaves with 26 to 38 m.e. of Ca/100 gm dry matter in the tops as against 40 m.e. in the normal plants and of K-deficiency with a value of 46-56 m.e. as against 87 in normal plants like premature burning of tips in old leaves were noted in the plants under moderately alkali conditions with E.C. value 2 m. mhos/cm in saturation extract and S.A.R. value of 24. These symptoms also became very severe with age.

When the culture medium had E.C. value of 8 m. mohs/cm and S.A.R. value of 48 representing saline sodic soil condition, the plants showed wilting, purpling and burning of old leaves, yellowing of the new leaves from the 4th week, heavy burning in the 9th week with Na reaching a high value of 80 m.e./100 gm. d.m. while the Ca, K., and P values remained almost normal. These symptoms and more severe ones under more saline-alkali conditions. Of all the plants 25 per cent died in the fourth week, and mortality increased with age.

All the above symptoms agreed with those obtained in the fields at the Nangloi (Delhi State) where they were found to occur at about the same S.A.R. and salinity of the soil extracts when averaged up to 0·6″ for the drying and highly stunted plants and up to 0·12″ soil depth for all other plants. Gram, therefore, appears to be suitable as an indicator plant for characterizing the soils.

MANAGEMENT OF NON-SALINE NON-SODIC SOILS IRRIGATED WITH GROUND WATERS

Success in agriculture in this group more than in any other depends on the suitability of management practices including the selection of crops adapted for the natural resources like the irrigation water quality and quantity available, the nature of the soil and the climate of the locality. The U.S. Salinity Laboratory Staff (1954) have on the basis of the electrical conductivity, classified irrigation water into four classes, C_1 with values from 0-250 micro-mhos/cm, C_2 with 250-750, C_3 with 750-2250 and C_4 with values above 2250. Durand (1955) and Kanwar (1961) modified the 4th class into C_4 with 2250 to 5000 E.C. and C_5 with 5000 to 20000 E.C.

This has to be further modified into C_4 with 2250 to 6750 E.C. and C_5 with 6750 to 20250 E.C. to maintain the dependence of water suitability on the logarithm of the conductivity of irrigation as originally proposed by the U.S. Salinity Laboratory Staff (1954). Since there is a positive interaction between salinity and sodic effects on plant growth, the U.S. Salinity laboratory staff (1954) take different values of the S.A.R. for the different alkali hazard classes depending upon the logarithm of the conductivity of the water. These four classes of alkali hazard S_1, S_2, S_3 and S_4 are usually adopted without modification. Although the water quality is also adversely affected by boron and HCO_3 contents amongst other things and favourably affected by NO'_3 contents, they are considered to be of special interest only in certain localities. The adverse effects of the first two are considered respectively as suggested by Wilcox (1955) and Eaton (1950).

Soil factors like texture, cation exchange capacity, permeability, presence of $CaCO_3$ and other sources of calcium in the soil as well as of impervious sub-soil layer are important in determining the suitability of irrigation water for any soil. Of these, soil texture is the one most easily determined in the field and the most general one and is used to classify the soils for irrigation purposes. The influence of this factor can be seen from the fact that the logarithm of the maximum permissible conductivity (c) of irrigation water suitable for the growth of semitolerant crops on different types of soils given by Durand (1955) follows a linear relation with percentage of sand generally characteristic of these soil groups and is given by the equation: $\text{Log } C = 0{\cdot}00952 \times \text{Sand } \% + 2{\cdot}57$.

Clay in the lighter textural groups and percentage sand in the heavier soils will be more appropriate for general classification of soils for this purpose on a quantitative basis. Setting a value T_3 for the textural index of loams and increasing it by a unit for every 20 per cent reduction in sand, the textural hazard class of clay loams will be $T_{3\cdot5}$ and of clayey soils will be $T_{4\cdot0}$ Similarly reducing it by one unit for every 10 per cent reduction in clay, the sandy loams become $T_{2\cdot5}$ and the sandy soils $T_{2\cdot0}$.

The plants are also to be classified according to their salt and alkalinity tolerance. As Russell (1961) points out, the lists of salt tolerance of crops are still largely made on practical experience in which the factors of salinity and alkalinity effects are not separated out. A beginning in this separation has been made by Bernstein and Peterson (1956), Peterson and Bernstein (1958), Singh (1963), and Miglani (1964) but more work is necessary to include all other common plants. In the meantime, the salt tolerance of crops as given by the U.S. Salinity Laboratory Staff (1954) and revised by Kanwar (1961) may be used with the notation P_1 for the salt tolerant class including sugar beets, gram and turnips which may perhaps be alkali tolerant, barley, cotton and radish belonging to alkali semi-tolerant; spinach belonging to alkali sensitive and *Dhaincha*, tobacoo, rape, sugarcane, *Taramira*, asparagus, Kale, date palm and *Falsa* as alkali unclassified. The P_2 or salt semi-tolerant group includes turnips (fodder) in the alkali tolerant, wheat, oats, rice, *Jowar*, lucerne, berseem, tomato, cabbage, cauliflower, carrot and peas in the alkali semi-tolerant, maize sunflower, lettuce and potato in the alkali sensitive and *Arhar*, flax, castor beans, *Senji*, Sudan grass, *Methi*, *Jowar*, cowpeas, onion, cucumber, pumpkins and bitter gourd in the alkali unclassified sub-groups. The P_3 or salt sensitive group includes celery in the alkali resistant; radish (English variety) in the alkali semi-tolerant; field beans in the alkali sensitive and *Guar* in the alkali unclassified sub-groups.

On this basis, the permissible extent in the water quality when made to almost agree with the lists given by previous workers, Durand (1955) and Kanwar (1961) as given in table I shows that the sum of classification index of water quality (e.g. 3 for water S_2C_1 Class), the textural index of the soil (e.g. 3 for a loam of T_3 class) and the salt tolerance index (e.g. 3 for field beans of P_3 Class) is 9. This constant value of the sum total of index numbers can be used to calculate the plant tolerant group that can be grown on any soil with the given type of water quality from a knowledge of the soil textural and water quality classes of the resources available.

TABLE 1: Upper limit of suitable water class for different soil textural class

Soil textural class	P_1 *Tolerant crops*	P_2 *Semi-tolerant crops*	P_3 *Sensitive crops*
T_4-Clay	S_1C_3 S_2C_2	S_1C_2 S_2C_1	S_1C_1 —
$T_{3\cdot5}$ -Clay Loam	$S_1C_{3\cdot5}$ $S_2C_{2\cdot5}$ $S_{2\cdot5}C_2$	$S_2C_{1\cdot5}$ $S_1C_{2\cdot5}$	$S_1C_{1\cdot5}$ $S_{1\cdot5}C_1$
T_3-Loam	S_1C_4 S_2C_3 S_3C_2	S_1C_3 S_2C_2 S_3C_1	S_1C_2 S_2C_1 —
$T_{2\cdot5}$ -Sandy Loam	$S_1C_{4\cdot5}$ $S_2C_{3\cdot5}$ $S_3C_{2\cdot5}$	$S_1C_{3\cdot5}$ $S_2C_{2\cdot5}$ $S_3C_{1\cdot5}$	$S_1C_{2\cdot5}$ $S_2C_{1\cdot5}$ $S_{2\cdot5}C_1$
T_2-Sandy soil	S_1C_5 S_2C_4 S_3C_3 S_4C_2	S_1C_4 S_2C_3 S_3C_2 S_4C_1	S_1C_3 S_2C_2 S_3C_1

If, however, the sum total of the soil textural class and the water quality class numbers is already 9 or more, an improvement in the quality of irrigation water is necessary.

If the irrigation water reclamation is necessiated by a high salinity hazard, Wilcox (1955) recommends the addition of gypsum. The utility of this procedure depends on the condition that this way of lowering the S class should compensate for the usual increase in the C class of the irrigation water. Gypsum can also be used to lower the R.S.C. and also sometimes the boron contents but here again, the gain should be more than the loss due to an increase in salinity. If the abnormality in the irrigation water is largely due to the high salinity hazard, this water is to be diluted either with any alternative source if available or by using only as a supplemented irrigation to the meagure rains of the arid zone or by using it in alternate years and allowing the rain water of the intervening years to leach out the soils in bunded field. In all these cases, additional quantities of irrigation is to be given to meet the leaching requirements on the use of saline waters as may be calculated from the formulae given by the U.S. Salinity Laboratory Staff (1954). Direct experimental evidence is necessary to test the possibility that making up of the P deficiency caused by the use of saline water reported by Miglani (1964) may also be helpful in this regard.

Fireman and Ramamoorthy (1962) have indicated that there are no major saline-alkali soil problems when the annual rainfall in any area exceeds the limitting rainfall characteristic of the mean annual temperature. If the actual rainfall of any locality is less than the limitting rainfall that can be read of from the curve of these workers for its mean temperature, additional amount of irrigation water is to be provided in proportion to this rainfall defecit in order to take into account the climatic factor in the management of soil-water-plant complex in the arid zone.

MANAGEMENT OF NON-SALINE NON-SODIC SOILS DEPENDENT ON CANAL IRRIGATION

In India the irrigation water from the major rivers is generally of good quality. Yet, many acres under this have gone out of cultivation due to saline-alkali troubles caused by a rise of water table. The precautions to be taken, therefore, consist of ensuring good surface and internal drainage of the soil, and cutting of the seepage from canals. A suggestion worth considering is the simultaneous use of such water combined with pumped out ground water so that the available water supply from the two sources is increased and the water table is not allowed to rise.

MANAGEMENT OF SODIC SOILS

Since the sodic soils are formed by the gain of exchangeable sodium at the expense of exchangeable calcium, the reclamation measure should include the restoration of calcium and effectively washing away of the sodium thus released by providing drainage so that alkalization is prevented. In non-calcareous highly alkali soils an amendment like gypsum is necessary. In non-calcareous alkali soils of low intensity, addition of organic matter plus calcium carbonate and in calcareous soils of the same alkali intensity organic matter alone may be sufficient. In some soils sources of calcium, like gypsum or calcium carbonate, may be present in the upper sub-soil and these can be utilized by deep ploughing and inverting the soil. In every alkali soil, internal drainage has to be improved after addition of the most suitable amendment as mentioned above, by deep ploughing and breaking hard pan if it is within reach, alternative wetting and drying of the soil, encouraging crop growth with heavy doses of fertilizers and to heavy irrigations at long intervals, which will encourage development of root system deep in the sub-soil. The soil has also to be cut off from the source of sodium.

The U.S. Salinity Laboratory Staff (1954) have reported that the adverse effects of exchangeable sodium are modified by the presence of potassium, soluble silicates and organic matter. Additions of these may also, therefore, ameleorate alkali soils but more direct experimentation on their use is necessary.

MANAGEMENT OF SALINE SOILS

The management of saline soil differs from that of the alkali soil in that there is no need for any amendment. The soil has to be cut off from the source of salts, levelled properly for even spread of irrigation and providing drainage both surface and internal and leaching with sweet water. Amongst the agronomic methods shown to ameleorate these soils are: (1) heavy irrigation before sowing; (2) more frequent irrigations; (3) planting crops on the side of the ridges just above the water line after putting the field into furrows and ridges; and (4) the growing of salt tolerant crops. The more liberal application of phosphatic fertilizers to saline soils and perhaps organic matter and copper might also help in ameliorating these soils but here again more direct experimentation on their use is needed.

A combination of the above two techniques is employed in the reclamation of saline-sodic soils.

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DISCUSSION

C. T. Abichandani: Whether any salinity and soil puffiness have been developed in lysimeter experiments and under what salinity and irrigation conditions ?

B. Ramamoorthy: I have described soil character only under alkali condition and plant characters under saline, alkali and saline-alkali conditions as the soil characters under saline conditions are pretty well known.

P. G. Adyalkar: Would you please explain what you mean by " synthetic irrigation water " ?

B. Ramamoorthy: By ' synthetic irrigation water ' I mean water artificially made upto different values of salinity and S.A.R., but not necessarily present at any location under natural conditions.

J. S. P. Yadav: Total salt content being the same, the relative proportion of the various anions in the salts has varied influence on the growth response, deficiency symptoms, etc., of plants. Has this aspect been examined in this study ?

B. Ramamoorthy: The proportion of anions was kept more or less constant and was not varied in this study and therefore, this aspect has not been examined.

S. A. Naqvi: I would like to know whether correlation studies with different metabolic changes have been done ?

B. Ramamoorthy: No, please.

A. R. Zafar: Are you aware of the fact that in the U.S.S.R. crops have been improved by the addition of sodium chloride to the soil ?

P. C. Raheja: The addition of sodium to heavy soils brings about dispersed state. In some soils there is deficiency of chloride which improves growth. In the U.S.S.R. it is possible, NaCl may have given good results on the basis of such response.

S. P. Raychaudhuri: Regarding the question of adding sodium salts for crop growth, the paddy farmers in certain places of district Burdwan in West Bengal use crude common salt for growing paddy and get beneficial results. Possibly the soil in such areas are deficient in chloride or sodium, but, in such cases the beneficial effect of sodium chloride has been practically established.

B. Ramamoorthy: Harmer in 1945 has actually indicated that crops are benefitted by sodium chloride and this is included in the classification of plants given in the paper.

QUALITY OF GROUND WATERS IN SIWANA, JALORE AND SAILA DEVELOPMENT BLOCKS[1]

by

R. C. MONDAL[2]

INTRODUCTION

AVAILABILITY of irrigation water in any arid region is one of the important limiting factors for agricultural development. Surface water in such tracts is usually inadequate and ground water of proper quality is, therefore, made use for irrigation purposes. Auden (1950) reported that the ground waters of western Rajasthan are generally highly saline. According to Taylor *et al.* (1953) most of the well waters of Pali region are moderate to highly saline with an average chloride concentration of 1000 p.p.m. The Department of Agriculture, Rajasthan, (1960) conducted qualitative tests on 13 wells located in different soil types in the Jawai canal commanded area and reported a range of 255 to 3112 p.p.m. of total dissolved salts in these waters. Sarma *et al.* (1963) analysed 51 representative ground waters from wells located along both the banks of the Luni River in the Lower Luni basin of western Rajasthan and reported a range of 0·90 to 13·00 m. mhos/cm. at 25°C of electrical conductivity of these waters along with the ranges of the variation of soluble sodium percentage, residual alkalinity and sodium absorption ratio which are of vital importance for assessing the quality of waters for irrigation. (Richards 1954, Ed). By analysis of 74 well waters of Jodhpur district and 85 of Pali district Sankarnarayan *et al.* (1963) have indicated that these waters have electrical conductivity of the range of 0·90 to 55·00 m. mhos/cm. at 25°C with more than 65 as soluble sodium percentage in 85·4 per cent of these waters. These authors also examined these waters according to the concept of Richard (1954) for irrigation. Adyalkar and Ramesam (1963) classified 13 well waters of western Rajasthan on the basis of electrical conductivity which vary from 1 to 40 m. mhos/cm at 25°C. In a study of correlation of various ions with electrical conductivity of ground waters of western Rajasthan, Mondal and Jain (1966) have reported a variation of 546-3997 micromhos/cm of electrical conductivity and 0·63 to 30·54 of sodium absorption ratio in 72 ground water samples along with the variation of soluble cations and anions.

However, although some analytical data of ground waters of the regions are available, much more work is needed to assess their suitability for irrigation and to classify them accordingly. It has, therefore, been attempted in this paper to classify some of the ground waters for irrigation on the basis of the concept of Richard (1954) with some modification in relation to adjusting the local factors. Samples of ground waters have been collected mostly from Siwana, Jalore and Saila blocks of the Luni River basin of western Rajasthan.

QUALITY OF GROUND WATERS FOR IRRIGATION

Five per cent of the well waters of the various test groups viz. sweet, brackish and saline as classified in the village revenue records have been examined for electrical conductivity and sodium adsorption ratio (Chatterji and Mondal, 1964). The classification of these waters based on chemical test has indicated that the grouping of these waters on the basis of oral test shown in the revenue records does not agree with the scientific classification except in the extreme cases of salinity.

The ground waters have been classified according to the concepts of Endersen (1955), C.S.I.R.O. (1956-57), Durand (1949) and I.C.A.R. (1961). Waters having more than 7000 p.p.m. of total soluble salts, is normally considered as unfit for irrigation. In Siwana Development block, however, very high saline waters having even upto 10,000 p.p.m. of T.S.S. have been in use for irrigation on light soils. In the present classification, therefore, waters having total soluble salts within the range of 7000-10000 p.p.m. have been grouped as class VI (C_6). Ground waters having total soluble salt of more than 10,000 p.p.m. are used for stock drinking purpose and, therefore, such waters have been put under a separate class named as class VII (C_7). The various classes of ground water and the area in which each class occurs have been presented in Table 1:

Major portion of the region has C_3 and C_4 type of waters C_2 type is confined mostly to the duny areas, C_3 type to the intermontane area, C_4 and C_5 type to the foot hill zone, and river tract, and C_6 and C_7 type to the plain tract.

The availability of C_2 type of ground water in the dune areas is probably due to the fact that these zones are normally in close proximity to the hills and water of ephemeral streams, originating from the hills,

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Analytical Chemist at the Institute.

TABLE 1: Different classes of ground waters and their coverage in Siwana Development block*

S. No.	Class	Range of T.S.S. in p.p.m.	Percentage of the total area
1	Class I (C_1)	Upto 180	Nil
2	Class II (C_2)	180-500	14·69
3	Class III (C_3)	500-1500	35·94
4	Class IV (C_4)	1500-3200	25·80
5	Class V (C_5)	3200-7000	18·10
6	Class VI (C_6)	7000-10000	5·34
7	Class VII (C_7)	Over 10000	0·12

*Chatterji, P. C. and Mondal, R. C., 1964.

gets infiltrated in highly permeable dune areas. Surface soil layer contain very little soluble salts and thus the ground water aquifers are recharged with non-saline fresh water to the maximum extent. Adyalkar and Ramesam (1963) have, however, stated in their general field observations that in the dune country the ground waters tend to be more saline due to lack of effective recharge. The existence of C_3 type of water in the intermontance area is probably due to the fact that there is very little soil cover in this zone and ephemeral streams do not flow for a long distance through the salt affected soil cover as is the case of waters of higher salinity classes. The higher salinity of the water in the intermontane areas than in duny areas is probably due to its contamination with the weathering products of rocks. In the foot hill and river zone there is deep deposition of salt affected soils and the streams flow for a long distance before the surface waters accumulate in the lower strata thus rendering the ground waters more saline of C_4 and C_5 types. The plain tracts do not have many ephemeral drainage channels to recharge the under ground aquifers which probably creates more saline condition of the type of C_7 in the ground waters.

While considering the sodium adsorption ratio along with total soluble salts for classification of irrigation water, U.S.D.A. Handbook No. 60 does not provide any information for the water of which the total soluble salt content is more than 3,200 p.p.m. Therefore, for such classification, the waters having more then 3200 p.p.m. of total soluble salts have been excluded. The result of such classification is given in Table 2.

TABLE 2: Distribution of ground water according to total soluble salts and S A.R. values*

S. No.	Type of ground water	Percentage of total wells upto class IV(C_4) type	Percentage of the total area under various types of ground waters
(1)	(2)	(3)	(4)
1	C_2-S_1	2·13	19·21
2	C_3-S_1	36·17	43·46
3	C_3-S_2	8·51	6·95
4	C_3-S_3	2·13	1·14
5	C_4-S_1	25·53	19·96
6	C_4-S_2	12·76	4·23
7	C_4-S_3	8·51	1·85
8	C_4-S_4	4·26	3·20
	Total	100·00	100·00

*Chatterji, P. C. and Mondal, R. C., 1964.

These types of ground waters are available in 65 per cent of the total number of wells examined in this tract and cover 27·9 per cent of the entire block area. This represents in all 76·43 per cent area of the ground water exploitation zone.

Electrical conductivity and sodium adsorption ratio of a total number of 236 ground waters of Siwana, Jalore and Saila Development blocks have been taken into consideration for classification of these waters. In this classification the range of electrical conducti-

TABLE 3: Classification of different types of ground water

Range of conductivity micromhos/cm at 25°C	Total No. of water sample	Per cent of water	S.A.R. groups (shown as per cent under each conductivity class)					
			0-10 (S_1)	10-18 (S_2)	18-26 (S_3)	26-34 (S_4)	34-42 (S_5)	Over 42 (S_6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0-250 (C_1)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
250-750 (C_2)	14	5·9	100	Nil	Nil	Nil	Nil	Nil
750-2250 (C_3)	67	28·4	80·59	10·44	5·97	2·96	Nil	Nil
2250-5000 (C_4)	70	29·6	47·14	28·57	17·14	4·28	1·43	1·43
5000-10,000 (C_5)	62	26·4	20·96	25·80	22·58	12·90	8·06	9·69
10,000-15,000 (C_6)	17	7·2	5·88	23·52	35·29	5·88	5·88	23·52
Above 15,000 (C_7)	6	2·5	Nil	Nil	33·33	33·33	16·66	16·66

vity for various classes of waters have been chosen on the above stated basis. In case of sodium adsorption ratio some arbitrary range have been taken for the very high S.A.R. waters so that some differentiation of such waters could be shown. The various S.A.R. values of waters in different conductivity classes have been given in Table 3.

The majority of the waters (84·4 per cent) are distributed in three conductivity classes like C_3, C_4 and C_5 which are normally used for irrigation in these regions. Water having electrical conductivity of more than 10,000 micromhos/cm at 25°C is normally unsuitable for irrigation. Such class comprised 9·7 per cent of the total number of water samples from the wells.

The results further show that out of the total of 236 ground water samples, the various S.A.R. groups i.e. S_1, S_2, S_3, S_4, S_5 and S_6 have 115, 47, 38, 16, 8 and 12 samples, respectively. All the waters of the C_2 type are least affected by S.A.R. groups.

The occurrence of S_1 waters in each conductivity class, decreases with increase in electrical conductivity with a corresponding increase of the other higher S.A.R. groups. In other words, the percentage of the higher S.A.R. groups of waters expressed as percentage of the total number of waters under each conductivity class, increases with the increase in conductivity.

The above classification thus shows the suitability of the ground water of arid and semiarid areas of western Rajasthan for irrigation purposes.

INTER-RELATION OF CONCENTRATION OF VARIOUS IONS. SODIUM ADSORPTION RATIO AND ELECTRICAL CONDUCTIVITY

To avoid the tedious and time consuming task of chemical analysis, Mondal and Jain (1963) determined correlation between various characters of waters so that some easily estimable character or some characters in combination can precisely estimate the other characters of the waters which are necessary for the assessment of its quality. Seventytwo ground water samples of western Rajasthan, having electrical conductivity of less than 4,000 micromhos/cm at 25°C have been chemically analysed. Results of analysis are given in Table 4.

TABLE 4: Chemical analysis of ground water*

Character	Range of variation	Mean
1. Electrical conductivity in micromhos/cm at 25°C	546 to 3997	1949·75
2. *pH*	6·7-8·9	7·57
3. Na (meq/l)	1·04-36·95	12·86
4. K ,,	0·02-5·35	1·06
5. Ca ,,	0·42-9·97	1·99
6. Mg ,,	0·47-7·43	3·15
7. CL ,,	1·00-27·10	9·35
8. SO_4 ,,	0·22-13·98	4·55
9. HCO_3 ,,	0·56-19·63	5·32
10. CO_3 ,,	0·00-3·44	0·61
11. S.A.R.	0·63-30·54	8·52

*Mondal, R. C. and Jain, M. B., 1966.

Total correlation coefficient between electrical conductivity and various ions along with the linear regression equations have been given in Table 5.

TABLE 5: Total correlation coefficients between electrical conductivity and various ions and S.A.R. values along with the respective regression equation*

Correlation between electrical conductivity (X) and — (in meg/l)	r	Regression equation
(1) Chloride (Y_1)	+0·8418***	Y_1=0·005375× −1·1314
(2) Sulphate (Y_2)	+0·5917***	Y_2=0·002181× +0·2965
(3) Bicarbonate (Y_3)	+0·5390***	Y_3=0·001984× +1·4545
(4) Sodium (Z_1)	+0·9208***	Z_1=0·008500× −3·7111
(5) Magnesium (Z_2)	+0·3056**	Z_2=0·000463× +2·2453
(6) Calcium (Z_3)	+0·2279	.
(7) Calcium + Magnesium (Z_4)	+0·2008	.
(8) Chloride+Sulphate +Bicarbonate (Y_4)	+0·9627***	Y_4=0·009537× +0·6252
(9) Sodium+Calcium +Magnesium (Z_5)	+0·8270***	Z_4=0·007848× +2·8330
(10) Sodium+Potassium+Calcium +Magnesium (Z_6)	+0·9732***	Z_6=0·009498× +0·8399
(11) Total soluble salts in ppm (S)	+0·9681***	S=0·6628× −7·9643
(12) S.A.R. (ratio)	+0·8108***	S.A.R.=0·005355× −1·9249

***Significant at 0·1% level. *Electricity conductivity in micromhos/cm at 25°C. **Significant at 1% level.

*Mondal, R. C. and Jain, M. B., 1966.

Except in the case of Ca and Ca+Mg, electrical conductivity is highly and positively correlated with (1) Na, Mg, Cl, SO_4 and HCO_3 ions; (2) summation $Cl+SO_4+HCO_3$ ions; (3) summation Na +Ca + Mg ions; (4) summation Na + Ca + Mg + K ions and (5) total soluble salts. Sodium adsorption ratio (S.A.R.) is highly correlated with electrical conductivity ($r = 0{\cdot}8108$).

The multiple correlation coefficient between Na and Ca and Mg is not significant but as soon as either Ca or Mg, or Ca and Mg, or Ca + Mg with electrical conductivity in each case when taken as independent variates for the prediction of sodium, the multiple correlation coefficient in all the cases become highly significant. Several multiple regression equations for

TABLE 6: Multiple correlation coefficients (R) and multiple regression equations*

Particulars	*R*	*Multiple regression equation*
1.0 Sodium (Z_2) in terms of	—	—
1.1 Magnesium (Z_2) and Calcium (Z_3)	+0·0880***	—
1.2 Elec. cond. (X) and Calcium (Z_3)	+0·9393***	$Z_1=0{\cdot}0098X-0{\cdot}9011Z_3-2{\cdot}7127$
1.3 Elec. cond. (X) and Magnesium (Z_2)	+0·9529***	$Z_1=0{\cdot}0092X-1{\cdot}5687Z_2-0{\cdot}1942$
1.4 Elec. cond. (X), Magnesium (Z_2) and Calcium (Z_1)	+0·9679***	$Z_1=0{\cdot}0096X-1{\cdot}8606Z_2-1{\cdot}3452Z_3+2{\cdot}6190$
1.5 Elec. cond. (X) and sum of Calcium and Magnesium (Z_4)	+0·9467***	$Z_1=0{\cdot}0089X-0{\cdot}8268Z_4-0{\cdot}1670$
2.0 Sulphate (Y_2) in terms of	—	—
2.1 Chloride (Y_1) and Bicarbonate (Y_3)	+0·3726**	$Y_2=0{\cdot}1436Y_1+0{\cdot}2294Y_3+1{\cdot}9854$
2.2 Elec. cond. (X) and Bicarbonate (Y_3)	+0·5928***	$Y_2=0{\cdot}0023X-0{\cdot}0510Y_3+0{\cdot}3749$
2.3 Elec. cond. (X) and Chloride (Y_1)	+0·6856***	$Y_3=0{\cdot}0042X-0{\cdot}3969Y_1+0{\cdot}5894$
2.4 Elec. cond. (X), Chloride (Y_1) and Bicarbonate (Y_3)	+0·8803***	$Y_2=0{\cdot}0060X-0{\cdot}5790Y_1-0{\cdot}0795Y_3+10{\cdot}2676$

**Significant at 1% level. ***Significant at 0·1% level. *Mondal, R. C. and Jain, M. B. (1966).

the prediction of the concentration of Na have, therefore, been worked out and presented in Table 6.

The applicability of these simple and multiple regression equations for the prediction of Na and, thereby, S.A.R. values have been tested with some waters of the western Rajasthan analysed by Sharma *et al.* (1963). The figures of the observed and the predicted values of sodium have been given in Table 7.

The very high correlation coefficients of the order of + 0·86 to + 0·99 between the observed and the predicted values of sodium indicates that the proposed equations for the prediction of sodium (Table 5 and 6) are quite dependable for the well waters of the western Rajasthan.

S.A.R. of these waters have been calculated from its relationship with electrical conductivity (S.A.R. $= 0{\cdot}005355 \times - 1{\cdot}9249$; where, X = electrical conductivity in micromhos/cm. at 25°C) as well as from the predicted values of sodium (Table 7).

It is observed that when the predicted values of sodium were taken for the calculation of S.A.R. very highly significant correlation coefficients of the order of + 0·93 to + 0·99 between the observed and the predicted S.A.R. values are obtained. When electrical conductivity alone has been considered for the prediction of S.A.R. value, the correlation coefficient is also highly significant ($r = + 0{\cdot}77$).

In the U.S.D.A. Hand Book No. 60 (1954) it has been suggested that in irrigation water S.A.R. of the range of 0-10 is low, 10-18 is medium and 18-26 is high. The application of any of these prediction equations for the calculation of S.A.R. does not affect this classification at all in case of 12 to 13 waters out of 17 under study. The predicted S.A.R. values of the rest 4-5 waters do not, however, differ much from what has been observed by chemical estimation. The misfit classification of these rest 4-5 waters is probably due to the reason that these waters have got observed S.A.R. of the order of 10 or 18 which are the marginal figures of one class to another.

SUMMARY

The ground waters from three Siwana, Jalore and Saila Development blocks in the central Luni River basin have been classified for their suitability for irrigation according to the standard concept with some modification to adjust the local factors. In Siwana Development Block, 35·8 per cent of the area is covered by ground water exploitation zone. In this zone 63 per cent of the total number of wells have C_2 to C_5 type of ground waters which are used for irrigation on light soils. These waters have further been grouped according to sodium adsorption ratio.

Various ranges of electrical conductivity and sodium adsorption ratio have also been considered while classifying 236 ground waters of all the Siwana, Jalore and Saila Development blocks. Majority of the waters (84·4 per cent) are similarly distributed in three conductivity class-C_2, C_4 and C_5 having electrical conductivity varying from 750 to 10,000 micromhos/cm. The distribution of these waters in various sodium adsorption ratio (S.A.R.) groups of waters expressed as percentage of the total number of water under each conductivity class increases with increase in electrical conductivity.

ACKNOWLEDGEMENT

Grateful thanks are due to Dr. P. C. Raheja, M.Sc., Ph.D., D.Sc., F.W.A., Director, for providing facilities and encouragement for this work. Thanks are also due to Dr. B. B. Roy, Head of the Basic Resource Studies Division, for his valuable suggestions while going through the manuscript.

TABLE 7: Observed and predicted concentration of sodium and S.A.R. for the waters of western Rajasthan

Name of the village	Electrical conductivity (m.mhos/cm**)	Observed sodium (meq/1)**	Predicted sodium (meq/1) by Eq. (4) Table 5	Eq. 1.2 Table 6	Eq. 1.3 Table 6	Eq. 1.4 Table 6	Eq. 1.5 Table 6	Observed S.A.R.**	Predicted S.A.R. by Eq. (4) Table 5	Eq. (12) Table 6	Eq. 1.2 Table 6	Eq. 1.3 Table 6	Eq. 1.4 Table 6	Eq. 1.5 Table 6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Hathigaon	0·95	5·15	4·36	2·13	8·06	5·78	4·72	3·52	2·97	3·16	1·44	5·48	3·89	3·21
Duthwas	1·00	6·21	4·78	2·67	7·52	6·63	5·77	4·56	3·52	3·43	1·96	5·52	4·87	4·24
Surachan	1·00	7·31	4·78	4·38	7·16	7·33	6·10	5·85	3 80	3·43	3·47	5·68	5·81	4·84
Tampi	1·20	5·37	6·49	6·53	2·41	2·00	4·74	2·88	3·47	4·50	3·49	1·28	11·06	2·53
Bedia	1·40	8·48	8·19	7·40	7·73	6·68	7·53	5·08	4·82	5·57	4·35	4·54	3·92	4·32
Tampi	1·40	8·68	8·19	7·59	7·73	6·95	7·70	5·74	4·90	5·57	1·54	4·62	4·16	4·61
Jalberi	1·80	9·18	11·59	9·36	9·92	6·33	8·81	4·45	5·62	7·71	4·53	4·81	3·07	4·27
Tampi	2·50	19·71	17·54	16·29	17·50	21·10	17·61	11·59	10·32	11·46	9·58	10·29	12·41	10·35
Agnawa	2·60	15·07	18·39	12·47	22·74	14·53	15·15	6·87	8·47	12·00	5·74	10·47	6·69	6·98
Tampi	2·50	18·32	17·54	18·10	17·35	15·30	16·23	9·74	9·33	11·46	9·62	9·22	8·13	8·64
Keria	2·90	18·48	20·44	14·68	22·52	13·11	16·78	7·57	12·81	13·60	5·99	9·22	5·37	6·64
Saruwas	2·90	26·35	20·44	20·94	24·10	24·40	22·40	18·82	14·96	13·60	14·95	17·24	17·42	16·00
Bhimgida	3·10	26·71	22·54	20·91	26·91	24·78	23·04	15·48	13·89	14·68	12·82	16·50	15·20	14·13
Jhambarai	3·40	23·49	25·19	21·06	27·12	20·86	22·05	10·67	11·45	16·28	9·57	7·78	9·58	10·22
Haliwas	3·60	31·25	26·89	25·00	32·17	29·83	27·51	19·29	16·50	17·35	15·33	19·73	18·30	16·87
Dungari	3·60	25·25	26·89	27·53	17·04	15·64	21·84	10·29	10·93	17·35	11·19	6·93	6·35	8·27
Raipur	4·00	36·43	30·29	31·08	29·59	29·49	28·85	18·89	16·46	20·50	16·87	16·08	16·02	15·67
Correlation coefficient between observed and predicated value			+0·8647*	+0·9709*	+0·9232*	+0·9604*	+0·9922*		+0·9340*	+0·7755*	+0·9653*	+9431*	+0·9759*	+0·9953*

*Significant at 0·1% level; **Sharma, D. L., Jain, V. S., Mehta, K. M. (1966).

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DISCUSSION

K. V. Raghavarao: What is the sampling period of the water samples? Have you taken into consideration the hydrological cycle and flushing of ground waters?

R. C. Mondal: We have collected the samples when the irrigation starts.

P. G. Adyalkar: Have you prepared iso-chlor, iso-bicarb and iso-sulphate maps of these areas and with what results?

R. C. Mondal: So far, we have prepared these maps only for Siwana Block. We will be preparing these maps for other areas also.

N. C. Rawal: What is the percentage error involved in this rapid conductivity method? Whether it can be applied for a large analytical work of water analysis required for pre-irrigation work? Standardization of such method before it can be put in use for irrigation water is warranted.

R. C. Mondal: The derived formulae have been tested. The analytical data of sodium and sodium adsorption ratio of 17 waters of Central Luni River basin do not vary much from the corresponding predicted figures obtained by the prediction equations. Therefore, this easy technique of analysis could be satisfactorily applied for the analysis of the ground waters of western Rajasthan.

P. G. Adyalkar: Normally geologists, hydrologists and hydro-geologists take two samples, pre-monsoon and post-monsoon, as representative of the year. Have you also followed the same technique?

R. C. Mondal: Yes, please. But, we have not included those data in this paper.

K. V. Paliwal: How many samples have been analysed? Are these correlations applicable to all types of waters?

R. C. Mondal: Seventy water samples were analysed. In this area these correlations predict approximately corredct values.

MOISTURE RELATIONS OF SOME DESERT PLANTS[1]

by

A. N. Lahiri[2]

The primary consideration in any study related to moisture relations of plants is that a certain hydrature of the tissue must be maintained for the continuation of active processes at cell level. The status of moisture in the tissue is considerably altered with aging and development of organs or by environmental factors. Nevertheless, in active cells moisture content is usually higher and, therefore, adjustment of moisture balance in plants growing under low moisture levels is of particular interest. The arid region of Western Rajasthan provides an ideal condition for such studies in view of the low precipitation and prolonged rainless weather encountered in this region. Investigations on certain aspects of plant and soil moisture relations have been carried out in this Institute since the latter part of 1960. This paper summarizes some of the results of these investigation.

TRANSPIRATION DURING DRY PERIODS

Extensive work has been carried out (Oppenheimer, 1951; Stalfelt, 1956; Stocker, 1956; Vaadia *et al*, 1961) on the moisture turn-over of plants with reference to climatic and edaphic factors. When the transpiration rate is low or when the soil moisture potential is high, the effect of soil moisture variations upon water deficit is small, since the soil moisture is not the limiting factor for transpiration. On the other hand, under high transpiration conditions there is appreciable effect on water deficit of the plant. Contradiction in relation to moisture availability and transpiration behaviour of plants are, however, well known (Veihmeyer, 1956) and do not require elaboration.

Investigations on the diurnal variations in transpiration in some Indian desert plants with reference to micro-climatic changes, have been carried out here in different seasons. However, in the present context transpiration behaviour of plants during the dry period (i.e. October to June) with special reference to soil moisture status is of interest. Studies on transpiration have been carried out following rapid weighing method and moisture loss of leaf was measured during the minute immediately following detachment from the plant. Mean rate of transpiration in certain plants in hot summer days in May and June and the moisture status of the sites at different depths are presented in Tables 1 and 2 respectively. During these months moisture status of the soil was low because the onset of showers in these areas occurs during July. In the stabilized dunes near Barmer and Gadra Road, soil moisture was below 1 per cent upto the depth of 91 cm and it never went above 3 per cent level at any depths up to 183 cm. During this period all the grasses were dry excepting plants like *Aerva javanica, Salvadora oleoides, Crotalaria burhia, Prosopis spicigera, Tecomella undulata, Calotropis procera* and a few others.

Moisture determinations on two consecutive days in May at Jodhpur indicated almost a similar status of moisture. It is interesting to note that the rate of transpiration is quite high (Table 1) in spite of the low moisture regimes observed upto the depths of 183-200 cm. Wilting point of dune sand being Ca. 1·0 and that of soil of Jodhpur Ca. 2·5, the effective moisture balance could be only maintained by these plants by tapping moisture from deeper depths, as otherwise, such unrestricted moisture expenditure could not have been possible. It is possible that moisture from the upper layers of soil was depleted in vegetated sites by the quick growing annuals and grasses that come up immediately after the rains.

However, in the unstabilized dunes which are and not covered by vagetation, high moisture content (ca. 2·0%) was recorded within 30 cm from the surface. Investigations of Dabadghao *et al.* (1962) indicate that maximum depth of root system in grasses (19 months old) like *Cenchrus ciliaris, Cenchrus setigerus, Panicum antidotale* and *Dichanthium annulatum* are between 117-196 cm. In case of *Lasiurus sindicus*, roots went down upto 403 cm. During summer months these grasses dry up due to adverse soil moisture stress. On the contrary, transpiration character of perennials presented in Table 1, indicates that they are completely drought evading. In winter season the active period of transpiration is shortened, but, the rates of transpiration observed during the afternoon hours are comparable with these observed in the early hours in the summer. This reduction in active period of transpiration is due to low temperatures in the morning and decrease in the intensity of light towards the evening.

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Plant Physiologist at the Institute.

TABLE 1: Transpiration rates of certain xeric plants during snmmer months

Species	Time of year	Site	Transpiration rate mg/g/hr at indicated hours													
			6	7	8	9	10	11	12	13	14	15	16	17	18	19
		Site A														
S. oeoides	14-6-63	(Gadra Road sand dunes)	—	—	280·0	352·0	385·2	346·0	242·0	304·2	240·8	200·4	416·2	153·6	136·6	—
A. javanica	do	do	—	—	519·0	919·4	798·0	816·0	1040·0	1056·0	926·8	1103·6	1070·4	674·4	400·2	—
P. spicigera	do	do	—	—	394·2	653·8	567·4	761·8	646·0	609·8	826·4	951·9	954·1	746·7	588·4	—
		Site B														
S. oleoides	12-6-63	Barmer (Sand dunes)	—	—	386·0	410·0	272·6	288·0	302·0	398·0	259·0	152·0	498·0	406·0	52·0	—
T. undulata	do	do	—	—	334·2	525·4	772·4	762·5	809·4	1075·5	122·0	1210·0	982·0	1046·0	542·4	108·6
A. javanica	do	do	—	—	421·3	646·0	652·1	623·4	600·5	902·6	925·2	1260·4	611·8	606·0	0·0	—
		Site C														
P. spicigera	27-5-63	Joshpur (Flat sandy plain)	504·1	877·4	669·1	833·5	43·3	697·2	550·7	593·4	789·6	1013·5	539·3	689·7	248·9	—
P. spicigera	28-5-63	do	450·0	565·0	799·0	868·8	930·8	888·7	879·9	693·7	581·5	475·0	451·1	793·1	684·4	—

TABLE 2: Moisture content of the various sites

Moisture content of indicated sites	Method	Surface	% moisture at indicated depths in cm from the surface																	
			5	15	25	31	46	50	61	75	76	91	100	106	122	137	150	152	167	183
Site A	Gravimetric	0·0	—	0·1	—	0·5	0·7	—	0·9	—	1·0	0·8	—	1·5	—	1·3	1·8	—	1·8	2·0
Site B	do	0·0	—	0·2	—	0·8	1·0	—	0·7	—	0·8	0·9	—	1·9	1·5	1·4	—	1·7	1·9	2·6
Site C 1.	Gypsum block	—	1·0	—	0·3	—	—	1·1	—	1·9	—	—	2·2	—	—	2·3	—	—	—	—
2.	do	—	1·0	—	0·2	—	—	1·1	—	1·9	—	—	2·2	—	—	2·3	—	—	—	

MOISTURE LEVEL AND TRANSPIRATION RATE IN *TECOMELLA UNDULATA*

These studies were conducted during 1961-62 and the physiological responses of these tree seedlings have been investigated with reference to the level of moisture supply. The seedlings of *Tecomella undulata*, growing in closed containers under different levels of watering indicated that (i) moisture out put by transpiration was curtailed under low levels of watering and (ii) total leaf area of the plants, as well as, area of individual leaves were reduced in plants growing under low moisture regimes. The total moisture output, irrespective of the season, is consistently low in plants growing at low soil moisture level. A definite gradation in this output could also be observed in different levels of watering.

In Fig. 1 a few results from the routine weekly observations have been illustrated. The determinations of transpiration rates do not present the exact picture of moisture expenditure because of the reduction in surface area of leaves under low soil moisture conditions. This relative reduction of leaf area in different moisture regime, changes with time and depends upon the growth and regeneration processes. However, reduction in total transpiring surface is not mediated by leaf shedding alone but also by reduction in leaf size in accordance with reduction of soil moisture (Table 3).

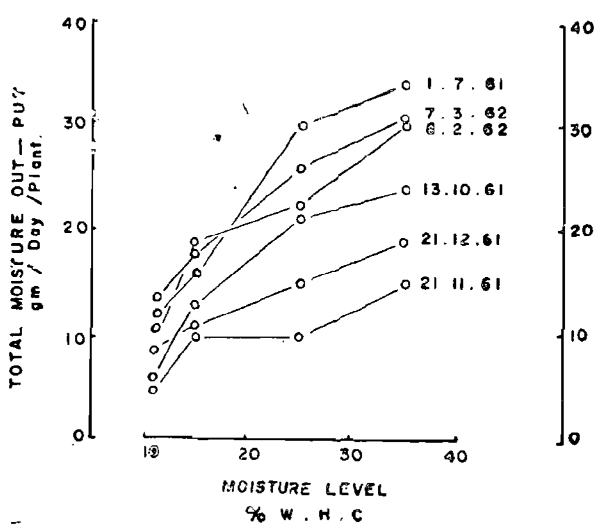

Fig. 1 — Relationship between level of watering and total moisture output per plant on different dates

Restriction of leaf area according to availability of moisture has also been observed in certain other species (Shmueli, 1948). In this connection, emphasis given by Oppenheimer (1951 & 1960) on leaf area in the context of moisture balance problem seems to be quite appropriate. The rate of transpiration, as such, is minimized considerably with the loss of turgidity of leaves during the periods of drought.

TABLE 3: Reduction in leaf area of individual leaves with reduction in dosage of watering

Moisture level %W.H.C.	*Mean leaf area (mm) of indicated pair of leaves from apex*				
	2nd	*3rd*	*4th*	*5th*	*6th*
35	21·7	16·3	29·6	30·3	33·0
25	13·9	12·2	13·6	21·2	22·0
15	9·4	7·2	12·0	9·8	4·8

In one experiment, drought was imposed by withholding watering, when initial relative turgidity percentage of leaf was 81·16, transpiration rate was 17·2 mg/cm^2/hr and soil moisture was 6·52 per cent. At the end of drought period on the 10th day from the commencement of drought when the soil moisture in closed container was brought down to 1·37 per cent, R.T. per cent was reduced to 23·53 and transpiration rate came down to 1·8 mg/cm^2/hr. Within a few hours of rewatering R.T. per cent increased to 74·14 and rate of transpiration increased to 18·9 mg/cm^2/hr. This indicated that the plant had the power to regain the normal hydrature quickly and this was coupled with unrestricted moisture turnover.

INTERNAL WATER BALANCE IN *PROSOPIS SPICIGERA* COMMUNITY

Investigations on the water balance of this tree community were recently initiated to study the growth and internal water relationships of plants, in relation to soil moisture status and atmospheric conditions. The approach to the problem was similar to that outlined by Slatyer (1962). A limited number of *P. spicigera* trees and one metre by one metre quadrats of the ground cover (consisting mainly of *Dactyloctenium sindicum*) were frequently irrigated to eliminate soil moisture stress. The unirrigated natural community served as the control. Assessment of growth in *P. spicigera* tree was attempted from the measurement of changes in length and weight of 4th order branches, which proved to be unsatisfactory due to recurring mortality of the branch apices. The results indicated that soil moisture is the main limiting factor for the growth of (determined in terms of NAR and LAI of central 20 cm $\times$ 20 cm portion of the quadrats) of the ground cover during the rainless period of the year. However, elimination of moisture stress brought about regeneration of the grass cover coupled with normal growth and development.

In the *P. spicigera* tree, shedding of old leaves; regeneration of new leaves and flowering and fruiting was also observed during March and April. Moreover, the expenditure of soil moisture by transpiration was not restricted by this plant during the rainless periods of winter and summer seasons. From the experiments conducted on two consecutive days in February, May and August it was estimated that the mean total moisture out put per day from a tree was ca. 153·82, 111·60 and 98·65 kg respectively. This large expenditure of soil moisture coupled with unimpaired developmental processes during dry periods strongly suggests that the tree is suitably adjusted with the arid environment. However, elimination of soil moisture stress, by irrigation, brought about significant changes in the relative turgidity of the leaves (Table 4).

TABLE 4: R.T. per cent in irrigated and unirrigated *P. spicigera* trees

Treatments	*R.T. % on indicated dates*			
	15-3-63	30-3-63	15-4-63	4-5-63
1. Irrigated	86·45 ±2·2	94·87 ±2·1	87·00 ±0·9	88·58 ±1·1
2. Unirrigated	80·02 ±1·7	80·53 ±2·3	70·12 ±1·9	75·64 ±1·8

This indicated that internal moisture status of the plant is improved when soil moisture is readily available to the plants. In relation to the experiments in *T. undulata* it was observed that the leaf turgidity was regained immediately after the establishment of favourable soil moisture status. In *P. spicigera* tree a similar trend of quick moisture absorption and transport was observed after a shower of 5·8 mm, between 29th to 31st of March, 1963. Changes in the relative turgidity percentage of leaves were measured daily for the next six days, along with the changes in soil moisture, below a tree, between two trees and away from the tree grove. Results of the relative turgidity determinations are presented in Table 5. The restoration of tissue hydrature after rain is of significance because it indicates the magnitude of dessication that the tree had undergone. The relatively low state of turgidity that was observed on 30th March with only 1·75 mm of rain, increased significantly after the completion of rainy period on 1st April. Thereafter, a gradual and significant lowering of relative turgidity was observed on every day. Slatyer's (1962) observations on *A. aneura* under conditions of high rainfall (13·5 mm) and low initial R.T. % (ca. 45%) indicate similar trends during the recovery stage. However, four days were required under his conditions for the complete recovery whereas a much less time lag was observed in this case. In *P. spicigera* relative turgidity in the range of 45-50 per cent has never been recorded even during driest periods. Small differences in relative turgidity values between the irrigated and unirrigated trees further indicate that tissue dehydration in *P. spicigera* tree does not reach extreme limits.

TABLE 5: Changes in relative turgidity in the leaves of *P. spicigera* after a shower

Dates	*R.T. %*
A. 30-3-63	80·53 ±2·3 (n=5)
B. 1-4-63	92·26 ±0·78 (n=6)
C. 2-4-63	87·32 ±1·31 (n=5)
D. 3-4-63	83·68 ±0·86 (n=5)
E. 4-4-63	82·68 ±3·9 (n+6)
F. 5-4-63	78·09 ±3·4 (n=6)
G. 6-4-63	79·60 ±2·4 (n=6)

A : Rain started on 29-3-63 and only 1·75 mm rain was recorded at the time of observation on 30-3-63.

B—A : Difference of means = 11·73, t=4·88**
B—C : Difference of means = 4·94, t= 3·18**
B—D : Difference of means = 8·58, t= 7·15**
B—E : Difference of means = 9·58, t= 2·15*
B—F : Difference of means = 14·17, t=14·13**
B—G : Difference of means = 12·66, t= 5·06**
*Significant at 5% level.
**Significant at 1% level.

Moisture status of the soil after shower presented an interesting picture. It was observed that 5 cm of the top soil was only wetted (5% moisture) due to this shower at positions between two trees and away from the tree grove. No change in moisture content was observed below the tree which could be due to partial interception of rain by leaves and branches. In any case, it is certain, from day to day records, that addition of moisture in soil due to this rain only penetrated a few cm in the upper layer of soil and no significant change occurred in deeper layers. Thick secondary growth of roots in the upper layers of soil and the absence of any extensive root development in the wet portions (upto 25 cm depth) between two trees and away from the tree grove, suggested that the sudden change in the internal moisture balance due to this shower could not be due to absorption by the roots. Direct absorption of moisture by the tree foliage could be the only other means by which the abrupt change in relative turgidity was brought about.

STUDIES ON DROUGHT RESISTANCE IN *PANNISETUM TYPHOIDES*

The crop *Pennisetum typhoides* (Bajra), is extensively cultivated in the arid tracts of western Rajasthan. It is supposed to be drought resistance plant, although, quantitative data regarding the performance of the plant under low levels of soil moisture conditions is not adequate. However, the results published by Misra and Daulay (1963) indicate that mortality under the drought conditions is fairly high in this plant which was found to vary in different varieties with the stage and durarion of the drought. The capacity to grow under arid conditions, even with low mortality percentage, does not necessarily imply that optimum state of growth and yield is achieved by the crop which is obviously the sole object of growing them. A detailed analysis of drought effects on the growth and yield of this plant with respect to stage of development was, therefore, deemed necessary. The different approaches to the problem of drought resistance which have developed (Levitt, 1951 & 1956; Ilji, 1957; Asana, 1957; Henkel, 1962) during the recent years do not require further elaboration. However, it seems to be fairly certain that drought resistance varies with physiological age and falls steeply during the formation of generative organs. In these experiments the drought was imposed at various stages of growth (i.e. at 2-, 3-, 4-, 5- and 6-week stages). The performance of the plants under conditions of drought at various stages of growth is shown below (Table 7).

of days taken for ear emergence increased progressively with advanced stages of droughting and the differences with control are significant, except in plants droughted at two week stage but adverse effects were magnified from the second week onwards. In case of grain yield per ear and 1000-grain weight, differences over control were significant only at the advanced stages (5- and 6-week stages).

Studies conducted on another variety (var. RSK) indicated similar trends of results. It was observed with respect to growth characters that the effects of drought may be reversed in young plants under conditions of optimum moisture regime at the initial stages, but this reversion mechanism becomes weaker with age. During the reproductive phase this reversion mechanism becomes least effective.

Investigations have also been carried out to study the alterations in the nitrogen fractions (protein, soluble and total nitrogen) and starch and sugar (reducing and non-reducing) contents of the leaf tissue in the droughted and under droughted plants at different stages of growth. Although, marked change in nitrogen fractions have not been observed, it appeared that at the advanced stage (6-week) moisture deficit caused accumulation of starch in the leaf tissues. It is possible that at that stage grain yield was drastically lowered due to reduced hydrolysis of starch into sugars and the impeded movement to the shoot apex for grain formation. However, sugar, starch and nitrogen contents of the grain, obtained from droughted and undroughted plants, do not show any significant change.

TABLE 7: Performance of *P. typhoides* (*var. T* 55) *ptants droughted at various stages of growth*

Observations	*Un-droughted control*	*Droughted at 2-week stage*	*Droughted at 3-week stage*	*Droughted at 4-week stage*	*Droughted at 5-week stage*	*Droughted at 6-week stage*	*L.S.D. at* 5%	*L.S.D. at* 1%
1. Final growth in height in cm	88·6	82·4	56·4	53·7	35·7	69·6	12·82	17·89
2. Leaf No.	15·3	14·6	13·0	12·5	10·5	12·3	1·20	1·69
3. No. of days taken for ear emergence	54·30	58·30	62·15	62·38	67·25	68·25	1·41	1·26
4. Length of ear in cm	20·30	18·69	16·02	16·97	14·04	11·64	3·94	5·45
5. Grain wt. per ear of the main shoot in gm	2·70	2·43	1·59	1·60	0·26	0·31	1·14	1·58
6. 1000-grain wt in gm	4·87	4·54	3·85	4·33	1·78	2·15	1·62	2·25

It may be observed that final growth-in-height and leaf number per plant were significantly affected due to drought and the magnitude of the effect increased with the age of the plant, the minimum (difference not significant with control) being at 2-week stage. The plants droughted at 6-week stage were very much advanced in growth and thus drought effects were not of high order. The number

In the older plants moisture content of the root and shoot tissues, under conditions of drought, remains higher than those at younger stage. Bnt, the greater impact of drought at these stages suggest that a large part of this moisture may remain unavailable for physiological processes.

SUMMARY

The results of the investigations indicate that higher rates of transpiration in certain desert plants during the dry period under low soil moisture conditions may be related with their deep rooting character. During winter the effect period of transpiration may decrease due to low temperature conditions in the morning and decreased intensity of sunlight in the evening. Relatively higher moisture status of unstabilizhed dunes is due to the absence of vegetation.

The moisture turnover from the seedlings of *Tecomella undulata*, grown in closed containers was significantly reduced under low levels of watering and this was coupled with reduction in leaf area.

Studies on water balance of *P. spicigera* community indicated that relative turgidity of the leaves of this tree species increased markedly under irrigated conditions. Similarly, after the shower relative turgidity showed immediate increase, due to foliar absorption of rain water, which was followed by a progressive decrease as the time elasped. The elimination of soil moisture stress by irrigation induced pronounced growth of the ground cover, which remained completely dry during the rainless months in the unirrigated plots. *P. spicigera* tree, however, showed high rates of transpiration even during the summer. The general growth characters of the tree indicated that it is suitably adjusted with arid environment.

In the shallow rooted crop of *P. typhoides*, effects of soil moisture deficit at different developmental stages have been studied with reference to its growth, flowering and yield characters. In general, susceptibility to drought increases with the age of the plant, although, magnitude of responses alter in different phases with respect to different characters under consideration. With respect to growth characters in the younger plants effects of drought may be reversed under conditions of optimum moisture regime, but, this reversion mechanism becomes weaker with age. Drastic reduction in yield due to droughting at advanced stage of 6-week may be due to reduced hydrolysis of starch into sugars in the leaf tissues and their impeded movement to the spike for grain formation.

ACKNOWLEDGEMENT

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DISCUSSION

P. G. Adyalkar : By the word xeric, do you mean xerophytes ?

A. N. Lahiri : Yes.

S. P. Raychaudhuri : Whether attempt has been made to correlate moisture stress in your study with the RF value of the soil i.e. the energy relationship ?

A. N. Lahiri : We are now engaged in converting our data in terms of energy relationships.

U. N. Chatterjee : Has this study any relation to total water requirement of plants ?

A. N. Lahiri : No attempt has been made in the present study to derive the water requirements of plants because it is now known that water requirement of any plant is not absolute but is solely dependent on environmental conditions.

J. C. Jain : I have noted while conducting diurnal studies that R.T. per cent decreases and leaf weight per unit area increases with increase in day temperature. Whether this decrease in R. T. per cent may be attributed to a higher rate of transpiration or to a increased leaf weight per unit leaf area ?

A. N. Lahiri : In **P. spicigera** tree, rate of transpiration increases from early morning and declines in the evening with an intervening ' noon day drop '. Under similar conditions R.T. per cent may decrease with the advance of the day. That is why it is a practice to record R.T. in the early hours of the morning. However, increase in leaf weight per unit area per hour should be very small.

EVALUATION OF HYDROLOGICAL CONDITION OF GRASSLANDS[1]

by

N. D. Rege & S. C. Gupte[2]

In India, 21 million acres cover classified grazing lands. These together with 59·7 million acres of cultivable waste lands and 30 million acres of long period fallows constitute about 13·7 per cent of the total geographical area and serve primarily as grazing lands. The grassland in most parts of the world have been very improperly managed and have so badly deteriorated that these have become a regular source of sediment load and excessive run off. These cause considerable damage through floods and early siltation of dams and reserviors. In India most of these serve as exercise grounds to the large number of livestock. Such areas are capable of producing high quality forage with proper protection.

High intensity and the amount of rainfall are primarily responsible for the floods, but it is equally true that improperly managed grassland, in view of the poor grass cover on the land, enhances the rate of erosion. If the sediment load going to the rivers and reservoirs is to be reduced, the grasslands have to be managed properly. The principal objectives of grassland management are to influence water regime in the area, to prevent floods and to augment ground water supply, in addition to controlling the soil loss and to have a good supply of forage. As these grasslands form a part of the watershed, their condition will definitely reflect on the watershed behaviour.

In order to improve the deteriorated grasslands and to manage them properly, it is necessary to have a survey to assess their present ecological status. This survey normally takes into account the following points: (1) the amount of ground cover in the form of living or dead vegetation, (2) the kind of vegetation making up the cover, (3) the vigour of the vegetation, (4) the degree of grazing, (5) soil characteristics with special reference to the growth of grasses, (6) the amount and kind of soil erosion and (7) the characteristics and amount of run-off, streamflow its rate, duration, etc.

This survey gives comprehensive information for developing good forage and control of soil erosion. But some more information will have to be collected (in addition to item 7) such as soil type, rainfall to antecedent soil moisture, etc., in order to get a clear picture of hydrologic condition of a grassland.

Hydrologic condition is defined as that condition of an area which reflects its ability to influence run-off. There are many factors such as soil, climate, slope, erosion, and vegetative cover which have considerable influence on run-off. If the soil happens to be shallow or impervious, there will be considerable amount of run-off even if the ground is fully covered. Steep and erodible slopes will require a thick cover which can protect them through its binding action. Similarly low density of plant cover with high percentage of weeds will lead to high run-off.

To get an accurate picture of the hydrologic condition of an area, a good deal of research effort has to be put in. This involves also time factor. Further, hydrologic condition will go on changing when there is some radical change in the management of the area. Therefore, in order to get an approximate hydrologic condition of an area, simple technique has to be developed so that eroded or badly managed areas can be improved in shortest possible time.

The Forest Service of the United States Department of Agriculture have developed a simple method for determining the hydrologic condition. This method consists of using the different ratings for each of the factors of soil, rainfall, vegetative cover, slope, erosion, etc., information on which is already obtained by survey. These individual ratings are then added together to arrive at total run-off ratings which indicate the condition of the area as poor or good. Higher the rating, higher will be the run-off, thus indicating poor hydrological condition of the area.

Example of rating table for hydrological condition and instructions for its use are given in appendices A and B respectively.

This method was used in arriving at the hydrologic condition of two watersheds comprising of natural grasslands one of 6·7 hectares (x) and another of 27·6 hectares (y) at Chalesar, Agra. The ratings obtained for these grassland watersheds are given in Table 1. The watershed 'X' is much better in hydrologic condition than 'Y'. This observation can be correlated with the data of run-off actually collected from such areas.

1. Contribution from the Soil Conservation Research Demonstration and Training Centre, Agra.
2. Deputy Adviser on Soil Conservation (Research & Training), Ministry of Food & Agriculture (Department of Agriculture), New Delhi. (Presently Dy. Commissioner (Soils) Water management unit, MFA, New Delhi) and Assistant Soil Conservation officer (Forestry), Agra.

TABLE 1: Rating of watershed for hydrological condition (at Chalesar Farm, Agra)

Factors	(At Chalsar Farm, Agra)			
	Watershed 'X'		Watershed 'Y'	
	Description	Rating	Description	Rating
Soil texture	Loamy sand	35	Loamy sand	35
Sub-soil	Loamy sand	12	Loamy sand with Kankar at places	15*
Depth	Deep	20	Deep	20
Ground cover	85% cover of grasses and small shrubs	−12	30% ground cover + 30% tree cover	−10
Composition	Mostly perennial bunch grasses	−1	Mostly annual grasses and weeds	+5
Grazing	No grazing	0	Heavy grazing	3
Burns	None	0	None	0
Erosion	Moderate gully erosion	+7**	Deep gullies	+10
Storm rainfall	Storms usually occur with the intensity between 1″-3″ for duration of 30 minutes & over but occasionally storms having intensity between 3″-6″ may occur for 15 minutes or so	—	—	—
Antecedent*** moisture	Average	—	Average	—
Total		±71		+88

Remarks: *Higher rating has been added for watershed 'Y' for Kankar pan at places.
**There are earthen check dams constructed in watershed 'X' and hence low rating is given.
***The soils being deep & porous, maintain an even rate of infiltration for a longer period and hence rating for average condition has been added. Moreover, the soils are in a dry condition when the maximum runoff is expected during monsoon.

The ratings given in appendix A is hypothetical and instructions for its use are intended to illustrate the effect of soil cover and land use on hydrologic condition and run-off ratings. This can be modified, if necessary, while undertaking similar investigations.

INSTRUCTIONS FOR THE USE OF THE TABLE FOR DETERMINING HYDROLOGIC RATING

(1) Soil ratings — Determine the texture of the top soil and the sub-soil; determine whether the soil is deep (20″), medium (10″-20″), shallow (6″-10″) or very shallow (0-6″).

Give the rating for these characteristics by referring to the Table A.

(2) Cover rating — Give the cover rating depending upon the density percentage as found out by the 'pace transect' method. Deduct this from previous rating estimated for the bare soil. Use the greatest deduction for the light soils with better structure. Only the least value should be deducted for heavy or shallow soils.

Add the rating for the type of grassland vegetation, i.e. bunch grass, sod grass, weeds, etc.

(3) Erosion rating — Rating for the effect of past erosion is to be added. Depending upon the type and extent of erosion, the corresponding rating is to be added.

(4) Land use rating — For grasslands rating for grazing has to be added depending upon the intensity of grazing — light, medium or heavy. If the area has suffered burns, a rating for that should also be added.

(5) Rainfall rating — A rating must be added for the storm types and antecedent moisture conditions that the watershed must withstand. In India it is difficult to get information for the intensity of storm for most of the places. In such cases, a rating for the total rainfall during the storm can be added based on the run-off data from the gauged watersheds.

For antecedent moisture in the soil before a storm occurs a rating can be added to the soil rating. For heavy and shallow soil add up to 15 points, for light deep soils 5 points.

(6) Total rating — To get the total rating add all the individual ratings algebrically (steps 1-5). If the area is gauged, adjust this total to the actual run-off from the areas.

APPENDIX 'A': Rating Table for Hydrologic condition

Soil texture	*Top soil*	*Sub-soil*	*Depth*	*Total*
(A) Light (Sands)	30	10	20 (Deep)	60 (highest infiltration)
(B) Medium (Sandy loam)	40	15	20 (Medium)	75 (above average infiltration
(C) Heavy (Clay loam)	45	20	25 (Shallow)	90 (below average infiltration)
(D) Extreme (Clays)	50	20	25 (Extreme)	95 (extremely impervious)
Ground cover	*% cover*			*Composition*
Grass and litter	0-10	0-1*		Bunch grass −1
	11-30	2-5		Sodgrass +1
	31-60	4-10		Annual weeds +5
	61-90	7-15		
	91-100	10-20		

**From the soil rating, substract the cover rating using greatest reduction for light soils (A)*

Land use	*Grazing*		*Burns*	*Erosion*	*Sheet*	*Gully*
	Light	+1	Recent (0−1 Yr.)+10	Slight	+1	+ 5 shallow, few
	Moderate	+2	Old (above 3 yrs) +1−5	Moderate	+2	+ 7 Moderate
	Heavy	+3		Severe	+3	+10 Deep, frequent

Storm rainfall:	*Max. intensity*	*Duration, minute*			*Antecedent Soil moisture*	*Soils*		
	0-1"/Hr.	15	30	60	Average	*C*	B	*A*
	1"-3"/Hr.	−100	−70	−50	Wet	+15	+10	+5
	3"-6"/Hr.	−10	0	0				
	6"-10"/Hr.	−10	+15	+20				
		−20	+20	+50				

DISCUSSION

B. Ramamoorthy: It was not clear from the talk whether there is a need for rating soil texture for hydrological purpose.

N. D. Rege: There are other factors besides soil texture for determining the performance of grasses. It will be interesting to compare the different values of rating for different purposes.

V. Mahadevan: Is not grassland management and utilization of grasses affecting the make up of the soil with respect to moisture content in soil ?

N. D. Rege: Removal of grasses to an extent of 50 per cent or more by grazing or any other process, has a direct relationship. Moreover, management is a primary factor in hydrologic condition of grasslands.

P. G. Adyalkar: Phreatophytes are those which derive water directly from the water-table. What weeds come in this category ?

N. D. Rege: Not being a Botanist, I regret that I cannot mention the names off hand.

S. P. Raychaudhuri: Regarding obtaining hydrological data for grassland the best way would be to directly estimate the runoff on a comparatively large watershed and build up our knowledge which may take 10 years or so.

N. D. Rege: This would be a better method but this will take time. Therefore, for immediate use the method of soil rating has been suggested.

AGRONOMY

AGRONOMIC INVESTIGATIONS IN ARID ZONE[1]

by

D. K. MISRA[2]

INTRODUCTION

THE successful farming in the arid zone depends upon such agricultural practices as will reduce the chances of soil erosion to the minimum and provide conditions of soil and water conservation and high soil fertility. A few scientific investigations on improved agronomic practices in the desert soils of Western Rajasthan have been reported.

STUBBLE MULCH FARMING

The stubble mulch farming is practised in dry land conditions, where evaporation of moisture from the soil and soil blowing present serious problems, which retards water run-off, decreases soil erosion and increases water infilteration during intense rains. The practice of using crop residues as stubble mulch on grain fields began in the U.S.A. as early as 1910 (Carter and McDole, 1942). Stubble mulch farming is regarded as one of the most significant contributions to dry land agriculture where wind erosion is serious (Lowdermilk, 1953). In the mid-west dust bowl of United States, large scale mechanized stubble mulch farming is practised as a measure of protection to the cultivated farm land from wind erosion. The stubble mulch farming is a step towards maximum efficiency of rainfall utilization (Duley *et al* 1939). A crop residue of 5 to 2, m tons per hectare has proved beneficial for sandy soils to prevent blowing Misra, 1960.

The study of stubble mulching with crop residue of *Pennisetum typhoides* (Bajra) in the desert soils of Western Rajasthan was initiated at Jodhpur in 1958. The crop stubble of different sizes including 15·0, 30·0, 45·0 cm size and whole stalk stubble were maintained. No crop stubble was left in control plots. The minimum soil loss due to wind erosion was noted in case of whole stubble i.e. 761·1 kg/ha. followed by 45 cm stubble 949·9 kg/ha. The soil loss in smaller stubble plots was 1116·5 and 1491·3 kg/ha in 30 and 15 cm stubble plots respectively. Maximum amount of soil 2087·8 kg/ha was blown from control plots (Table 1).

TABLE 1: Soil loss in Kg

	15 cm stubble	*30 cm stubble*	*45 cm stubble*	*Whole stubble*	*Control*
Mean per ha	1491·3	1116·5	949·9	761·1	2087·8
SEm					±242·55
'F' test					Sig.
C.D. at 5%					709·49
C.D. at 1%					975·83

The soil collection data were highly significant and indicated that 45 cm stubble was very effective in preventing soil loss. The crop residue of 45 cm also increased the grain yield by 5·7 per cent over the control treatment. The differences in grain yield due to various treatments of crop residue were statistically not significant.

WIND STRIP CROPPING

In the wind strip cropping investigations on the perennial protective strips consisted of *Lasiurus sindicus* and *Ricinus communis* established at right angle to the general direction of the prevailing winds to reduce the impact and threshold velocity of the wind to minimize wind erosion. In between the protective strips the field is cultivated and crops are rotated. Average crop yields of 484·4 kg/ha of *Phaseolus radiatus* and 372 kg/ha of *Phaseolus aconitifolius* were obtained from protected plots as compared to 272·0 kg and 256·9 kg per hectare of *Phaseolus radiatus* and *Phaseolus aconitifolius* respectively from non protected plots. In addition to the grain yield in the protected plots the yield of *Ricinus communis* at the rate of 746·5 kg/ha and 1650·0 kg/ha of dry matter of *Lasiurus sindicus* were obtained. These preliminary observations show that the intervening crop strips yield higher return than the strips where such protection has not been afforded to the grass strips (Bhimaya *et al*, 1958).

Soil moisture studies at every 3 m distance on the leeward side of protective strip at 15 cm and 22·5 cm depth indicated 0·5 to 1·5 per cent higher soil moisture content in protected cropped land as compared to unprotected land at these depths respectively.

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WEED CONTROL

The extent of competition offered by weeds to crops under arid and semi arid conditions is more critical due to special limitations of moisture and plant nutrients. Loss of water through weeds estimated at Sholapur during 1941-1942 indicated that the transpiration co-efficients were 556 for *Ischaemum pilosum*, 813 for *Cynodon dactylon*, 1104 for *Tephrosia purpurea* and 1402 for *Tridax procumbens* while it was only 430 for Jowar (Kaul & Raheja, 1952).

The study of weeds, weeding frequencies, their effect on soil moisture conservation, grain and straw yield was taken up in 1959 at Jodhpur. The weeds which have high density in cropped land are *Convoluvulus pluricaulis, Tribulus terrestris, Indigofera cordifolia* and *Zizyphus nummularia*. Their root lengths are 114, 112, 107 and 147 cm respectively. At 15 cm soil depth the moisture in unweeded plots was 2·5 per cent as against 4·1 per cent in weeded plots in the first observation and these differences continued in the subsequent observations (Misra & Kumar 1962).

TABLE 2: Percentage of moisture in different weeding treatments

Date	*Depth of sampling cm*	*Per cent soil moisture*				
		W_1	W_2	W_3	W_4	W_5
4-8-60	15	4·1	4·1	3·7	4·0	2·5
25-8-60	15	3·1	3·7	2·8	2·8	1·8
15-9-60	15	1·4	1·6	1·4	1·4	1·1
SEm			±0·004			
'F' test			Significant			
C.D. at 5%			0·012			

TABLE 3: Average yield of millet grain

Symbol	*Treatment*	*1959*		*1960*	
		Kg/ha	*Per cent increase over control*	*Kg/ha*	*Per cent increase over control*
W_1	One weeding	838·0	9·6	269·3	56·2
W_2	Two weedings	839·8	9·8	276·2	57·3
W_3	Three weedings	771·9	1·9	294·0	59·9
W_4	One weeding & one spraying 2, 4-D (80%) sodium salt)	815·1	7·1	177·2	33·5
W_5	Control (no weeding)	757·3	—	117·8	—
SEm		±97·2		±66·0	
'F' Test		Not sig.		Not sig.	

The favourable effect of two weedings on grain yield is evident from the data given above in both years to the extent of 9·8 and 57·3 per cent in 1959 and 1960 respectively. One weeding also has shown quite an appreciable beneficial effect in increasing grain yield in both the years. Thus, it is indicated that weeding is an essential cultural operation for ncreasing grain production in the arid zone.

DEPTH OF SEEDING

Successful crop stand is essential for optimum cereal production. Amongst the preliminary factors which influence establishment are depth of seeding, quantity of seed and variety. The seed of *Pennisetum typhoides* which is the major crop of the arid region is very small in size. This being a rainfed crop and moisture being the limiting factor, it is all the more necessary to place the seed at proper depth and thereby provide most conducive environment for the uniform germination. Perry *et al* (1955) have reported that deep furrow drilling generally produces better stand of grasses. McGinnies (1959) concluded that use of 5-10 cm deep furrow significantly increases soil moisture available for seed germination on a range soil by reducing the rate of soil moisture loss.

The field investigations were conducted at Jodhpur from 1959 to 1961 comparing the treatments of depth of seed placement at 5·0, 7·5, 10·0, 12·5 and 15·0 cm. The study of various plant characters at growth and development stages were recorded. The grain yield data are presented in Table 4.

TABLE 4: Grain yield in quintals

Depth of seed placement in cm	1959	1960	1961	1962	*Mean*	*Percent increase over lowest*
5·08	15·14	9·58	11·14	73·61	86·49	5·7
7·62	16·61	11·36	95·98	88·37	90·46	9·8
10·16	15·77	8·20	91·68	74·69	83·06	1·8
12·70	15·37	7·66	91·59	82·84	83·94	2·8
15·24	15·42	15·02	88·33	68·76	81·57	—

The above data reveal that the seed placement at 7·5 cm has given best response by the way of emergence of seedlings, plant height, number of tillers and grain yield. The treatment of seed placement at 5·0 cm has responded next to the above treatment. The response of other three treatments, i.e. 10·0, 12·5 and 15·0 cm seed placements were less effective than 7·5 cm depth of seed placement.

CROP ROTATIONS

In conservation farming and more so in the arid zone the crop rotation occupies an important place. A crop sequence that reduces loss of soil and conduces to more economic use of conserved water is the most suitable for adoption. Such a rotation should also include soil cleaning crop which will effectively control weeds and reduce the cost of frequent weedings. The cost of cultivation for the various crops in the rotation should be low enough to enable their inclusion under conservation farming (Misra, 1960).

Six 2-course crop rotations were included in an experiment including *Bajra-Bajra*, *Bajra-Jowar*, *Bajra-Moth*, *Bajra-guar*, *Bajra-green gram* and *Bajra-fallow*. The observations for the past four years have indicated that the rotations of *bajra guar* and *bajra-mung* have been very efficient, producing 11·06 quintals of bajra and 5·44 quintals of guar/ha and 10·03 kg/ha of bajra and 8·68 dz/ha. The rotations of *fallow-bajra*, *moth-bajra* and *bajra-bajra* and *bajra-Jowar* gave yields in the descending order. The best crop rotation which increased crop production to the extent of 17 per cent grain as compared to bajra cultivation year after year in desert soil.

MIXED CROPPING

The practice of mixed cropping is very common in dry framed areas, where usually cereals are mixed with pulse crops. The advantages consist in better growth of the associated non-legumes on poor soils and prevention of utter failure of the crop in regions of uncertain rainfall. It is more for insurance against deficiency of rains than for improving the quality of cereals or reducing the incidence of diseases that mixed cropping is practised. Mirchandani & Misra (1957) obtained higher crop yields, maximum utilization of space and improvement in soil fertility status. They reported much higher grain yield than by growing pure cereal crop. Considering the large area under mixed cropping, the investigation was planned and laid down in the field in 1959. The main plot treatments consisted of *bajra* as cereal and its mixture with other four legumes viz. *Vigna sinensis*, *Cymopsis tetragonoloba*, *Phaseolus radiatus* and *Phaseolus aconitifolius*. Methods of sowing were the sub-plot treatments. These consisted of inter-row sowing, one row of cereal and one row of legumes, two rows of legumes and one row of creal, six rows of legumes and four rows of cereal and cross sowing. The experiment has been repeated for four years and mean values of results are presented. The seed mixture of *bajra+Guar* gave the highest grain yield (*bajra* = 8·36 dz/ha and *guar* = 2·43 dz/ha) followed by bajra+*vigna sinensis* (*bajra* = 7·84 dz/ha and *Vigna catajang* = 1·37 dz/ha) and *bajra+Phaseolus radiatus bajra* = 7·27 dz/ha; *mung* = 1·87 dz/ha). The content bajra +*P. aconitifolius* gave the lowest grain yield. Among sub-plot treatments of seeds ratios, normal seed rate of cereal, with 1/2 of legume gave the highest average yield.

The data have been statistically analysed by converting grain yield values into money value as the comparison of different crops is not possible where the size of seed and kernal weight are different.

	Main plot Rs./ha	*Sub-plot* Rs./ha	*Interaction* Rs./ha
SEm ±	10·89	2·97	1·98
'F' ratio	Sig	Sig	Sig
C.D. at 5%	34·83	8·19	5·46
C.D. at 1%	50·05	10·79	7·19

The statistical analysis also indicated the same trend of beneficial effect of *bajra+guar* mixture followed by *bajra+lobia* and *bajra+mung*. The seed ratio of normal cereal rate in addition to 1/2 of normal legume seed rate gave maximum profit. The interaction between crop mixtures and seed ratios was also highly significant.

FERTILIZER APPLICATION

(a) Major nutrients: One of the important limiting factors for crop production in Western Rajasthan is the deficiency of plant nutrients. Jain *et al* (1961) studied the effect of fertilizers on desert soils at Durgapura Farm, Rajasthan in the period 1954-57 and concluded that nitrogen was the limiting factor for increasing wheat production. Kanwar and Bhumbla (1959) observed that application of 13-15 lb nitrogen on wheat under unirrigated conditions in the Punjab significantly increased the yield. Misra (1961) observed that a dose of 22·4 kg/ha nitrogen to *bajra* crop in Jodhpur soil gave an average per hectare grain yield of 17·20 quintal as against 8·51 quintal grain yield without fertilizer.

A replicated trial was laid out in different parts of western Rajasthan to test the crop response to nitrogenous fertilizer. Another experiment having the treatments of N, P, K, singly in the doses of 16·8, 22·4 and 22·4 kg/ha and in combination was laid down at the Institute Farm, Jodhpur. These experiments have been repeated for two years and three years respectively. The grain yield results indicate an increase of 26 per cent in case of 22·4 kg/ha nitrogen over control. The increase in the NPK when assessed singly indicated that nitrogen and phosphate increased the grain yield by 18·0 per cent for individual factors for all the three years, while potassium applied alone depressed the yield for all the years. These results showed that application of nitrogen and phosphate is essential for crop production in this region.

TABLE 5: Effect of trace element on yield performance of *Pennisetum typhoides*

Treatment	*Grain yield in dz*				*Treatment*	*Stalk yield in tonne*			
	1958	1959	1960	1961		1958	1959	1960	1961
Fe	9·69	8·13	6·57	8·47	Fe	2·13	5·40	2·63	2·14
Mn	8·39	10·28	3·33	6·47	Mn	2·02	5·68	1·93	1·92
Zn	9·96	9·91	4·73	7·54	Zn	2·09	5·54	2·14	2·02
Cu	8·44	8·08	4·59	5·84	Cu	1·92	4·30	2·14	1·84
B	7·67	7·95	3·73	7·63	B	1·98	4·85	2·03	2·01
Mo	7·90	7·03	4·84	6·94	Mo	1·91	4·39	2·07	1·85
Mg	8·79	8·71	5·11	8·57	Mg	2·02	5·74	2·36	2·02
Mixture	1·13	8·99	4·14	6·85	Mixture	2·09	4·60	1·99	1·82
Control	8·53	8·66	4·14	5·64	Control	1·88	4·61	1·74	1·87
SEm	±1·13 kg/ha	±0·98 kg/ha	±0·47 kg/ha	±1·66 kg/ha	SEm	±0·20 Tonne/ha	±0·48 Tonne/ha	±0·054 Tonne/ha	±0·197 Tonne/ha
'F' Test	Not sig.	Not sig.	Highly sig.	Not sig.	'F' Test	Not sig.	Not sig.	Highly sig.	Not sig.
C.D. at 5%	—	—	1·40 dz/ha	—	C.D. at 5%	—	—	0·158	—
C.D. at 1%	—	—	1·90 dz/ha	—	C.D. at 1%	—	—	0·195	—

(b) Micro-nutrients: The investigations on the effect of micro-nutrients in dry land farming have been relatively few. Blair *et al* (1936) found that small quantities of trace elements will produce quick response in increasing crop production on sandy soils. Riceman (1945) observed that trace elements play an important part in the development of large desert area in south Australia. Raheja *et al* (1959) critically reviewed the crop response to micro-nutrients under Indian conditions. They observed that trials conducted to study the response of micro-nutrients with *Jowar, Maize, Bajra, barley, oats, Ragi* and other millets are few in number. However at various research centres the increase in yield of these crops has been reported.

In order to assess the response of micro-nutrients on crop yields in the arid zones an experiment was laid in the field in 1958 and repeated till 1962. The treatments included are $FeSO_4$-32·6, M_nSO_4-16·6, $ZnSO_4$-11·2, $CuSO_4$-11·2, Na_3B_4 O_7-5·6, $(NH_4)_6Mo_7$-0·24, $MgSO_2$-163·0 kg/ha individually and in all combinations and control. The observations were recorded on plant characters of height and tillers every year. The mean values for all the four years indicated that Cu, Zn, Mo, Mn, and Mg were the elements which affected the plant height in order of merit. The study of number of tillers at maturity for four years indicated that Fe, Mg, B and Mn, had shown higher number of tillers over control. The mean increase in tillers for four years worked out to be 10·7, 10·7, 7·7 and 6·2 per cent due to Fe, Mg, B and Mn respectively. In 1960, in spite of severe drought condition, the increase in number of tillers due to Mn, Mg, Fe and Cu were 19·4, 16·7, 11·1 and 11·1 per cent over control respectively.

The response of trace elements on grain and straw yield of *bajra* is summarized in Table 5. The beneficial effect of Fe, Zn, Mg and mixture of all trace elements had been well exhibited by increase in grain yield over control in each of the four years. The mean percentage increase in grain yield were 21·6, 18·0, 15·0 and 5·4 due to Fe, Zn, Mg, mixture of all trace elements and Mn respectively.

The stalk yield indicated favourable response to trace elements application in all the four years of experimentation. The mean percentage increase in stalk production for four years was 29·5, 27·4, 24·1, 21·0 due to Fe, Mg, Zn and Mn respectively. All other treatments of micro-nutrient application showed better stalk yield than control.

The test weight of 1000 kernels was recorded for 1960-61. The mean increase for two years was 37·3, 21·3, 21·0 per cent over control in test weight due to Zn, Mg, and Fe respectively. The increase in test weight was observed in all other treatments as compared to control which indicated that micro-nutrients had definite role in increasing kernel weight. Data was subjected to statistical analysis and was found significant at 1 per cent level in 1960 and at 5 per cent level in 1961. Thus it is observed that the response of the *Bajra* crop to micro-nutrients in arid zone is favourable on growth, development and grain yield.

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DISCUSSION

S. P. Raychaudhari : How far deficiency of micro-nutrients has influenced production ? Were iron and manganese applied as spray or as soil application ?

D. K. Misra : Micro-nutrients have shown very high response in *Bajra* production. Iron and manganese were applied both as spray and as soil application. Spray application proved more beneficial than application to the soil.

Fr. Santapau : Why *Zizyphus nummularia* is not eliminated from the cropped fields ?

D. K. Misra : It provides valuable leaf fodder for livestock and the shrub is preserved in the fields.

W. V. B. Sundara Rao : Was basal dose of P_2O_5 applied to the legumes ?

D. K. Misra : Yes.

W. V. B. Sundara Rao : Was rhizobium culture applied to the legume crops ?

D. K. Misra : The culture was applied to the *Moong* crop. It increased nodulation.

U. S. Madan : How far have the farmers taken up stubble mulching ?

D. K. Misra : So far few farmers have taken to this practice.

A. R. Zafar : What iron salt was used as fertilizer ?

D. K. Misra : It was applied as ferrous sulphate.

PRODUCTION PROBLEMS OF ARID REGIONS – BELLARY TRACT[1]

by

S. CHATTOPADHYAY[2]

INTRODUCTION

THE material presented in this paper is based on the work done earlier at the Agricultural Research Station, Hagari and subsequently at Bellary Centre on Black Soils. This paper is intended to analyse the production problems of arid and semi-arid regions and discusses the work done on this aspect and future lines of work.

The local black cotton soils have a slope of 0·5 to 1·5 per cent. They are poor in structure, heavy, alkaline in reaction with nodular Ca Co_3 distributed throughout the profile. Depth varies from 6″ to 48″ with invariably a zone of salt concentration between 18″ and 36″ depth. Gypsum is the major constituent of the salt-layer. The presence of water more pebbles and red gravelley material below the calcareous murrum suggest genesis from erosion deposits. The soils are low in nitrogen (0·002 per cent), available P_2O_5 (5 kg/ha) and organic matter (0·02-0·03 per cent).

The average rainfall of this region is 50 cm half of which is received during the months of September and October. These soils are quite retentive of moisture (F.C. 38 per cent, P.W.P. 17 per cent) and *Rabi* cropping is the rule. *Kharif* cropping is not practised because of uncertain rains in June-July. The average yield of any crop of this region is in the order of 200 to 250 kg/hectare.

LOW RATE OF MOISTURE INTAKE

Since inception of this Centre, conservation practices were taken up to find out their suitability and work out economics for increasing the production on a sustained basis. Towards the latter part of 1960-61, it became apparent that none of the conservation practices will prove effective unless the water intake capacity of the soil is improved *per se*. This is reflected by the low infiltration rate, i.e., 0·01″ to 0·03″ per hour; the intensity of rainfall being 1″/hr. Hence, the first problem faced by an agronomist is to increase the intake rate of rainwater to the maximum. It may be mentioned here that, the rain of 50 cm is good enough to give a good assured crop, provided adequate amount of rainfall that is received is stored. The distribution of rainfall is also an important consideration, though it is beyond control. The 20″ of rainfall that received is disposed of as follows: evaporation loss 11·5″, run-off loss 6·5″. Water used for crop growth 2·0″.

It would be noted that only 10 per cent of the rain received is utilized by the crop.

The low infiltration of these soils are due to: (1) soil type, (2) aggregation and (3) cropping pattern of the tract.

Regarding soil type and cropping pattern, no choice is left because of peculiar seasonal and other conditions.

The only factor which can be suitably modified to achieve the desired purpose is the improvement in aggregation. Aggregation can be improved by:

1. Application of F.Y.M. and Compost: Studies carried out in the Centre clearly indicated that application of F.Y.M. at 2000 lb/acre continuously or alternately does not materially improve the aggregation of soil. A long term experiment with F.Y.M. was carried out at this Centre for six years and the summary is presented in Table 1.

TABLE 1: Grain yield of *Jowar* in Kg/Ha

Treatments	1958-59	1959-60	1962-63	1963-64
Control	526·8	114·45	171·57	494·00
Control	—	161·87	200·78	316·10
2000 lb/acre every year	452·5	70·74	179·40	563·50
4000 lb/acre alternate year	499·5	195·61	205·47	502·55
do	477·1	106·83	158·54	508·30
6000 lb/acre once in 3 years	513·0	146·85	223·72	523·25
do	524·2	100·78	212·29	500·25
do	462·6	115·46	203·39	471·50
S. Em. in kg/ha ±	28·9	34·50	29·67	71·30
'F' Test	N.S.	N.S.	N.S.	N.S.

N.B.: Due to failure of rains crop could not be sown during 60-61 and 61-62.

The effect of F.Y.M. to the tune of 12,000 lb/acre over a period of 6 yrars had no effect either on the yield of *Jowar* or on cotton or on aggregation as reflected by the data presented in Table 2.

1. Contribution from soil Conservation Research Demonstration and Training Centre, Bellary.
2. Assistant Soil Conservation Officer (Agronomy). Present Address: 61/4 Belgachia Road, Calcutta-37.

TABLE 2: Dispersion ratio for long term F.Y.M. experiment

Treatments	*Av. dispersion ratio* (63)
Control	0·2422
Control	0·2300
F.Y.M. 2000 lb/acre/year	0·2392
F.Y.M. 4000 lb/acre/alternate years	0·2306
F.Y.M. 4000 lb/acre/alternate years	0·2189
F.Y.M. 6000 lb/acre/once in 3 years	0·2194
do	0·2237
do	0·2195
SEm. ±	0·015
'F' test	N.S.

Concurrently, laboratory experiments were taken up to investigate why F.Y.M. is not improving soil aggregation. These studies indicate that unless the organic matter applied to soil decomposes in *situ*, there can be no improvement in aggregation. The results are presented in Table 3.

TABLE 3: Aggregation in soil

Treatments	*Mean weight diameter*	
	Soil A *mm*	*Soil B* *mm*
Control	0·339	0·1108
Compost	0·347	0·1144
Jowar straw	0·449	0·1644
Cassia leaves	1·185	0·3800
Glucose	1·365	—

The results clearly show that organic matter must decompose within the soil to promote aggregation. The above results point towards the possibility of exploring green-manwring as a measure for improving soil aggregation.

Regarding the possibility of green-manuring in this tract, it may be noted that efforts to raise a G.M. crop in the *Kharif* have failed completely in the past, and only one alternative is left i.e. to grow a G.M. crop in the *rabi* and take a main crop in the second year *rabi*. However, the following problems still remain unanswered:

1. Whether it is economical to raise a G.M. crop in the *rabi* season over continuous cropping?

2. Does the beneficial effect of G.M. last till the next *rabi* season? Work on these aspects is in progress.

It is a recognized fact that ley farming improves aggregation. Laboratory tests carried out at this Centre has shown that the infiltration under grass cover is ten times more than under ordinarily cultivated land. A few of the data are recorded in Table 4.

TABLE 4: Aggregation of soil particles as influenced by crops

Soil samples from	*Mean weight diameter mm*
1. Bare soil	0·186
2. Cotton plots	0·218
3. *Jowar* plots	0·230
4. *Dicanthium annulatum*	0·300
5. Kunda grass (Ischaemem pilosum)	0·319
6. *Cenchrus setigerus*	0·394

Experiments are in progress at this Centre to find out the economics of ley farming together with an answer to the question "How long a grass should be grown for good aggregation" and "How long the beneficial effect lasts". Attempts are being made to find out an answer to these questions.

Another possibility is the change over to mixed farming from arable farming. No data are available in this regard except that a hectare (grass plot) yields about 2000 kg of green grass per year. This quantity of grass fetches a gross income of Rs 100/- per hectare. The cost of cultivation will be roughly Rs 50/- per hectare giving a net profit of Rs. 50 per hectare as compared to Rs. 15 to 20 in case of *Jowar* and Rs. 25 to 30 in case of cotton per hectare.

To sum up, the possible ways and means for improving aggregation are:

(1) raising a G.M. crop in the *rabi* season and study its effect on crop yields in the next *rabi*;
(2) ley farming in these tracts;
(3) introducing mixed farming over the present system of continuous cropping.

UTILIZATION OF MOISTURE STORED IN SOIL

It is one thing to improve the moisture regime of a soil; it is entirely different thing to make full utilization of the stored moisture. This is, to put moisture to productive use. An Agronomist has now to choose the suitable crops, its spacings, crop rotation and cropping system.

1. *Crops*: The crops grown in this tract are *Jowar*, Cotton and sometimes, *Setaria*.

Setaria is sown in mid August, Cotton in September and *Jowar* in September-October. Except in years of abnormally low rainfall there is adequate moisture in the soil till February when the soil begins to crack and rapid dessication follows.

Under such conditions crop varieties of about 120 days duration are likely to evade drought. The first concern of the agronomist, therefore, is to search for short duration and less " leafy " varieties.

Conditions at Bellary indicate that the most critical stages in the life cycle of plant are: (1) germination, and (2) 40 days after sowing. The black soils do not come to working condition till 48-72 hrs after rains and sowing is possible at a time when the surface moisture is decreasing at a very fast rate. Any germinating seed whose radicle elongation does not keep pace with rapidly receding moisture, does not sprout. The result is low plant population and uneven stand. An attempt has been made to overcome the problem by presoaking the seed in water and nutrient solution but with little success. Work to study the effect of growth regulators like Gibberellic acid and Napthyl acetic acid has been taken.

The other critical period, namely, 40 days after sowing marks beginning of the inflexion in the growth curve. To sustain the rapid growth that follows, the plant must at this stage proliterate its root system both in depth and in spread. The soil moisture at this stage is below 6″. The few mm of rain received in November, though small in amount are considered in valuable for the *Jowar* crop. In the absence of these showers a good percentage of the plant population either dies or remains so stunted as to be unproductive (ear-less). Information is being collected on the growth rate of the *Jowar*.

Among the nutrient elements, phosphorus and calcium have beneficial effect on root proliferation and the local black soils are severely difficient in phosphorus. It is planned to study the effectiveness of phosphorus from this point of view.

Jowar: The local standard is H-1. It has excellent grain quality but suffers from the two defects, namely, long duration (145 days) and its " Leafiness " so much as that in years of low rainfall, which are more frequent, the yield is low. The Maldinnis (M 35-1 and M 47-3) of about 125 days duration are on an average better yielders. J-718, a cross between H-1 and Maldinnis is under study.

TABLE 5: Yield of grain for different varieties of *Jowar* (1963-64)

H-1	585 kg/ha
M 47-3	650 kg/ha
M-35-1	700 kg/ha

Cotton: The local variety W-1 is deep rooted and is resistent to pests and diseases. Its defects are long duration of 160-175 days and medium staple length. There is at present no variety which confidently can replace W-1.

Recently, I.C.A.R. (PIRRCOM, Coimbatore) has evolved some crosses with Russian strains of 120 days duration and in which sympodial branching is suppressed. The first year of trials appears to be quite promising.

Safflower: The crop is hardy and comes up in eroded areas unsuitable for *Jowar* or Cotton. Normally grown as trap crop, we are studying its economics as a pure crop.

2. *Rotation*: The only regular rotation followed in the tract is characterized by the absence of legume in the sequence — *Jowar*, Cotton. Bengal Gram has been successfully introduced in this rotation. It should be sown in October immediately after *Jowar*.

3. *Plant population and spacing*: Plant population assumes greatest importance in scarcity area. Low seed rate and wider spacing is the theme of dry forming and has been long recognized by farmers. The spacing between rows is rigidly controlled by the seed drill used whereas control of spacing in the row is indirectly controlled by the seed rate adopted. No thinning of plants within a row is practised. Blade harrows commonly used for intercultivation can also be used for thinning. The optimum spacing of crops is being re-examined. On the basis of preliminary data, a spacing of 36″ ×12″ for cotton gave higher yield of lint than 36′ and continuous sowing with seed rate of 7 lb/acre. In the case of *Jowar* 36″×12″ is as good as 18″ and continuous sowing with 4 lb/acre seed rate.

4. *Inter-cropping*: While pure crops of *rabi* Jowar and Cotton is the rule, in years when low rainfall or delay in the onset of September rains is expected, *setaria*-cotton are sown as a mixed crop. Under the above conditions, the farmers are reconciled to failure of either one of the crops, it being very rare that both the *setaria* and cotton yield satisfactorily.

TABLE 6: Yield of *Jowar* grain as affected by spacing (1963-64)

Main Treatments	*Yield/ kg/ha*	*Sub-treatments*	*Yield/ kg/ha*
36″ bet. rows.	511·70	6″ bet. plants	494·93
18″ bet. rows.	511·81	12″ bet. plants	561·41
		18″ bet. plants	480·09
SEm.	±0·16	SEm.	±0·20
'F' test	N.S.	'F' test	N.S.

Data obtained at Hagari Research Station show that *setaria*-cotton is not a good combination. They mutually compete or soil moisture and nutrients.

Although only 16″ rainfall was received during 1963-64 it has been possible to grow successfully an intercrop of Bengal gram with cotton. We will be trying Bengal gram with *Jowar* spaced 36" apart.

TABLE 7: Yield of cotton/ha as a pure crop and intercrop with Bengal gram

Crop	Yield in Kg/hectare		Gross income
1. Cotton (pure crop)	209·6 kg		Rs. 197·12
2. Cotton with Bengal gram as intercrop	172·5 kg of cotton	+1020 kg of Bengal gram	Rs. 252·76

N.B.: Price of cotton — Rs. 94/- per quintal.
Price of Bengal gram — Rs. 62 per quintal.

SOIL FERTILITY

Literature is full of data on the supply of plant nutrients and moisture utilization. They indicate that the evapotranspiration quotient of a plant adequately supplied with nutrients is considerably less than that of under-nourished plant. Further, a well fed plant has a longer root system and can tap soil moisture which is otherwise unutilizable.

The local black soils are severely deficient in nitrogen and phosphorous; yet the response to fertilization is rarely economic, particularly, for *Jowar*. The cause appears to be more connected with want of placement than with inadequate moisture. There is reason to believe that at least two rains must be received during the interval between fertilizer application and sowing.

None of the other nutrient elements is lacking in the soil. In fact, there are cases on record of crops suffering from manganese and boron excess, the contents being 0·5 per cent and 8-10 ppm respectively.

CONCLUSION

1. Application of F.Y.M. to the tune of 12,00 kg per hectare had no effect either on the yield of *Jowar* or cotton or on the soil aggregation.
2. In black cotton soil, aggregation can only be achieved if the organic matter is allowed to decompose *in situ*.
3. Crop varieties of 120 days or less duration are likely to succeed under these conditions.
4. The black cotton soil is rich in micro-nutrients and is poor in nitrogen and available phosphorus.

ACKNOWLEDGEMENT

It is impossible to acknowledge one and all on whose work the present paper is based. I have drawn freely from the records of the Hagari Agricultural Station. Credit is also due to the research workers in the various fields at the Bellary Centre.

My thanks are due to Dr R. V. Tamhane, Adviser Soil Conservation Government of India, for his guidance and keen interest in the conduct of research at the Bellary Centre.

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DISCUSSION

S. P. Raychaudhari: Is bunding practised at Bellary as a water and soil conservation measure? The properties of Bellary soils are different than those of Bombay-Deccan and, therefore, the improved farming practices evolved at Sholapur can not be applied under Bellary conditions. It is significant to note that well decomposed organic matter has not helped in overcoming the adverse effect of erratic weather.

S. Chattopadhyay: This practice of bunding is adopted by progressive farmers. Contour bunds have not proved a success as water does not infiltrate readily into the soil. High dose of decomposed organic matter may prove effective.

R. V. Tamhane: Modified form of bunding should be tried.

S. Chattopadhyay: Experiments are in progress in this respects at Bellary.

W. V. B. Sundara Rao: What about phosphate content of Bellary soils?

S. Chattopadhyay: The total P_2O_5 content si 0·2 per cent while available P_2O_5 ranges from 8 to 10 lb per acre. The application of all plant nutrients except phosphate will not increase crop yield.

G. B. Maxey: What is the concentration of boron and is its toxicity manifested?

S. Chattopadhyay: Its toxicity is not manifested.

EFFECT OF IRRIGATION WATER WITH DIFFERENT SODIUM AND SALINITY HAZARDS ON THE GROWTH OF THE CROPS AND THE PROPERTIES OF THE SOIL[1]

by

D. R. BHUMBLA, J. S. KANWAR, K. K. MAHAJAN & BHAJAN SINGH

INTRODUCTION

IN the Punjab about one-third of the total irrigated area is irrigated by wells. Kanwar (1961) presented data on the quality of ground waters in the Punjab and possibilities of their utilization. A number of standards have been proposed for judging the quality of irrigation water (Puri, 1949; Durand, 1954; U.S.D.A. 1954; Kanwar, 1961; Wilcox, 1958). Most of these standards have been fixed either on the basis of visual observation in the fields or on theoretical reasoning arising from cation exchange equations. Standards fixed by U.S.D.A. Salinity Laboratory are most widely used even though a number of observations have been reported from different countries indicating their limitations. Durand (1954) reporting on the quality of irrigation water in Algeria has given data to show that waters with very high salt content (E.C.$\times 10^6$—5000-20,000) have been used successfully for many years. Kanwar (1961) and Kanwar and Manchanda (1964) in a study on the quality of irrigation waters of Gurgaon district in the Punjab reported that waters containing as high salts as 58000 micromhos showed no adverse effects on the growth of crops in the field.

In India, a number of studies have been reported on the quality of irrigation waters. Quality of irrigation waters of Uttar Pradesh has been reported by Agarwal *et al.* (1956). Similar studies with respect to waters in Rajasthan have been given by Darra *et al.* (1964): Kanwar and Manchanda (1962) studied the quality of irrigation waters of Gurgaon district in the Punjab. Effects of exchangeable sodium and soluble salts on plant growth and soil properties have been investigated extensively in U.S.A. Bernstein and Pearson (1956) studied the effect of exchangeable sodium on the yield and chemical composition of a number of plants. Chang and Dregne (1955) studied the effect of exchangeable sodium in soil properties and on growth and cation content of alfalfa and cotton. Chang (1961) studied the effect of saline irrigation water and exchangeable sodium on soil properties and growth of alfalfa. Steyn (1959) in South Africa studied the influence of saline irrigation water on wheat and maize in lysimeter. Similar studies have been reported from Israel (Ravikovitch & Muravsky 1958, Waisel & Bernstein, 1959). Most of these studies were conducted in pots. In India very few studies have been reported on the effect of the use of saline water for irrigation on soils and crops. Kulkarni (1961) presented data of his studies on the use of irrigation water for sugarcane and dhanichá in Bombay.

The present studies were undertaken to study the effect of irrigation waters varying in salinity and alkalinity hazards on the growth of maize and wheat grown in small field plots, and on the properties of soil.

MATERIALS AND METHODS

The experiment was conducted in small plots ($5' \times 5'$) in a field of the College of Agriculture, Ludhiana. The soil of the experimental field was sandy loam in texture, with *p*H of 8·0, slightly calcareous and non-saline (E.C.$\times 10^3$= 1·28).

Irrigation waters were prepared artificially so as to have approximate electrical conductivity of 3300(C_1), 5600(C_2), 11200(C_3), 20,000(C_4) micromhos/cm at 25°C (33·0, 56·0, 112·0 and 200·0 me/l). The cations were so varied so as to give waters with sodium adsorption ratio (S.A.R.) approximately 4, 8, 12 and 16. The plots to which tube-well water alone was applied served as control.

Maize and wheat were grown in succession for three years (1961-62 to 1963-64). The yields of the crops were recorded. After three years the soil samples were taken and analysed to study the effect of different treatments on the soil. Saturation extract was analysed according to methods as given in U.S.D.A. handbook (Richards, 1954).

During the growth of crop 81 inches irrigation was applied. Each irrigation was enough to wet the soil to a depth of about 24 inches.

RESULTS AND DISCUSSIONS

The yields of wheat grain and straw and of maize fodder are given in Tables 1, 2 and 3. In case of

1. Contribution from the Punjab Agricultural University, Ludhiana.

wheat grain lower yields were obtained by the application of saline water but the differences between contiol and C_1 were significant only in 1961-62. When the individual effects of salinity and S.A.R. were compared it was observed that the differences between S.A.R. 4, 8, 12 and 16 were non-significant. Similarly the differences in yield due to the application of C_1 and C_2 were non-significant, C_4 gave significantly lower yield than C_1, C_2 or C_3 in both years. More or less similar effects were observed in the yield of wheat straw. The interaction between salinity and S.A.R. was non-significant.

Reduction in yield to the extent of 50 per cent was observed only when C_4 (EC-20,000 millimhos) waters were used.

Increasing salinity resulted in lower yields of maize fodder and the differences between different level of salinity were significant. Reduction in

TABLE 1: Effect of the quality of irrigation water on the yield of wheat grain (gm/plot)

Treatments	1961-62 (*control*=815)				*Mean*	1963-64 (*control*=644)				*Mean*
	C_1	C_2	C_3	C_4		C_1	C_2	C_3	C_4	C_4
S.A.R. 4	648	639	447	112	461	650	574	554	126	476
S.A.R. 8	750	764	537	154	551	589	600	639	114	485
S.A.R. 12	682	608	443	207	485	662	605	586	268	530
S.A.R. 16	756	657	453	151	479	669	548	523	317	514
Mean	709	667	445	156		642	582	575	206	
S.E.	27·6 gm/plot					45·5 gm/plot				
L.S.D. @5%	54·1 gm/plot					89·3 gm/plot				
L.S.D. @1%	74·5 gm/plot					117·2 gm/plot				

By the F-test the effect of conductivity was significant while that of S.A.R. was non-significant.

C_1= 3300 E.C.$\times 10^6$
C_2= 5600 E.C.$\times 10^6$
C_2=11,000 E.C.$\times 10^6$
C_4=20,000 E.C.$\times 10^6$

TABLE 2: Effect of the quality of irrigation water on the yield of wheat straw (gm/plot)

Treatments	1961-62 (*control*=1267)				*Mean*	1963-64 (*control*=1393)				*Mean*
	C_1	C_2	C_3	C_4		C_1	C_2	C_3	C_1	
S.A.R. 4	1014	988	602	173	694	1349	1260	1020	286	979
S.A.R. 8	1277	1146	823	197	861	1261	1212	1298	223	989
S.A.R. 12	1146	838	614	309	727	1463	1357	1202	397	1105
S.A.R. 16	1053	914	598	197	666	1468	1376	827	395	1067
Mean	1123	971	634	219		1385	1326	1086	350	
S.E.	61·0 gm/plot					75·2 gm/plot				
L.S.D. @ 5%	119·7 gm/plot					147·3 gm/plot				
L.S.D. @ 1%	137·8 gm/plot					193·8 gm/plot				

Effect of conductivity was found to be significant in both the cases by F-test, while effect of S.A.R. was found to be significant in 1961-62 and non-significant in 1963-64.

C = 3300 E.C.×10
C = 5600 E.3.×10
C =11,000 E.C.×10
C =20,000 E.C.×10

TABLE 3: Effect of the quality of irrigation water on the yield of maize green fodder (gm/plot)

Treatments	1963-64 (*control* = 2425 *gm/plot*)				*Mean*
	C_1	C_2	C_3	C_4	
S.A.R. 4	1889	1742	1406	936	1493
S.A.R. 8	1733	1648	1357	790	1382
S.A.R. 12	1740	1516	1343	989	1397
S.A.R. 16	1823	1310	971	905	1252
Mean	1795	1554	1269	905	—
S.E. for conductivity	= 91·6 gm/plot				
L.S.D. @ 5%	=179·6 gm/plot				
L.S.D. @ 1%	=235·8 gm/plot				

C_1= 3360 E.C.×10_6
C_2= 5600 E.C.×10_6
C_3=11200 E.C.×10_6
C_4=20000 E.C.×10_6

yield to the extent of 50 per cent occurred only when C_4 water was used. Application of water with S.A.R. 16 gave significantly lower yield than S.A.R. 4 water.

These results indicate that in areas where rainfall is 50 cm per annum or higher and the soils are sandy, highly saline waters can be used for crops like wheat. In case of wheat, at concentrations used in these studies the S.A.R. is without any effect. But in case of maize though effects of salts on yield are far greater than exchangeable Na, yet lower yields were obtained as waters of higher S.A.R. were used. Chang (1961) reported that at intermediate salt and ESP levels the depressing effect of exchangeable sodium and soluble salts on alfalfa yield appeared to be additive, but the present studies did not reveal any interaction-positive or negative. Ravikovitch and Muravsky (1958) in a study of irrigation with waters of varying degrees of salinity and its influence on soil and crops reported that wheat was one of the crops that gave good yield when grown with relatively saline water but maize gave less than average yield.

Effect of the application of different waters on properties of soil is presented in Table 4.

After three years of application of water the electrical conductivity of the saturation extract increased. As expected, the water with higher salt content resulted in higher conductivity. Even the use of water with 5600 micromhos conductivity did not produce salinity which could be considered critical for maize and wheat (Fig. 1). At higher S.A.R. value (12 and 16) the conductivity of the saturation extract was higher than at lower S.A.R. value. Sodium adsorption ratio of the saturation extract was of similar order as S.A.R. of the irrigation water. A trend of lower sodium adsorption ratio with increasing conductivity of irrigation water is apparent. This may look contradictory to accepted principles. But as the soil on which studies were conducted is calcareous, it is likely that calcium carbonate of the soil might have become soluble at higher salt concentration.

In an ideally drained and irrigated soil, the electrical conductivity of the saturation extract could

TABLE 4: Effect of the quality of irrigation water on the properties of soil (average of 4 observations)

Treatments	*Saturation extract*							
	pH	*E.C.*%10^3	Na^+ (*me*/1)	Ca^{++} (*me*/1)	Mg^{++} (*me*/1)	*S.A.R.*	HCO_3^- (*me*/1)	Cl^- (*me*/1)
Control	8·1	1·28	4·37	4·20	2·85	2·23	2·71	3·06
C_1 SAR 4	7·9	2·92	11·53	7·70	1·75	5·31	3·33	12·54
C_2 SAR 4	7·8	2·72	13·10	12·10	2·10	4·92	4·16	9·27
C_3 SAR 4	7·4	6·42	21·17	31·10	4·36	4·96	2·90	39·19
C_4 SAR 4	7·4	9·00	24·46	55·50	56·0	4·47	1·90	66·41
C_1 SAR 8	7·9	2·71	11·60	8·60	—	—	5·27	10·54
C_2 SAR 8	8·2	2·37	21·77	7·65	2·35	9·54	6·07	10·68
C_3 SAR 8	7·7	4·63	20·87	31·48	5·52	4·85	2·00	30·46
C_4 SAR 8	7·5	10·77	25·80	53·20	3·00	4·87	2·51	75·36
C_1 SAR 12	8·0	4·21	26·23	7·68	2·82	11·45	4·45	20·64
C_2 SAR 12	8·1	4·46	27·40	7·70	2·90	11·90	6·00	18·99
C_3 SAR 12	7·8	8·70	36·38	26·93	4·00	9·26	1·97	49·20
C_4 SAR 12	7·3	10·80	39·40	31·88	3·80	9·47	2·00	76·01
C_1 SAR 16	8·0	3·16	21·00	6·25	2·88	9·68	3·96	13·80
C_2 SAR 16	7·7	5·65	30·57	9·00	1·66	13·23	3·75	25·15
C_3 SAR 16	7·4	9·07	35·04	18·56	1·65	11·02	2·72	44·23
C_4 SAR 16	7·4	13·00	37·96	32·85	5·10	8·70	2·27	79·55

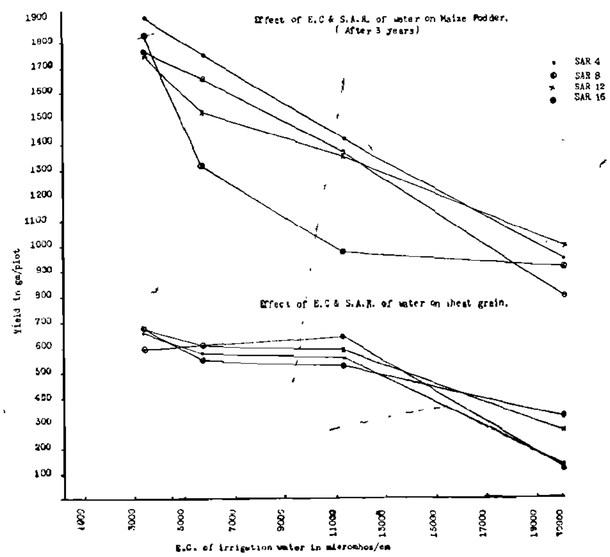

Fig. 1

approximate half the value of the electrical conductivity of irrigation water (Bernstein, 1962). The data given in Table 4 clearly show that with waters of S.A.R. 4 and S A.R. 8, the electrical conductivity of the saturation extract was about half that of irrigation water but at higher S.A.R. higher values were obtained, which indicates that drainage conditions were not ideal at higher S.A.R. Singh and Kanwar (1964) also reported that under good management practices in the field the electrical conductivity of the saturation extract of the soil is lower than that of irrigation water.

Kanwar and Manchanda (1964) reported that highly saline waters of Rewari tehsil which have as high as 15050 micromhos/cm electrical conductivity and 14·74 S.A.R. produced bumper crops of wheat and barley and had no deleterious effect on soil. As these waters contained appreciable quantities of nitrates and potash so Kanwar and Manchanda thought that the tolerance of crops to such highly saline water may be due to presence of nutrients apart from leaching of salts due to heavy rains The present studies indicate that for crops like wheat (and for barley, which is more tolerant of salts) waters with much higher conductivity than the established standards can be used with advantage. If the canal irrigation is available tube-well waters can be mixed with canal water and used. In dry areas of the Punjab where sub-soil water is brackish, barely and wheat are the principal crops in *Rabi* and *Bajra* (*Pennisetum*) in *Kharif*. All these crops are tolerant of salinity and alkalinity. For such areas the use of water with about 4000 micromhos conductivity can be safely recommended for light textured soils. Similarly, in areas where crops suffer because of the closure of canals at critical period of crop growth, tube-well can be recommended to supplement the irrigation water even if the sub-soil water is brackish.

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DISCUSSION

J. J. Chinoy: If the germination of seed can be carried out with the use of nonsaline water and seedlings are allowed to grow for about 30-40 days and then water of fairly high salinity is applied, the plants do not suffer in growth or yield provided the nutritional level of the soil is high.

D. R. Bhumbla: Largely this is a fact.

B. Ramamoorthy: The comparison of the author's results with those of U.S. Salinity Laboratory is not appropriate as the standard of 50 per cent reduction in yield of the authors is at 700 m. mhos and is different from that of the latter. The effect of salinity on plant yield is not always linear.

D. R. Bhumbla: Fifty per cent reduction in yield was obtained at 20,000 micromhos. Comparison with the U.S. Salinity Laboratory standard has not been attempted.

C. T. Abichandani: High salinity water upto 7 gm per litre and 22 S.A.R. values are used in the arid zone of W. Rajasthan for growing salinity resistant variety of wheat. Results of these experiments are, therefore, very interesting. By using these results the irrigation potential with saline ground water in the arid zone will increase.

D. R. Bhumbla: Further research is necessary to recommend extensive use of such highly saline sodic waters on different soils.

MANAGING ARABLE LANDS IN ARID & SEMI-ARID REGIONS

by

N. D. Rege*

It is rather difficult to define arid zone as the definition will have to take into account data on climate, soil, vegetation etc. However, it is customary to describe the arid zone as an area having minimum of precipitation and maximum of temperature. Rainfall in this zone is scanty, localized, erratic and often comes in short storms. In semi-arid region, it may be as high as 30 inches annually but here also more often it is extremely erratic.

Shantz (1) included all the area from extremely arid to semi-arid area under arid zone. Further the methods adopted for arid lands can be safely utilized in semi-arid lands with success.

It has been estimated that 43 per cent of the land area of the earth is arid, on the basis of soil. The soils are pedocals and have dry sub-soils. On the basis of vegetation, it works out to be 35 per cent and if based on climate and internal drainage it works out to be 36 per cent and 35 per cent respectively. It can, therefore, be seen that nearly 1/3rd of the total land area of the earth has moisture as the limiting factor in crop production. Plants have thus to adjust considerably to this limitation if they have to put good growth and give economic returns.

Early history has shown that it is not difficult to raise a good crop even under such conditions. The Hopi Indians on the South West of United States had been outstanding in raising crops successfully under arid conditions. Even with the low rainfall they had developed irrigated and dry farming systems to a degree which even with the help of modern techniques on soil chemistry, plant physiology etc. has not been achieved under modern agriculture. Because ordinary maize seed could not reach the surface if planted over 3 inches deep, they developed a variety known as Hopi maize. It has a very elongated hypocotyl and the seed can be planted as deep as 14 inches. Further, it has only one root (instead of normal three roots) and can go deep into the soil in search of moisture. Beans, squash and melons were grown without irrigation.

The Papagoes practiced dry farming with or without flood water. Maize, wheat, beans, barley and cotton were the main crops. So also in Egypt and other Arab countries development of olive culture by wider spacing and clean cultivation was done in dry land. There is a considerable evidence in literature that in ancient times grain agriculture was a m jor industry with Carthaginians in arid areas.

Agriculture in arid and semi-arid regions is still a gamble in view of the fact that successful crop production primarily depends upon the availability of soil moisture. Rainfall in this area, as pointed out earlier, is very meagre particularly so in the extreme arid areas. It often comes in short spells with high intensity. The quantity of rain may be sufficient to grow a good crop but most of it goes of as run-off and evaporation before the crop is ready to utilize it. More often it is less than even the evapo-transpiration potential. Drought conditions are very common leading to failure of crop and forage production.

This means one has to either follow dry farming techniques or irrigation. Irrigation will be possible if there is good ground water available in addition to water available from canal. But even this supply is not very assured as some time under-ground water gets exhausted faster than it gets replenished, and secondly it may not be also of good quality.

Dry farming in this area can be adopted with a considerable amount of success provided adequate steps on the following lines are taken:

1. to catch water where it falls;
2. to hold it in the soil;
3. to use it as soon as possible through crop adjustment.

In order to achieve the first two objectives, the following measures will have to be taken:

(a) Adopting soil conservation measures to prevent run-off and soil loss;

(b) To adopt such tillage practices which would conserve moisture;

(c) To modify soil physical properties to make maximum moisture available to plant.

In regard to item (3) it would be necessary to select cropping pattern to utilize water as fast and withdraw it from lower zones wherever possible.

The soil and water conservation measures which will be necessary in this regard are: (1) Contour farming, (2) Contour ridging, (3) Basin listing, (4) Level terraces, and (5) Water spreading.

It has been observed (2) that contour farming alone can reduce the soil loss by about 50 per cent and loss of water by about 15-20 per cent on land where corn and cotton is grown. Contour farming can give as much as 5-10 per cent increase in yield of row crops more due to the conservation of moisture. The effect is more pronounced in the year of low rainfall during growing season. At Bellary in Mysore State

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(India) (Annual Progress Reports) Contour cultivation alone has given as much as 15 per cent increase in the yield of *sorghum*.

Level terraces are invariably used in arid and semi-arid region. These are meant primarily to catch run-off water in order to make it enter the soil. Sometimes these are closed at the ends. The moisture thus conserved gives quite an appreciable increase in the yield. This becomes more pronounced when contour cultivation is adopted on level terraces as can be seen from the following table 1.

TABLE 1: Effect of contour rows and contour rows with level terraces on available moisture and yield

Type of practice	*Average available moisture in upper five feet of soil on May 20*	*Yield if lint-cotton per acre*
1. Row with slope	3·06	130
2. Row with contour	3·33	165
3. Row with contour supplemented with closed level terrace	3·72	206

Contour bunds or narrow base ridge terraces help considerably in conserving the moisture and control soil erosion. When bunding was supplemented with application of organic matter, the increase in yield of grain becomes more pronounced. At the Dry Farming Station, Sholapur, (4) it has been found that application of 5000 lbs. of Farm Yard manure per acre in the medium deep soils gave an increase of 23 per cent in grain of sorghum. In case of deep soil, the increase was even more, the range being 43-45 per cent. So also green manuring in these areas gave consistent increase in grain to the order of 17 per cent yet the application of green manure in the years of low rainfall was of doubtful value.

Interculturing was able to reduce the loss of available moisture through weeds and evaporation. The increase in grain yield of *sorghum* with interculturing at Bijapur, Mysore State, India (5) was 29 per cent in medium and 23 per cent in light soils. Fallowing an crop rotation has also helped in increasing the sorghum grain by 15 per cent in deep soils and 40-46 per cent in limy soils. However, fallowing was not useful in lighter soils.

Water spreading is one of the methods adopted to collect the fun-off which otherwise would be lost as run-off. This has certain limitations as collection of run-off and its use for growing crops will depend upon topography and the soil type. In recent years this idea is gaining momentum in States of Rajasthan, Uttar Pradesh, Madras and Andhra Pradesh in India.

MODIFYING SOIL PHYSICAL CHARACTERISTICS

Soil physical characteristics can be modified to some extent through crop practices, use of amendments, tillage etc. The primary soil property which is much more important in conserving moisture is structure of the soil. It is well-known that if the soil has good structure—crumb or granular it conserves more moisture than soil having platy or blocky structure.

Soil structure can be improved through adopting cropping practices which will give water stable aggregates. It has been observed that grass develop better water stable aggregates than sorghum. Experiments carried out at Soil Conservation Research Centre at Bellary, Mysore State, India (a separate paper is given by this Centre) have clearly shown the effect of ley farming on infiltration under grass cover. So also the researches carried out at other Soil Conservation Centres in India has proved that grass cover helps in increasing the infiltration in the Soil as well controls erosion.

Investigations carried out in U.S.A. (6) have also given the value of organic matter in building up stable aggregates. One such study has clearly indicated that for each 0·1 per cent increase in percentage carbon, increase in the total soil aggregates is from 17 per cent for the untreated to 32·1 per cent for 2 per cent carbon level.

In India, also it has been noticed that organic matter increases the total soil aggregates. Further it is found necessary to incorporate organic matter into the soil and allow it to undergo decomposition for increasing soil aggregates. However in areas where the rainfall is low and erratic, the raising of green manuring poses a serious problem and hence, it is rather difficult to recommend the use of green manuring.

Polyelectrolytes (7) such as Krilium, VAMA, can be used as soil conditioners to increase soil aggregation.

CONCLUSION

It is thus seen that by developing such techniques which will go a long way to conserve moisture and making it available for plants it is possible to manage arid and semi-arid lands more beneficially. In addition to these emphasis will have to be given on evolving plant varieties which have less water requirement and stand drought conditions. If Hopi Indian could do this centuries back when soil and plant science was in infancy, there is no reason why with modern technological progress, we cannot even surpass this.

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DISCUSSION

J. S. P. Yadav : What is the significance of dry spells in crop performance.

N. D. Rege : The dry spells strongly influence crop performance. Therefore, varieties of crops should be selected which would suit local conditions. In order to overcome the serious effect of dry spells time of planting or sowing date experiments should be performed so that sowing is adjusted to predicted periods of dry spells.

P. Jagannathan : The frequency distribution of the number of years when eastern and western Rajasthan experience 0, 1, 2, 3, etc., weeks of drought have been referred to in this symposium. Shri T. R. Shrinivasan has reported the study of drought spells in Rayalaseema. The probability of a particular pattern of " dry " spell sequence interspersed between " wet " spells can be worked out statistically from the available records of rainfall. The anticipation of crop performance during a coming season is related to quantitative precipitation forecasting for the relevant period.

P. C. Raheja : What is the duration of the dry spell that damages the crop ?

A. R. Bhaskaran : This varies from 15 days onwards and is related to moisture availability in the soil to the crops.

C. T. Abichandani : Have any studies been conducted on soil moisture regime and correlated with dry spells and growth of crops ?

J. S. P. Yadav : Up to what depth of soil is the moisture exhausted during the dry spells ? Which particular nutrient elements become unavailable due to dry spells ? What are factors associated with deficient availability of nutrients to crops accompanying dry spells ?

A. R. Bhaskaran : The soil moisture loss varies from one soil type to another.

AFFORESTATION

AFFORESTATION STUDIES IN THE ARID ZONE OF INDIA[1]

by

R. N. KAUL & B. N. GANGULI[2]

INTRODUCTION

1. *The Region:* The arid region of India falls in the Indo-Pakistan sub-group of the broad North-African-Eurasian arid province (UNESCO, 1958) between 24°N. latitude and 70°E. longitude, covering a total area of 213,668 sq km forming the northwest portion of Rajasthan State.

The climate is characterized by high temperatures. The diurnal variation is 14°C., mean maximum being 32·7°C., and mean minimum being 18·8°C. The mean relative humidity is 41 per cent as the rainfall is limited and erratic. It ranges from 50 mm. to 350 mm. in different parts of the arid zone (Govt. of India, 1963).

The soils of the region belong to the category of mineral soils which are mechanically disintegrated. They contain a high percentage of soluble salts and significant amounts of $CaCO_3$. The *p*H value varies from 7·0 to 9·0. The soils are immature, structureless, very coarse in texture, low in water-holding capacity and with low nutrient status. Moisture deficiency is the chief limiting factor (Yadav, 1960).

The vegetation consists of sparse and scattered thorny trees, shrubs, and grasses and is classed as Tropical Thorn Forest (Champion, 1936). The most common species are:

Trees: *Acacia nilotica, A. leucopholoea, A. senegal, Anogeissus rotundifolia, Prosopis cineraria, Salvadora oleoides, S. persica* and *Tecomella undulata.*

Small trees and shrubs: *Acacia jacquemonti, Balanites aegyptica, Calligonum polygonoides, Calotropis porcera, Capparis decidua, Flacourtica indica, Gymnosporia spinosa, Leptadenia pyrotechnica, Lycium barbetum, Mimosa hamata* and *Zizyphus nummularia.*

Grasses: *Aristida* species, *Cenchrus catharticus, C. ciliaris, C. setigerus, Dactyloctenium sindicum, Dichanthium annulatum, Eleusine flagellifera, Lasiurus sindicus, Panicum antidotale, P. turgidum* and *Sporobolus pallidus.*

In the four principal edaphic habitats, namely, sand dunes, shallow sandy plains, semi-rocky and rocky areas occurring in this region distinct plant associations are found. The frequency and the cover of plant species decrease from east to west following the pattern of declining rainfall.

2. Need for Afforestation: As compared with arid zones in other countries, Rajasthan has a diverse population density ranging from 3 persons per sq. km. in Jaisalmer district to 120 in Jhunjhunu district. Its animal population expressed as cattle units has an average density of 177 per 100 grazing hectares (Govt. of India, 1961). In contrast to the arid regions of Australia, the United States of America, and Israel where kerosene oil, natural gas or petroleum provide most of the energy, in Rajasthan, the natural vegetation forms the chief source of fuel besides contributing to the requirements of small timber for agricultural implements and fencing material (Kaul, 1963). There has been a rapid growth in population and this has inflated the demand for fuel wood, resulting in indiscriminate cutting of shrubs and trees. These and the constant and excessive biotic activity near villages has seriously damaged the vegetation and in many places reduced its density. The traditional method of land use, which is to concentrate around water sources and practice extensive instead of intensive agriculture, has led to further and serious degradation of the native plant communities.

This has resulted in activating sand movement, and inducing the spread of sand over agricultural fields, grazing lands and villages. It has brought about an imbalance between the human and animal populations on the one hand, and the plant, water and land resources on the other. Thus, from both the sociological and ecological viewpoints, there is a need for tree planting in the arid region of India.

3. Scope for Afforestation: The natural plant communities are found in several stages of degradation. Therefore, it is rare to find the optimal proportions of the different components of the natural plant communities on different land types; there is scope for plantations as certain land types are more favourable for afforestation.

In areas receiving low rainfall (150-250 mm) the ideal sites for afforestation are those where sub-surface soil moisture is available, as in shifting sand dunes. In higher rainfall ($>$ 375 mm) tracts, refractory sites such as shallow soils can be successfully afforested by modifying the physical limitations imposed by the environment.

There is also great scope for extensive planting of windbreaks around cultivated fields where irrigated farming is practised to protect crops from desiccating winds. Avenue planting along highways and planting of village wood—lots for human needs have a special place in tree planting programme for the arid zones.

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Silviculturist and Asstt. Silviculturist respectively at this Institute.

SILVICAL STUDIES AND UTILIZATION OF TREE SPECIES

Studies were initiated on (i) silvical characteristics of the four important indigenous tree species; (ii) adaptability trials on exotic tree and shrub species introduced from isoclimatic regions of the world; (iii) afforestation techniques in relation to four edaphic land types, and (iv) utilization of topfeed species. The results obtained are briefly discussed below.

1. Silvical Studies: Silvical studies dealing with the water economy of nursery seedlings, optimal age of nursery stock suitable for transplanting, best time of transplanting, and soil management and method of reboisement on four indigenous tree species, *Prosopis cineraria, Tecomella undulata, Acacia senegal* and *Albizzia lebbek* are in progress under conditions of sandy soil and a mean annual rainfall of 300 mm.

(a) Nursery Studies: A well-balanced potting mixture containing essential trace elements was found necessary for the proper growth of seedlings. Seedlings of *Albizzia lebbek and Prosopis juliflora* in metallic containers exhibited increased plant population and growth-in-height as compared to those in earthen ones. Metallic containers also effected on economy in watering over earthen containers to the extent of 25 per cent. In general, increased levels of watering resulted in increased survival and growth-in-height of seedlings of *Albizzia lebbek* and *Prosopis juliflora*. However, nine litres of water at a time per set of 50 containers was found to be the most economic dose of watering for successful raising of nursery seedlings. When grown under shade, the water need of seedlings was less by 9·6 per cent as compared to those grown in the open. Seedlings kept in cemented beds under nine litres of watering levels required 29·8 per cent less water as compared to those kept in earthen beds, due to lesser number of root clippings in cemented beds. The use of metallic containers effected an overall economy of Rs. 6/- (U.S. $ 1·25) in production per 100 seedlings (Kaul and Ganguli, 1963).

Further studies on the material and optimal size of containers indicated that polythene containers 30 cm. long and 10 cm. in diameter were both economical and equally as efficient as metallic containers of the same size.

Field performance of *Albizzia lebbek* and *Prosopis juliflora* seedlings raised in different containers showed that the initial gains in height in metallic containers compared to earthen ones levelled off after the second year of transplanting, suggesting that the containers can be made of any material which is locally available, cheap, efficient in moisture conservation, and able to withstand transportation over long distances.

(b) Artificial Regeneration Studies: In preliminary observations, 6 and 9-month-old seedlings of *Prosopis cineraria* and *Albizzia lebbek* and one-year-old transplants of *Acacia senegal* showed increased establishment compared to two-year-old seedlings. Thus, in the arid region younger seedlings successfully withstand the physical limitations of the environment.

The planting of young seedlings instead of the general practice of using older transplants will substantially reduce the cost of production of nursery stock.

The species, *Prosopis cineraria, Acacia senegal, Tecomella undulata*, and *Albizzia lebbek*, exhibited increased survival when planted out in the field in the first fortnight of july as compared with other periods. The best planting period synchronizes with the onset of monsoon.

Compared with direct seeding, transplanting proved to be an assured method of reboisement. Soil working of 60 × 60 cm half-filled pits with a crescent-shaped ridge along the local slope gave a high rate of establishment.

2. *Adaptability Trials*: These covered 73 species of *Eucalyptus*, 20 species of *Acacia*, 8 species of *Casuarina*, and miscellaneous species of 24 genera from Israel, Australia, the United States of America, the USSR, Southern Rhodesia, etc. Amongst these, *Acacia tortilis* (Israel) and *Eucalyptus camaldulensis* (Australia) have shown good adaptability to this environment and are superior to the principal indigenous tree species in both survival and growth in height and diameter (Kaul and Ganguli, 1962, Kaul, 1963). Other promising species are *Eucalyptus melanophloia, E. terticornis, Acacia gregii, A. planifrons* and *Zyziphus spinachristi*.

Following the deep soil-working technique (90 cm deep pits 60 cm in diameter), species of various exotic genera were tried under conditions of shallow soil (22·5 cm. deep) and 400 mm rainfall. Based on data on survival and growth, the performance of various species in order has been *Eucalyptus camaldulensis, E. intertexta, E. melanophloia* and *E. tessellaris*. These species showed cent per cent survival. Other promising species are *Acacia tortilis*, *Melaleuca pubescens* and *Myoporum* species.

3. *Afforestation Techniques*

(a) Shifting Sand Dunes: In low rainfall areas (150 mm to 400 mm) human and animal interference with native vegetation has given rise to shifting dunes, particularly near habitations and townships. Techniques of afforestating shifting sand dunes were standardized after 10 years of experimentation (Bhimaya, Kaul and Ganguli, 1961). They consist of (i) protection against biotic interference, (ii) treatment of shifting sand dunes by fixing barriers in parallel strips or chess board design using local shrub material starting from crest down to the heel of the dune, and (iii) afforestation of such treated dunes by direct seeding and planting. The bush barrier protects the seedlings from burial or exposure by the blowing of sand. The two species commonly used for erecting brushwood barriers are *Zizyphus nummularia* and *Crotolaria burhia*. Direct seeding of grass species and creepers is carried out in lines 2 to 5 metres apart on the leeward side of the micro-windbreak. The nursery stock are raised either in containers or in specially prepared sundried planting bricks, consisting of a mixture of sand, clay and farm yard manure in the ratio of 1: 1: 1, within height of 30 cm and a cross-section at top and bottom of 10 and 15 cm square respectively. When transplanted, they give a high degree of establishment (Prakash and Pathak, 1957).

The indigenous and exotic species which have proved successful in different rainfall tracts are, Trees: *Acacia senegal*, *Albizzia lebbek*, *Ailanthus excelsa*, *Cordia rothii*, *Dalbergia sissoo*, *Prosopis juliflora*, *Tecomella undulata*, and *Zizyphus jujuba*, Shrubs: *Calligonum polygonoides*, *Cassia auriculata*, *Ricinus commumis*, and *Zizyphus nummularia;* Grasses *Lasiurus sindicus*, *Panicum antidotale*, *P. turgidum*, and *Erianthus munja*. *Eucalyptus oleosa* (Australia) and *Acacia tortilis* are promising exotic tree species for these habitats.

Sand dunes afforested in this way have at the end of 5 years produced wood ranging from 15 to 20 metric tonnes per hectare in the 200 mm. and 360 mm rainfall tracts respectively, thereby yielding a net profit of Rs. 142/- (U.S. $ 28/-) and Rs. 284/- (U.S. $ 56/-) per hectare respectively.

(b) Shallow Soils: Earlier experiments on the establishment of tree seedlings on shallow soils (22·5 cm. depth) overlying hard calcareous pan under rainfall of 375 mm. showed that *Albizzia lebbek*, *Eucalyptus camaldulensis*, and *Casurina equisitifolia* exhibited highest seedling survival in pits 30 cm in diameter and 60 cm deep (Bhimaya and Kaul, 1960). *Casuarina equisitifolia* failed to establish, while the other two remained stunted and did not put on any appreciable increment even after 7 years of growth. Subsequent experiments with deep soil working in pits of 60 cm diameter and 90 cm. depth perforating much of the hard pan consistently resulted in cent per cent survival and a mean annual height increment of 52·2 cm and 187·0 cm in *Azadirachta indica* and *Albizzia lebbek* respectively.

(c) Semi-rocky Areas: These soils are characterized by their shallow depth at the foothills in the 225 to 350 mm rainfall tract and are formed by colluvial silt and rock fragments. Among the different soil-working techniques tried in the experimental afforestation on an area of 283 hectares, seeding of *Acacia senegal* *Prosopis juliflora*, *Tecomella undulata*, *Acacia arabica*, and *Prosopis cineraria* on staggered contour ridge-cum-trench 3 m in length and 60 × 60 cm in cross section proved successful. Amongst these species, at the end of 9 years, maximum survival was recorded by *Prosopis juliflora* 50 per cent, *Acacia senegal* 36 per cent and *Cassia auriculata* 15 per cent. However, average growth in height and diameter at breast height recorded was *Prosopis juliflora* 4·8 m and 3·2 cm, *Acacia senegal* 1·5 m and 1·4 cm; and *Cassia auriculata* 1·3 m and 2·5 cm respectively.

Planting was done in 60 × 60 cm. half filled pits with a crescent shaped ridge across the local slope. Pre-sprouted stumps of *Prosopis juliflora* recorded 94 per cent survival and a mean growth in height of 4·8 m at the end of 9 years. *Albizzia amara* (96 per cent) *Azadirachta indica* (95 per cent), and *Holoptelea integrifolia* (90 per cent) were next in order in percentage survival. As the soil is shallow, the plants tend to slow down in growth as soon as their roots strike the rock or pan beneath. Sometimes as a result of the combined effect of consecutive drought years and adverse edaphic factors, plants have dried up after showing good initial performance in both survival and growth-in-height. Therefore, these land types may best be utilized for a short rotation (9-10 years) tree crop of *Prosopis juliflora* planted in pits with 90 cm deep worked soil.

(d) Rocky Areas: Barren rocky hills cover extensive areas and form one of the characteristic features of the landscape. Studies show that only those patches where about 30-40 cm depth of soil has accumulated should be planted with tree species. Pre-sprouted stumps of *Prosopis juliflora* in half-filled pits of 60 × 60 cm and direct seeding of *Acacia senegal* on ridges have given quite good establishment.

Ecological studies on one site revealed that, of the planted species, *Prosopis juliflora* and *Cassia auriculata* have become well established. Reduction in the number of some regressive species such as *Euphorbia caducifolia* and *Capparis decidua* has been observed. Development of trees and shrubs was better in compartments with a favourable micro-relief. Among the grasses, the regressive stage of *Oropetium thomeum*, *Tragus biflorus* is being replaced by a higher perennial grass stage of *Eleusine compressa*, *Dactyloctenium scindium*, the establishment being more successful in depressions than on the slopes or on bare rocky patches. Thus micro-relief is an important factor in planning afforestation in such areas (Bhimaya, Kaul, Ganguli and Bhatt, 1964, Bhimaya, Charian and Satyanarayan, 1964).

4. Roadside Avenue Planting: Experimental shelterbelts in the form of roadside avenues along the principal highways were established in different parts of the region to the extent of 200 km at a cost of Rs. 625/- (U.S. $ 105) per km.

The technique consisted of planting three staggered rows of trees on either side of the road (Kaul, 1957). In low rainfall (120 to 350 mm) tracts, regular watering of plants at 9 litres per seedling during the summer months for at least the first 2 years of planting, and with tree guards as protection against cattle gave a survival percentage of 62·4. The species in order of performance were, *Prosopis juliflora*, *Azadirachta indica* and *Albizzia lebbek*. In moderate rainfall (350 mm) these species under similar treatment recorded 95 per cent survival, whereas in the higher rainfall zone (400 mm) for *Azadirachta indica*, *Albizzia lebbek*, and *Dalbergia sissoo* without supplemental irrigation, 80 to 90 per cent establishment was recorded.

5. Topfeed Studies: Studies on the palatability and chemical composition of sixteen tree and shrub species occurring naturally in the grazing lands revealed that *Prosopis cineraria* and *Zizyphus nummularia* are the most important topfeed species of the

region (Ganguli, Kaul and Nambiar, 1964). Fourteen per cent density of *Zizyphus nummularia* was found to be optimal for maximum forage yield both in terms of *Zizyphus* leaves and grass per unit area of grazing land (Kaul and Ganguli, 1963). Investigations on lopping of *Prosopis cineraria* proved conclusively that complete as compared with partial lopping in the month of December resulted in maximum leaf fodder yield without adversely affecting the other growth attributes, viz., height and d.b.h. However, recurrent complete lopping reduced the leaf fodder yield, suggesting a need for a rest period for maximum sustained fodder yield (Bhimaya, Kaul and Ganguli, 1964).

FUTURE RESEARCH

Research will be conducted on (i) selection of economically important tree and shrub species capable of fully exploiting the resources of the site, namely, saline and alkaline soils and rocky areas under low (150-250 mm) rainfall regime, and development of clones of resistant strains, (ii) ecophysiology of adaptation of exotic species, (iii) nursery studies comprising inducement of drought and heat resistance, use of auxins on rooting of cuttings of tree and shrub species used for vegetative propagation and root regeneration potential of tree seedlings with respect to seedling age and factors of locality, (iv) water balance of tree and shrub communities, (v) application of "method steppique" on shallow soils under low rainfall regime, including investigations on its effects on soil moisture gradients, (vi) assessment of nutritional requirements of tree species and the field study of symptoms deficiency diseases and (vii) determination of the extent to which trees or shrub plantings influence the environment and productivity of adjacent areas.

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DISCUSSION

B. N. Muley : I would like to know some of the *Eucalyptus* species which could be planted for reclaiming marshy lands.

R. N. Kaul : Off-hand I could suggest a few species, namely, *Eucalyptus globulus*, *Eucalyptus robusta*, *Eucalyptus aggregata*, *Eucalyptus ovata*, *Eucalyptus viminalis*. Seed provenance is an important factor in the introduction of exotic species. The seeds of these species from forest trees in Tasmania and Australia should be tried for reclamation of marshy lands.

J. S. P. Yadav : Mr. Kaul in his paper has recognized the alkaline and saline flats as one of the five principal land types in arid zone Rajasthan. I would like to know the exact soil working technique and other methods which have been adopted for afforestation in such land type so as to keep the salinity and alkalinity status below the toxic limits for ensuring the success of species planted ?

R. N. Kaul : The esxperimental afforestation on saline and sodic soils has not yet been taken up by this Institute. This will soon be initiated in the Kutch region of Gujarat State.

S. P. Chatterji : You have referred to afforestation of shifting sand dune areas. How about afforesting fixed dunes ?

R. N. Kaul : Studies on afforestation of different land types in the arid zone have shown that shifting dunes are ideally suited for successfully raising economic plantations due to better soil moisture status and absence of competing vegetation. In case of fixed dunes, the existing natural vegetation competes with the introduced vegetation for soil moisture and thereby adversely affects the establishment and rate of growth of the introduced tree species. However, studies on afforestation of fixed dunes, following the agri-silviculture technique, are in progress, the results from which when obtained will throw light on the possibility of raising successful and economic plantations on such fixed dunes.

S. Pels : Under what conditions *Eucalyptus camaldulensis* grows well ? I am asking this question because in Australia the species is largely restricted to areas with shallow fresh ground water.

R. N. Kaul : In Australia I have observed that this species is largely restricted to areas adjacent to river banks but there are examples, namely, the rolling downs in Adelaide where good stands of *Eucalyptus camaldulensis* can be seen growing well away from river banks. In our trials in the arid zone of Rajasthan *E. camaldulensis* has shown great plasticity as this species survives even in areas receiving a mean annual rainfall of 250 mm and ground water at a depth of 100 metres.

U. S. Madan : Has *Acacia jacquemontii* been tried for sand dune fixation ? With regard to introduction of *Prosopis juliflora* Mr. Kaul has suggested that this species should not be introduced in areas receiving a mean annual rainfall of more than 375 mm as it tends to be an obnoxious weed. I would like to know why this species has been planted in Jodhpur which receives a mean annual rainfall of 375 mm and where it is becoming a pest. This has also become a menace in similar rainfall areas in Madras and Mysore State.

R. N. Kaul : As stated earlier due to better soil moisture status the shifting dunes are capable of supporting tree species of greater economic value than *A. jacquemontii* namely, *Prosopis juliflora* which has yielded 15 tonnes of firewood per hectare at the end of 5 years. Therefore, from both soil conservation and economic reasons *A. jacquemontii* is not an ideal species to be introduced for stabilization of shiting dunes.

Prosopis juliflora has not invaded the cultivated fields around Jodhpur and is, therefore, not a pest. Actually this species is a blessing as approximately two-third of the firewood requirement of the local population is met with by this species. Regarding this species becoming a menace in similar rainfall regions of Madras and Mysore state, it is quite likely that in those regions there may be better supply of firewood from other tree species as a result of which *P. juliflora* trees are not being exploited for fuel and therefore, has become a menace. However, an analysis of calorific value of different fuel wood species of the arid region of Rajasthan revealed that *P. juliflora* has the maximum calorific value which is of the order of 8000 BTU per lb of dry matter.

C. P. Bhimaya : *P. juliflora* is rather selective of soil and wants heavier saline soils. It does not grow well on consolidated sand dunes.

C. M. Mathur : Whether *E. salmonophol̲ia* and other promising species of *Eucalyptus* have been tried in the field and if so whether they were grown with or without watering ?

R. N. Kaul : These *Eucalyptus* species have been tried in arboreta located in different parts of the arid zone of Rajasthan. These tree species being exotic were given a restricted watering only in the first year of their establishment.

P. G. Adyalkar : In Pali area the ground water occurs at shallower depth in the joints and weathered mantle of the local granitic terrain. Is it due to this fact that this area is favourable for particular species due to peculiar position of ground water ?

R. N. Kaul : I am afraid I am not in a position to discuss about the success of the species in relation to occurrence of ground water in Pali region as we have not made any such study. As compared to other land types where experimental afforestation is in progress, Pali has the advantage of deep soil which provides larger volume of worked up loose soil. It is on this account that there is a larger retention of rain water in the root zone which results in better growth of tree species. Apart from this Pali as compared to other experimental sites in the arid Rajasthan receives comparatively an assured and fairly well distributed rainfall.

WILDLIFE POTENTIAL OF RAJASTHAN DESERT[1]

by

K. S. SANKHALA

INTRODUCTION

ONLY during the last decade, have modern planners recognized wildlife as one of the biological exploitable resources. The subject is attracting the interests of economists, naturalists and research workers the world over. The Rajasthan Desert is rich in its wildlife potential and if properly developed may contribute a substantial revenue to the State. It can come not only on the hunting map of the world but also for photosafari, for its fine species like the Indian black buck, Chinkara, the colourful panther and the delicious grey francolin, migrant Houbara and the common and Imperial sand grouse.

DESCRIPTION OF THE AREA

The Rajasthan desert is confined to the north-western part of the Aravalli mountain range which runs from south-west to north-east across the entire State of Rajasthan and divides it into two distinct geographical zones. The north-western part is a wide expanse of wind-blown sand, deficient in water and vegetative cover and represents the Rajasthan desert, commonly known as the *Thar* desert. It extends over 20 million hectares and covers Pali, Ajmer, Sikar, Jhunjhunu, Churu, Barmer, Jodhpur, Jalor, Nagaur, Bikaner, Jaisalmer and Ganganagar districts of the State.

Climate: The climate is characterized by extremes of temperature. The winter is quite cold and at places the temperature sometimes falls below the freezing point (minimum-4°C. at Jaisalmer). The heat during summer is intense and scorching and the temperature rises to 51°C. (50·50°C. at Pachpadra) in May-June. Owing to the dryness of the atmosphere during greater part of the year, the sandy nature of soil and lack of good vegetative cover, the diurnal variations of temperature is quite wide. Deserts are known for their clear skies and pleasant nights and the Indian desert is no exception.

Water resource: Water is scarce. Rainfall is poor and erratic. It ranges from 40 cm in Pali District to less than 10 cm in the extreme north of Jaisalmer. It is so uncertain that a whole year may pass without a shower, and again at times more than 2 year average rainfall may come in a few days, causing floods and general havoc. The Luni river and its tributaries, which flow for a few days only during the rains and remain dry during the rest of the year, drain the southern part of the area into the *Rann of Kutch*. Most of the area has closed drainage, the local *Nalas* running for a few miles to end in tanks of various sizes. A unique feature of the area is the formation of inland *Ranns*, the largest being the Sambhar Lake extending over 1000 ha. Other temporary marches are Tal Chapper in Churu, Lunkaransar Tal in Bikaner, Didwana in Nagaur and Pachpadra in Barmer districts. There are no living streams or springs. The few sweet-water wells that exist are widely scattered, sometimes 15-20 km apart. The water level in these wells goes down to 100 metres or more.

The water is generally brackish, and in some cases unsuitable even for animals. Most of the water required for human beings, livestock, and wild game is obtained from natural rainwater catchment basins in the form of small ponds or lakes. In the extreme north-west, water is a big problem. Whatever drinking water is available is from the few sweet water wells or from reservoirs in which rain water is stored under-ground. During the summer months, men, women and children are all kept busy in fetching water from long distances.

Agricultural crops: The agricultural pattern is interesting. It is confined to one crop during the rains, when handfuls of bajra (*Pennisetum typhoides*) are thrown on the sand dunes to be harvested either as a bumper crop or lost as shed grain. Bajra is the staple food of the people. The stalks serve as fodder for cattle. Jowar (*Sorghum* spp.) is grown mainly as a cattle feed. Whatever grain is obtained from Jowar is mixed with bajra and used as human food. A variety of cucumbers, pulses (*Phaseolus* spp.) *Moth* and *Moong* are also grown during the monsoon. Where the water table is high due to local factors like proximity to rainfed rivers or tanks, lift irrigation is practised in small checker-board patches, on which wheat and vegetables are grown for local consumption. The fields are protected from cattle by brushwood fencing.

Animal husbandry is the main occupation of the people of western Rajasthan. They rear large herds of sheep, goats, cows and camels. Herds move from place to place in search of new pastures but this movement is governed by the availability of watering places. The pastures where water is scarce remain ungrazed. A considerable part of each day is wasted in visits to waterholes for drinking. This results in

1. Contribution from Department of Forests, Rajasthan, Jaipur.

heavy grazing en route and around the few watering places and loss of actual grazing hours.

People: The people living in the region have a strong bearing on the wild-life. They are 99 per cent Hindus, and of these 60 per cent are vegetarians. A sect of Hindus known as Visnois, who live in the desert villages, are great protectors of wildlife, particularly the black-buck and the chinkaras. They actually worship these animals and will not allow hunting or shooting of them. They are thus an asset for the protection of wildlife in the region where they live. Fifty per cent of the other peoples living in the area, including many Rajput families, being under Jain and Vaishnava influence, are also vegetarians and would not allow any killing. Even in the non-vegetarian families, the ladies are mostly vegetarians. In many non-vegetarian families, meat is taken only on festive occasions and such meat days hardly amount to 30 or so in a year. There are, however, some nomad tribes such as Ban Bavariyas, Meenas and Sanshies, who are very destructive to wildlife and nothing escapes them. They often hunt with dogs, and are experts in setting snares and traps.

Before they were classed as criminal tribes, Ban Bavariyas were an integral part of the village community. They were village *Chowkidars* by profession and used to get a share of the village produce. Now they are employed by individuals to protect their fields, particularly from wild animals. They do not have any land of their own to cultivate and depend solely on what they get from their hunting expeditions. Bavariyas are expert Shikaries but very poor labourers. They net, trap, shoot with bows and arrows and hunt all kinds of animals and birds. They use their dogs to chase the animals, and their caged partridges attract the wild ones to be trapped. Bavariyas eat anything and everything which gives meat. Recently they have taken to killing of tigresses with cubs, for sale of the skin and live cubs at fabulous prices. They also practice large scale netting of partridges for city restaurants.

While Bavariyas are mostly confined to villages of Barmer, Pali, Jodhpur, Nagaur, Jaisalmer, Bikaner districts, Meenas, their counter-parts are found in Sikar, Jhunjhunu (Sekhawati) and Churu districts. They, too, were at one time the village *Chowkidars* and collected taxes from this *Chowkidari*. Since their classification as criminal tribes, they are leading an un-settled life and for food they hunt and kill whatever comes in their way. They even eat dead animals, sharing at times with vultures and jackals.

PAST HISTORY

During the Princely regime, wildlife enjoyed a high degree of protection. Every State had a '*Shikarkhana*' Department, which was responsible for the development of the habitat, protection, low enforecment and organized Shikar for the Ruling Prince. Nobody other than the Maharaja or his relatives and guests were allowed to shoot or hunt in the State. In the case of Jagirs, only the Jagirdar and his family enjoyed the exclusive privilege of hunting within their territorial jurisdictions. They, too, maintained a miniature *Shikar* Department. The rights of the Ruler over the subjets were absolute and nobody, even the tribes mentioned above, dared indulge in hunting. These tribes earned their living by burglary in the adjoining States or Jagirs.

With the rising consciousness of the people and the change of political structure, priorities of interest have changed, and unfortunately the preservation of wildlife fell to the last in the line. Organized eradication campaigns were launched in the name of 'Grow More Food' and in the course of 2 to 3 years, the wildlife capital built up over centuries dwindled practically to the verge of extinction. During the Second World War when Jodhpur was an important air base, black bucks and chinkaras were shot to the point of extinction by the foreign troops stationed there. Jodhpur was considered to be a vision farm and catered for Air Force parties all over the country.

In recent years, the Bavariyas, Meenas and Sanchies have become active in the process of destruction of wildlife. Their rank has been swelled by a new class of unscrupulous Government servants who have the advantage of free transport in government jeeps and high-power arms and ammunition. Through gross ignorance of the game laws and of close periods, or due to sheer cussedness because of their high official position, they do not respect any close period nor any game law. The recently dispossessed Jagirdars and Zamindars have also taken to promiscuous shooting. They, too, have the advantage of high-power arms and modern modes of transport.

WILDLIFE ECOLOGY

To evaluate the wildlife potential of the desert properly it is necessary to have some knowledge of the distribution of the fauna in relation to the flora and the agricultural pattern. As stated earlier, the rainfall varies from 40 cm to even less than 10 cm. So also does the topography vary, from flats to rolling sand dunes. Following the rainfall pattern, the vegetation too changes considerably from south to north. In Pali, Jalor and Sikar districts where the rainfall varies from 40 cm to 30 cm the offshoots of the Aravallies support scattered forests of *Anogeissus pendula*, sometimes pure, and often mixed with *Acacia senegal*, *Prosopis spicigera*, *Acacia leucophloea*, *Butea monosperma* and *Cordia mixa*. Shrubs like *Rhus mysorensis*, *Zizyphus mauritiana*, and *Grewia* occur in varying proportions. *Ficus glomerata* and *Dendrocalamus strictus* occur in moist localities. These forests contain a variety of grasses, the most common being *Apluda mutica* and *Themeda quadrivalvis*. There are barren hills without any vegetation other than a few shrubs of *Euphorbia nivulia*, *Zizyphus nummularia* and *Grewia* coming up in crevices; in the valleys where some soil has collected, occasional stunted trees of *Acacia leucophloea* and *Acacia senegal* and inferior grasses occur. Such hills are common near Siwana in Jalor, the environs of Jodhpur City and Nagaur.

These forests once supported a variety of wildlife. Sambhars (*Cervus unicolor*), neelgai (*Boselaphus tragocamelus*), chinkara (*Gazella gazella bennetti*), panthers (*Panthera pardus*), wild boars (*Susscrofa cristatus*), hyaenas (*Hyaena hyaena*), hares (*Lepus nigricollis ruficaudatus*), jackals (*Canis aureus*), were fairly common. Among game birds, grey francolin (*Francolinus pondicerianus*), painted francolin (*Francolinus pictus*), painted sand grouse (*Pterocles exusts*), Rock Quails (*Perdicula argoondah*), bush Quails (*Perdicula asiatica*), and green pigeons (*Treron phoeniceptera*) were found. During the princely regime, wild boars were maintained in large numbers near Jodhpur City by feeding them with corn and grasses for the Shikar of the ruling prince. They often strayed into the agricultural fields for crops and into the city lanes for kitchen waste. Panthers live on the young of animals, dogs, hares, monkeys, goats, sheep, etc. At one time they were very common, and for fear of them the inhabitants of some villages remained confined to their houses from dusk to sunrise.

The waste lands contain scattered trees of *Prosopis spicigera* and *Acacia leucophloea*. The common grasses are species of *Eragrostis* and *Aristida*, which are neither cut nor grazed by cattle except in the early stages. Actually nothing grows above a few inches as these lands are excessively grazed and everything is trampled in the early stages. When there was strict protection, herds of black buck and chinkaras, painted sand grouse and grey francolins were common.

As a measure against fodder famines which are not infrequent in this region, the ruling princes maintained a large number of grass preserves locally known as '*Jors*' and '*Birs*'. Since the merger of the States, most of these preserves have since disappeared, but there are still some excellent areas such as Guda Endla, Binjwa and Kalujor in Pali district. *Dichanthium annulatum*, *Cenchrus* and *Heteropogon* occur. These areas were excellent habitats for black buck and chinkara, and for a large variety of game birds. During the monsoon, floricans used to come and settle down to breed. Thousands of quails and partridges inhabited these areas. At places, the Great Indian Bustard lived and nested. Reckless killing has since reduced these species to the point of extinction.

The current position of the game in this locality is very poor. Sambhars have almost disappeared. Wild boars, chinkaras, and panthers are quite rare. The population of game birds, too, has dwindled.

In Jaisalmer, Nagaur, Bikaner, Churu and Jhunjhunu districts, where the rainfall varies from 30 cm to less than 5 cm the flats and the sand dunes contain scattered trees of Khejra (*Prosopis spicigera*), *Acacia senegal* and zerophytic shrubs of *Zizyphus* species *Acacia leucophloea*, *A. jacquemontii*, *Calotropis procera*, *Aerva tomentosa*, *Calligonum polygonoides*, *Leptadinia pyrotechnica*, *Sericostoma pauciflorum*, *Indigofera linifolia*, *I. cordifolia*, *Heliotropium strigosum* and *Tephrosia purpurea*. On hard and rocky areas, *Capparis decidua* occurs widely scattered. There are numerous varieties of grasses (some 88 species have been described from this zone). Some of the most common grasses are *Cenchrus* species, *Heteropogon contortus*, *Gracilea roylea*, *Eragrostis* spp., *Aristida* spp., *Cynodon dactylon*, *Sporobolus pallidus*, *Bothriochloa pertusa*, *Panicum turgidum*, *Panicum antidotale* and *Lasiurus hirsutus*, (common in Jaisalmer district). Most of these grasses, particularly, the perennial *Lasiurus hirsutus* (Sewan), provide excellent fodder for cattle and wildlife. Soon after the monsoon the annual grasses dry and disappear, and only the few perennial patches of *Lasiurus*, *Panicum* and *Bothriochloa* remain green and provide the grazing.

Such lands extend over thousands of hectares. The main occupation of the people is animal husbandry, large herds of cattle, sheep, goats and camels being maintained. The nomadic graziers move from place to place in search of fodder and water. A large number of goats, sheep and camels move to the eastern districts and even outside the State in autumn and return with the onset of the monsoon. Agriculture is practised on few sand dunes and depressions where some moisture collects during the rains.

Where grass and grazing are fairly plentiful there are numerous grey francolins and common sandgrouse. Common Rock Quails and other resident game birds are found in the woodlands and farms. Termites, insects, larvae, left-over grain in the fields and seeds of various weeds and grasses provide food for these birds. The brushwood fences are ideal for laying eggs and rearing of their chicks. The common sand grouse inhabits the vast desert flats. They are seen sitting in field furrows, and regularly visit waterholes at sunset and sunrise. Their food preference is seeds of wild plants and not field crops. The other species, the painted sand grouse, is found in rocky areas. It is interesting to note that some 2766 grey francolins and 2415 common sand grouse were netted and taken to Nevada in U.S.A. during 1958-62 under the U.S.A. Introduction of Exotic Game Birds' Programme from this area. An interim report on the introduction indicates that grey francolins are doing fairly well in certain localities which have a flora similar to this region of Rajasthan.

Large flocks of migratory Imperial sand grouse (*Pterocles orientalis*) and Houbara (*Chlamydotis undulata*) arrive during the winter. The former feeds on grass seeds, weeds and insects and the latter on *Zizyphus* fruits, insects and small reptiles, which are plentiful.

This region and particularly Bikaner and Jaisalmer areas, is also the last habitat of the country's rarest bird — the Great Indian Bustard (*Choriotes nigriceps*). They live in pairs or flocks of twos or fours and breed freely. A pair was netted during 1962 from Bikaner and lodged in the Bikaner Zoo. The birds are fed on garlic, onions and *bajra*. It is perhaps the only pair in captivity in the world at present. Indiscriminate shooting, mostly from running jeeps, by the class of Govt. officials mentioned earlier has made all these species of birds very shy and have driven them to the more inaccessible localities.

The extensive patches of inland *ranns* and shallow tanks support excellent duck weeds, water plants and small fish and insects. They attract millions of migratory ducks, teal, demoiselle cranes, geese, storks, flamingoes, including the lesser flamingoes during winter. These waters dry up by January and February, when all these migratory birds leave on their homeward journey. There are many species of birds that use these waters as their halting places during their southward or northward journeys.

There is no drainage from these inland depressions and the loss of water is by evaporation. The residue left is an incrustation of salts. Silting has been going on for ages, gradually reducing the depth of the water. The concentration of salt has been so excessive that some of these places are now being worked for the manufacture of common salt. The common vegetation found in these saline patches is scattered trees of *Salvadora procera*, *Tamarix dioica* and shrubs of halophytic species like *Haloxylon salicornicum*, *Suaeda fructicosa*, *Trianthema hydaspica*, *Sericostoma pauciflorum* and *Tamarix articulata*. Some grasses come up after water has receded, the common ones being *Sporobolus tremulus* and *Desmostachya bipinnata*.

Depressions of this type which have more or less completely silted up are known locally as *Chappers*. These *Chappers* are excellent habitats for black buck. They find plenty to graze and their unobstructed view saves them from natural enemies. But the modern four-wheel-drive jeeps and high-power cordite rifles with telescopic sights have taken a terrible toll of this population and only a few herds remain now. The Tal Chapper situated on National Highway No. 11 in Churu district is some 5 sq. kilometres in area. During the Maharaja's regime, the area was strictly protected, so that even now there are plentiful black bucks. It has since been declared as a Black Buck Sanctuary. The black bucks are found in groups; some are in family groups, other in pairs or in groups of discarded males, with some solitary males. Scattered groups of these antelopes also occur round the Sambhar Lake and similar areas in the desert zone.

SUGGESTIONS FOR DEVELOPMENT

The general topography of the land, the vegetation, particularly the extensive grasslands with good grasses, scattered water-holes, brushwood fencing of the agricultural lands, and the type of crops raised provide excellent feeding and breeding grounds for wildlife. What is needed for their development are their strict protection for a few years and strict adherence to the game laws and rules thereafter, and the co-operation of all classes of people.

The modern trend of thinking is that, except for the rarer species which are on the verge of extinction, it is not necessary to protect wildlife strictly for all times. Just like agricultural crops they could be harvested periodically. In agriculture, before any crop is harvested it has to be raised and tended to ripening. The same applies to wildlife also. Game birds and animals should also be given time to breed and rear their young before they may be allowed to be shot. Females and young ones must also be reasonably protected.

Modern man does not always go out to the wilds to kill game. Many derive considerable thrill in watching game in their natural habitat and taking still and moving pictures. Both these aspects should, therefore, be borne in mind for proper development of any Wildlife block.

WILDLIFE MANAGEMENT BLOCKS

For correct management, it is necessary to divide the locality into convenient and more or less independent blocks. It is suggested that the areas far from habitation and agricultural lands should be divided into blocks of 10 to 20 sq km, and those near villages and cultivation, into small units of 5 sq km. The former would be for development for big game and the latter for feathered game. It would take at least 5 years of strict protection to build up a stock in such a block before any harvesting could be allowed. Since there are vast areas fit for development, a phased programme is necessary. To start with, areas with comparatively easier and greater potentialities should be taken up. There should, however, be one authority for management affairs and there should not be any diarchy or triarchy. These blocks should be placed under the State Forest Department for management. Sizable blocks could also be leased out to private parties for development and subsequent exploitation for profit, under the over-all supervision of the State Government.

Development of big game: For development and management of any wildlife block, the possible future consequences of the development should be borne in mind. For instance, if the populations of predators like tigers and panthers, and browsers like sambhar and black buck are allowed to increase uncontrolled in any area where agriculture or livestock, crop or animal husbandry is being practised, this would lead to endless trouble with the people directly affected. A careful planning is, therefore, needed to strike a balance between the two opposing interests. At the start areas far from habitations or much sparsely cultivated or sparsely grazed should be selected. For instance, for increasing the population of panthers, the rugged hills of Jalor, Jodhpur, Nagaur, Sikar and Barmer districts provide excellent opportunity. These hills and their environs are quite sparsely populated, and there are numerous caves and crevices which would provide hide-outs. There are sufficient chinkaras to provide them with occasional food, which could be supplemented by stray goats or sheep and bovine calves.

Sambhars could be developed in the outer Aravalli hills where *Zizyphus* spp., *Bauhinias, Cordia mixa, Grewia* spp. and grasses occur in sufficient quantities to provide them with food. Sambhars and panthers could be developed in the same area where sambhars thrive. Wild boars could also thrive, as fruits of *Zizyphus, Cordia* spp. and a variety of shrubs would provide them with sufficient food. Due to the low rainfall, water is generally scarce and special arrangements will, therefore, have to be made. Small pools, dug-outs and anicuts will have to be constructed at suitable place.

The vast expanse of open arid waste with plenty of grazing of fine grasses and browsing of *Zizyphus* shrubs are ideal for the development of Indian black buck and chinkara. These animals can withstand considerable dehydration. Their water requirement is not a serious problem. The remote areas of Barmer, Jaisalmer and Jodhpur districts which are at present undergrazed are ideal places for their development. Construction of quail or antelope gazellers, which are more like 'Tankas' of the desert, would go a long way to solve the problem of scarcity of water. Recent research has evolved a cheap chemical which when mixed with sand acts as a cement impervious to water. The watersheds of small depressions could be treated with this chemical and the run-off collected in a covered underground tank, with an opening suitable for drinking animals. Such waterholes should be guarded wherever possible against cattle grazing in the range. Complete exclusion could be obtained by fencing, if this is also necessary. As the water requirements of wild animals are small, there should be no problem in providing sufficient watering places to the grazing livestock. For herbivors, salt is a very important item for their development, but as the arid zone has plenty of salt licks, this should not be a problem.

Black buck and chinkara could also be developed as a programme supplementary to the animal husbandry schemes of the State. Since they always graze in remote areas and their watering needs are very much limited, the increase in their population within reasonable limits would not interfere much with the grazing of cattle.

Feathered game: Game birds particularly the grey francolin and quails, could be developed easily near human habitations and agricultural fields. Since these birds are predators on insect pests of agriculture, they help farmers. They do not damage standing crops but pick only the left-over grain after the crops are harvested. The brushwood fences of fields provide them not only with ideal shelter and protection from their predators but also a place for nesting. Sand grouse do not require brushwood fences, but prefer to graze in crop fields where the furrows provide excellent comouflage for their protection. This can, therefore, be conveniently developed along with the partridges and quails. They require only sufficiently extensive watering places. The construction of small tanks and shallows is, therefore, necessary if natural ones are insufficient.

The migratory game birds, Imperial sand grouse and Houbara, come and settle in winter throughout the vast areas of the desert. They do not require any crops to feed on, no brushwood fencing for hideouts and nesting. Ducks, teal, geese, demoiselle crane, etc. also arrive during the winters and settle in shallow marshes. They require only protection.

Predator control: The predators like wild cats, civet cats, mongoose, foxes, jackals and snakes are the natural enemies of game birds and take a considerable toll of the birds and their eggs. The best way to eliminate these predators is by organized hunting during their breeding season. The Shikari tribes who are excellent hunters could be usefully employed for controlling the population of these predators within reasonable limits, their complete elimination being neither desirable nor necessary.

Bag limits: Before any block is opened for shooting, it is necessary to have a census of the stock. A census of the bigger animals could be taken by regular or periodic counting of their footmarks to and from every waterhole over certain fixed periods, tabulating the counts and obtaining a mean. A census of birds is generally taken by frequent personal observations. When the census has been taken, it should be possible to obtain a maximum limit of the bag which would be permissible for a whole season. The limit of the bag should also be prescribed for each permit during the season.

Close periods: Regulation of shooting is the key to proper wildlife management. The breeding periods or the seasons during which animals are easily shot on waterholes or on salt licks should be prescribed as close periods, and strictly adhered to. In the case of all animals (except hare) no shooting should be allowed from March to November. In case of birds, hunting should be limited to any one month between October and February when organized shooting is permissible. Young ones and females of all game species should be protected except where the female population is excessive. There need not be any bag limit in case of birds, because the short period of shooting would provide them with enough protection. In the case of animals, a bag limit is essential. The hunt should, of course, depend upon the population of the species but the number should be fixed on the basis of sustained annual yield.

Wildlife — a National property: As all natural resources like waters, minerals etc. are national property, they should be managed for the greatest good of the greatest number for perpetuity. Wildlife should be treated in the same way. No individual should have any rights except where prescriptive rights have been acquired. Free and unrestricted shooting by a few individuals should be discouraged.

The Rajasthan Wild Animal and Birds Protection Act, 1951, controls the shooting and hunting, netting and trapping of certain game birds and animals during the close seasons. In the non-close periods, there is no protection. If the decimation of the wild game birds and animals is to be prevented it is absolutely necessary to provide for the regulation of their shooting and hunting throughout the year.

Difficulties might arise in the shooting of partridges and quails on private land. The owner might refuge to allow any shooting or may demand some fees. In such cases it would be obligatory for the sportsman to take permission of the owner to enter his land and pay the fee. This difficulty may not arise in the case of migratory birds and big game as they seldom occur on private lands.

Any landlord or group of landlords may combine to develop an area for shooting and hunting. They should be entitled to demand a reasonable fee from sportsmen for the privilege of shooting on this land. But this shooting and hunting must be subject to the shooting rules, and close periods must be observed as prescribed by the law and rules made thereunder.

SANCTUARIES

If suitable areas are selected for sanctuaries and properly developed, they would attract large number of visitors who are interested in observing wildlife in their natural habitats, or are interested in wildlife photography. Well developed areas would also attract foreign visitors. Sanctuaries could be easily developed near Visnoi villages, as normally Visnois will not tolerate any shooting and hunting, particularly of black buck and other deer.

A sanctuary has been developed by the rulers of Bikaner at Tal Chapper in Churu district. Gajner with an area of 10 sq kilometres a personal property of H. H. Bikaner, is a wildlife sanctuary maintained by His Highness. Adequate arrangements for water, feed and protection have been made. There are herds of black bucks, chinkaras, wild boar, blue bull and flocks of common sand grouse and grey partridge. Hundreds of Imperial sand grouse come to this area every winter. At one time this area used to provide excellent shooting of Imperial sand grouse for V.I.Ps. In one of the princely shoots, a bag of nearly 4,000 birds was recorded in one day at Gajner, perhaps a world record.

Some areas in Bikaner and Jaisalmer districts where the Great Indian Bustard breeds could and should be declared as reserved areas and developed as sanctuaries for this beautiful, rapidly disappearing bird. Each desert district should have five to ten reserved areas where shooting, netting and trapping would be prohibited. These areas would provide breeding grounds for wildlife and would replenish the stock in adjoining areas open to shooting.

The whole programme of wildlife conservation depends upon public co-operation. To obtain this it is necessary to educate the public by constant propaganda. It is more from an ignorance of the game rules than for any other reason that most of the poaching is done. By constant publicity, frequent radio talks, lectures in public institutions and other modern means of publicity, this ignorance of the game rules should be removed and a proper climate of wildlife conservation developed. Only then can success be achieved.

CONCLUSION

Economic returns in the form of licence fees, tag fees and taxes on various items of use for hunting and shooting, watching and photography would in due course, be substantial. It would not be out of place to mention that areas of similar geography with less wildlife potentialities e.g. Arizona, Nevada and New Maxico in U.S.A. are earning millions of dollars every year directly from the sale of licences alone. Arizona State harvested 23,410 deer during 1956 which when converted into meat comes to $34 \times 23410 = 795940$ kg. The State of California harvested 70,871 deer in in the same year. There is no reason why we cannot have a similar crop from our game animals and birds and help in extra food production. East Africa is earning a substantial amount of foreign exchange from their game sanctuaries every year. We have a more varied and colourful fauna which can certainly cater for foreign tourists and earn much needed foreign exchange.

ACKNOWLEDGEMENTS

I am extremely grateful to Shri N. N. Sen, I.F.S. (retired) for his constant guidance in preparing this paper and for going through the manuscript. I am equally grateful to Shri T. N. Srivastava, Chief Conservator of Forests, Rajasthan, for giving me all opportunities to study the problem.

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DISCUSSION

A. D. Pandit: Has any work been done to develop game farms ? What specific investments and provisions are required in this direction ?

K. S. Sankhala: No steps have so far been taken for developing game farms. Protection particularly during the breeding season is the cardinal principle for development of such game farms.

G. B. Maxey: House farm concept is very successful in the U.S.A. for competitive wild animals. Non-competitive animals may be preserved and managed by even stringent laws. Sand grouse imported from India is now a great game bird in the U.S.A. and also "Chakor", a non-competitive species, is a leading arid zone game bird in the U.S.A.

I. Prakash: The Great Indian Bustard is found in very large number in the Indian desert and it is high time that sanctuary for this form of wild life be formed.

L. S. Ramaswami: The author referred to the extermination of species of wild life. Is it not possible to enact a legislation so that the vanishing wild life can be preserved ?

K. S. Sankhala: For preservation and conservation of wild life legistlation has already been enacted. The chief bottleneck lies in its enforcement.

M. L. Roonwal: Wild life in India, particularly in Rajasthan, is, almost doomed and we are fast approaching a point when wild life will be seen in our Zoos.

L. D. Ahuja: Will protection of wild life specially Chinkaras and Black buck not increase the grazing stress on the rangelands in view of the existing heavy stress of cattle, sheep and other livestock on grazing resources ? Has any work been done on the feeding habits of these forms of wild life ?

K. S. Sankhala: No systematic studies have been carried out regarding the preservation of Chinkaras and Black buck and their effect on the rangelands. But these can always be preserved in specified localities which could be declared as sancturies, which will not come into conflict with other grazing lands.

FOLIAR CONSTITUENTS OF SOME IMPORTANT TREE SPECIES OF THE ARID ZONE OF INDIA[1]

by

I. M. QURESHI[2] & O. N. KAUL[3]

INTRODUCTION

THE success of afforestation programmes of the dry zone depends to a great extent on the scientific appraisal of the complex ecologico-physiological requirements of the different species selected for the purpose. Undoubtedly many of the sites taken up for afforestation in the dry zone are of marginal fertility, and only such species need be selected initially which are capable of establishment under characteristic conditions of the locality.

In order, therefore, to get an indication of the mineral requirements and nutrient uptake, foliage of some important dry zone species were analysed to find out the concentration of essential nutrient elements. Of late much attention has been paid to foliar analysis for the study of tree nutrition on the assumption that the adequacy or otherwise of a particular nutrient is reflected in the concentration of that nutrient in the foliage (Mitchell 1936; Mitchell & Chandler 1939; Thomas 1945; Lundegardh 1951; Leyton 1954, 1958; Leyton & Armson 1955; Ovington 1959; Qureshi & Srivastava 1966).

MATERIALS AND METHODS

Leaf samples were collected from representative dry zone localities in the States of Rajasthan, Maharashtra, Mysore, Madras, Madhya Pradesh and Uttar Pradesh during the Dry Zone Afforestation Study Tour and Symposium held in January 1959. The species selected were *Acacia arabica*, *Azadirachta indica*, *Cassia siamea*, *Dalbergia sissoo*, *Eucalyptus tereticornis* (Syn. *Eucalyptus* hybrid or Mysore Gum of Chickbalapur origin), *Prosopis juliflora* and *P. spicigera*.

The samples after air- and oven-drying were analysed for their mineral content, viz., ash, Ca, Mg, K and P using standard methods (Loomis & Shull 1937; Wright 1934). *Total nitrogen was estimated separately* using the standard Kjeldahl's method.

1. Contribution from the Forest Research Institute & Colleges, Dehra Dun.
2. Director of Forestry Research.
3. Forest Eclogist.

RESULTS AND DISCUSSIONS

The results on percentage composition of ash and macronutrients (Table 1) show that the concentration of nutrients in all the species is generally in the order of Ca, N, K, Mg, and P except in *Eucalyptus* and *Prosopis juliflora* in which it follows N, Ca, K, Mg and P.

TABLE 1: Mineral constituents of leaves
(Percentage of oven-dry material)

Species	*Ash*	*Ca*	*N*	*K*	*Mg*	*P*
Acacia arabica	9·95	3·39	3·35	1·13	0·23	0·20
Azadirachta indica	10·45	3·12	2·73	1·54	0·46	0·18
Cassia siamea	8·48	3·87	2·32	0·83	0·19	0·20
Dalbergia sissoo	11·51	3·65	2·72	0·82	0·50	0·17
Eucalyptus	5·49	1·12	2·47	0·86	0·17	0·15
Prosopis juliflora	8·31	2·99	3·67	1·12	0·36	0·22
P. spicigera	12·45	3·97	3·14	1·10	0·43	0·17

The amount of ash is highest in *Prosopis spicigera* and *Dalbergia sissoo* and lowest in *Eucalyptus*. *Azadirachta indica* and *Acacia arabica* also have high amount of ash while there is not much difference in ash percentage of *Cassia siamea* and *Prosopis juliflora* though the contents are lower than the other species.

As is the case with ash content, the concentration of Ca is highest in *Prosopis spicigera* and the lowest in *Eucalyptus* leaves. Further the amount of Ca corresponds to ash content in the remaining species also except in *Cassia siamea* where low ash content is associated with high Ca content.

Variation in Mg does not correspond either with ash or Ca content, though lowest amount is again observed in *Eucalyptus*. Mg is accumulated in highest quantity in *Dalbergia sissoo* while *Azadirachta indica* and *Prosopis* spp. accumulate slightly lower amounts of this element. On the other hand *Cassia siamea* and *Acacia arabica* have little higher concentration of Mg than *Eucalyptus*.

Surprisingly, P concentration does not vary much in these species though the lowest amount is again seen in *Eucalyptus*.

The trend of K accumulation is also different from Ca and Mg. *Azadirachta indica* accumulated highest amount of K while almost the same amount is found in *Acacia arabica* and *Prosopis* spp. There is not much difference in K concentration in the remaining three species.

Nitrogen is accumulated more in leaves of *Prosopis* spp. and *Acacia arabica*. *Azadirachta indica* and *Dalbergia sissoo* have the same amount of N while the lowest concentration is found in *Cassia siamea* and *Eucalyptus*.

The study indicates that though, the species are growing in a dry climate, they accumulate large amounts of nutrients in their foliage. Different species even when growing under uniform conditions of soil and climate show wide variation in their nutrient content; even the two species of *Prosopis* differ widely in the uptake of Ca and N. *Prosopis spicigera* requires more Ca while reverse is the case with *P. juliflora* for N. Only in case of P, there does not appear to be much difference in their requirements. *P. spicigera*, *C. siamea*, *D. sissoo* and *A. arabica* require more Ca as compared to other species while N is accumulated more in the foliage of *Prosopis* spp. and *A. arabica*. Potassium requirement is higher in *A. indica*, *Prosopis* spp. and *Acacia arabica*, while there is not much variation in the amount of Mg in different species.

It thus appears that most of the macro-nutrients are required in relatively lesser quantities by *Eucalyptus* among the present list of species. This species, therefore, may succeed even on marginal soils. Other cultural experiments, conducted after this study was undertaken have indicated that though the requirements of this species are comparatively lower, N and P nutrients are of prime importance for the growth of this species, but for better growth a balanced dose of N,P,K, fertilizers will have to be determined. It has further been indicated that soils having low P and N may not be very suitable for the growth of this species (Kaul, Srivastava & Bora 1966; Kaul, Srivastava & Mathur 1966).

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DISCUSSION

S. P. Raychaudhuri : Whether attempts have been made to utilize the results of foliar analysis to find out the nutrient deficiencies and to correct the deficiencies either through fertilizer application in the soil or by foliar spray ?

I. M. Qureshi : The deficiencies are being corrected by fertilizer application in the soil.

N. D. Rege : Why *Eucalyptus* leaves do not decompose readily to give good humus and what is the percentage of oil in hybrid *Eucalyptus* ?

I. M. Qureshi : This may be due to the occurrence of essential oils in the leaves and its highly fibrous texture. So far quantitatively oil in the leaves of hybrid *Eucalyptus* has not been estimated.

SAND-DUNE FIXATION AT HASTERA[1]

by

K. S. SANKHALA

INTRODUCTION

SHIFTING sand dunes are a big problem in north-western Rajasthan. The arid climate, over-population of cattle, uncontrolled grazing and reckless felling of trees have disturbed the vegetative cover throughout the desert zone. Throughout the year, the increased wind velocity lifts the sand particles from bare soil for formation of sand dunes. These mobile sand dunes create problems for the road traffic, increase the risk of rail derailment, cover compound walls, march into villages and make agricultural fields sterile. These mobile dunes have reached gigantic proportions near many prosperous villages in the desert zone. The productivity of land has been reduced, soil erosion has been magnified and the general economic life of the people has been seriously affected. This paper describes in detail one aspect of the problem of shifting sand dunes in a village in Western Rajasthan.

HASTERA VILLAGE

Hastera is a village in Chomu Tahsil of Jaipur District, situated some 45 km from Jaipur City on the left bank of Menda river, towards the north-west. The average annual rainfall is 60 cm. It is hot during Summer (average maximum temperature 44°C) and cold during January (average minimum temperature 2°C). Frost is quite common from mid-December to mid-January. Average humidity is 54.8 per cent.

The village is said to be 1,200 years old and some 300 years ago it was a centre of business activities. There were nearly 7,000 families in the village. Most of them were agriculturists. People of other trades like potters, tailors, carpenters, *Banias*, etc. also lived in the village. Some 300 families of *Cheempas* (local calico printers) were living there. It is in the living memories of the people that these *Cheempas* were washing their cloths in the river all the year round. The river bed was 2 to 3 metres lower than the village level and there was a definite bank of the village side. A few older people still live to narrate the grim stories of their village disaster, which they attribute to their sins or to the narrow vision of the erstwhile *Jagirdars*.

1. Contribution from the Department of Forests, Rajasthan.

A DESERTED VILLAGE

Hastera is now a deserted village. The fallen walls of the Jagir fort, the double storey pucka houses buried under sand, the well-planned village *Bazar* all narrate the story of a once busy and prosperous village. A village mosque on the bank of the river indicates the size of the Mohammedan population once living there. But all are now in ruins and are being covered by the marching sand dunes. Most of the people have migrated to other villages and now there are only 1800 people living at Hastera. There is hardly any river bank on the village side and water gushes through in a few hours during floods. The river bed remains dry almost throughout the year. Even during October, the bed is dry and sand particles are picked up by the gentle wind to form sand dunes. This process is at its climax during the hot season (April, May and June) when one can see the formation of new dunes and the marching of the old ones.

PROBLEM OF SAND DUNES

The main cause of the disaster is the bad land management in the watershed of the Menda river. In the last few decades, the forests on the hills situated in the drainage basin of the river and its tributaries have been ruthlessly felled. The fixed sand dunes which developed a good cover of trees and shrubs by protection have been disturbed. The large unproductive cattle herds and above all the large number of sheep and goats have overgrazed the watershed. The unplanned animal husbandry and uncontrolled grazing have been the dominent factors in the mismanagement of the watershed. The hills and bare sand dunes hold hardly any rain water, which rushes through the *nallas* carrying sand from the dunes. This water heavily loaded with sand particles loses velocity when enters the plain area and the sand particles are deposited in the river bed, This process has been going on for the past few decades and has resulted in the raising of the river bed to the level of the village. The sand brought with the floods acts as readily available material for the summer winds to form new sand dunes towards the village. The problem becomes acute because of the overgrazing of the river bed and the banks. Whatever grass comes up is scrapped and the soil is kept constantly disturbed.

YOUNG MEN'S LEAGUE

The problems of the disastrous marching dunes and the disturbed village economy have attracted the attention of the younger generation in the village. The new concept of a balanced economy for a village took root in their minds; they formed a young men's league and started hunting for all help that could be obtained to restore the prosperity of their village. During the course of their campaign, they met the Forest Officers of the State, who studied their problem. A planned programme was launched. The task of rescuing the village by stabilizing the marching sand dunes was considered the first priority. The village youngmen's league was organized and work started in July, 1958.

TECHNIQUE

The first operation was to cover the dunes with some vegetation which could grow easily on unstable sand dunes. *Saccharum munja*, which was available locally, was selected as the first species to colonize them. Rhizomes with one or two leaves were taken from old clumps and planted on the dunes in contour lines on both windward and leeward sides. The lines were kept 1 to 3 metres apart (depending on the size of the dune); planting was done 2 feet in lines, and 40 to 50 cm. deep to cover the rhizomes. The earth was rammed properly. Care was taken to ensure that rhizomes were planted on the day they were removed from the parent stock. The area was closed to grazing. No fencing of any kind was raised, but the restriction was imposed by an executive order of the village Panchayat. The executive order of the Panchayat was observed very well, particularly because all the people were interested.

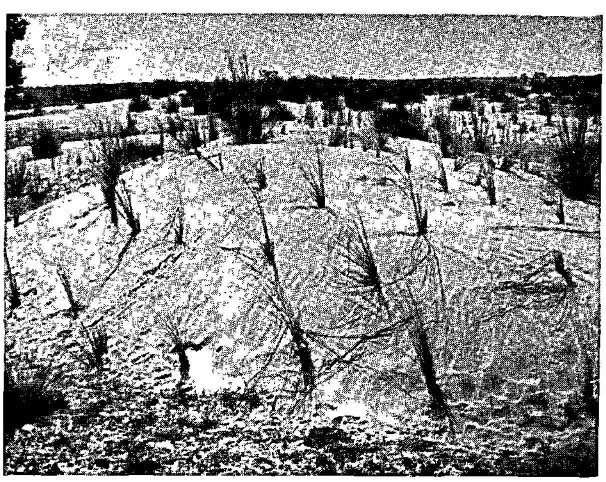

Fig. 1

Fig. 2

The old leaves of the rhizomes died in a few days, and new leaves appeared within 10 to 15 days. The rhizomes which failed to produce any green leaf were replaced. This replacement continued up to the end of September, 1958. Most of the rhizomes plant in July were successful, only 20 per cent replacement being considered necessary.

Next year (1959) another 100 acres were taken and planted with rhizomes *Saccharum munja* in the same manner. On this occasion, some seeds of *Acacia senegal* and *Butea monosperma* were sown with the rhizomes. Germination was quite good and the plants were promising. Nursery-raised seedlings of *Dalbergia sissoo* and *Holoptelea integrifolia* were planted on the leeward side of the *Munj* clumps of the previous year on the dunes. The spaces between the dunes were also planted with seedling of *Dalbergia sissoo, Parkinsonia aculeata, Casuarina equisetifolia* seedlings; line sowing of *Acacia senegal* and Castor were also done. The whole area was fenced partly by mud wall and partly by barbed wire.

The area responded very well to the treatment. The rhizomes sprouted, seeds germinated and plants showed indications of their establishment on the dunes. All the sowing in the flat ground failed, however, mainly due to high *p*H in these saline patches. *Cynodon dactylon* was already present, and soon covered the whole area.

Cuttings of *Ipomoea biloba* were placed all over the area; the creeper spreads well and covered the dunes. Cuttings of *Tamarix dioica* placed in the saline depressions have sprouted, and the trees are coming up. *Dalbergia sissoo* planted on the dunes have shown good growth and are shaping as trees.

The area was extended further in a horse-shoe shape to cover all the dunes which are on the western side of the village during 1960 and 1961. Thus total area tackled is nearly 300 acres. The growth of

Munj is quite satisfactory, and all the sand dunes have been fixed.

PARTICIPATION OF THE PEOPLE

An interesting aspect of the work is the enthusiasm of the people, who are proud of the afforestation work and consider it as their achievement. They rightly share the credit, for they were the planters of all the *Munj* rhizomes and most of the seedlings. It is they who have been able to close the area effectively against all opposition of individuals. Today they harvest the fruits of their labour. The village Panchayat auctions the contract of *Munj* cutting every year, to bring a return of nearly Rs. 2,000/- per year. The revenue covers the cost of maintenance of the plantation and also helps in running the services of the Panchayat. The yield of *Munj* helps nearly 20 women of the village to earn their livelihood throughout the year, by manufacturing *Munj sirkhies* as a cottage industry. The total amount invested for the farm on raising and maintenance of the work is Rs. 15,000/-. This was mostly on fencing, transportation of rhizomes and raising of seedlings in nurseries. This comes to Rs. 50/- per acre. The cost is low because of the people's participation or co-operation. The investment is earning Rs. 2,000/- per year from the sale of *Munj* alone.

CONCLUSION

The programme has not only solved the problem of the mobile sand dunes, but has also started yielding substantial returns. Similar techniques may be adopted with advantage in other villages in western Rajasthan which are faced with similar problems. It is proposed to take up nearly one hundred such villages for similar rescue operation during the Fourth Five Year Plan.

ACKNOWLEDGEMENTS

I am grateful to Shri T. N. Srivastava, Chief Conservator of Forests, Rajasthan, for guidance and facilities provided to me in preparing this paper. My thanks are also due to Shri Pancham Lal Hasteria for supplying the details of revenue and employment potential.

IRRIGATION

EFFECT OF SEA WATER DILUTIONS AND ITS AMENDMENTS ON TOBACCO[1]

by

T. KURIAN, E. R. R. IYENGAR, M. R. NARAYANA & D. S. DATAR

AN EFFECTIVE approach in growing plants under saline conditions warrants the further understanding of the physiological basis of salt tolerance of plants (Bernstein & Hayward, 1958). The plant growth, sometimes, linearly decreases to the concentration of salts present in irrigation water (Lunin *et al.* 1961). Considerable research has been conducted on application of saline water irrigation in arid and semi-arid regions and for crop production and its effects on soil characteristics (U.S.D.A., 1954; UNESCO, 1961).

Recently, investigations on the utilization of sea water for plant growth has emanated from the findings of Boyko and Boyko (1959), who have stated that the salt accumulation in the root zone does not occur, if the soils are sandy and extend deeper depth than the root zone. Irrigation with sea water in the humid regions on the sandy soils to supplement the rainfall has been discussed by Batchelder *et al.* (1963) in relation to the salinity effect on growth stages of plant and the cation composition of the plants and soils.

Heimann (1958) explaining the concept of 'Balanced ionic environment' under saline conditions stressed the need for evaluating the sodium-potassium relationship of irrigation waters. The antagonistic effect of ions on the uptake of the solutes by barley roots, indicates that potassium and phosphate impede the accumulation of sodium and chloride, but the intake of nitrate is not influenced by the presence of chlorides and sulphates (Reifenberg & Rosovsky, 1947).

The optimum dose of potassium salts in overcoming the effect of salinity under irrigation with highly saline waters on tobacco has not yet been determined. In the present study an attempt has been made to determine the effect of sea water dilutions and its amendments with potassium salts on the growth and chemical composition of tobacco variety Keliu-20.

EXPERIMENTAL

Tobacco variety K-20 was raised in nursery in 1963. Sixty days old seedlings were transplanted in earthen pots, 15″ × 25″ containing sandy soil (coarse sand 68 per cent, fine sand 26 per cent, silt and clay 3 per cent, carbonates 3 per cent). The plants were irrigated with tap water for complete establishment. One month after transplantation the seedlings received the treatments as shown in Table 1.

TABLE 1: Treatment media applied to the Soil for Tobbaco Crop

Sea water dilutions	*Total K m. eq./l*	*Total H_2PO_4 m. eq./l*
10,000 ppm	2·1	—
10,000 ppm amended	88·8	77·3
15,000 ppm	3·1	—
15,000 ppm amended	133·2	115·9
20,000 ppm	4·2	—
20,000 ppm amended	177·7	154·6
Control		
Tap water	—	—
Tap water amended	108·4	96·6

Sea water: 34·10 g/l (TSC) (Na-10·6, Cl-19·0, K-0·30 g/l).

Six replications were maintained for each of the treatments. The media were amended by applying KNO_3 and KH_2PO_4 of C.P. quality. Depending on the need for irrigation the above solutions were given at an interval of 7-11 days. The crops received 8 irrigations and per plant 8 liters of the media was supplied in each of the above irrigations.

Observations on growth in height, number of leaves, area of leaves and length of root of the plant, were recorded. The results were statistically analysed. Chlorophyll and nicotine of the matured leaves were estimated by the methods of Comar (1942) and Avens and Pearce (1939), respectively. The chlorophyll content was determined by using Hilger and Watts spectrophotometer H 700.

The soil salinization at different depth was worked out by sampling the soils at 10, 30 and 60 cm depths and determining the electrical conductivity of the 1: 1 soil-water extract by using Serfass conductivity bridge RCM 15B1. Sodium chloride in the extract was calculated by estimating sodium with Flame-photometer. The *p*H of these soil samples was determined in soil water suspension of 1: 2·5 by the Beckman electronic *p*H meter with glass electrodes.

RESULTS AND INTERPRETATION

Irrigation with sea water dilutions depresses the growth of tobacco plants but their amendments re-

1. Contribution from the Central Salt & Marine Chemicals Research Institute, Bhavnagar, Gujarat.

markably improves the growth. There was a heavy mortality in plants treated with 20,000 ppm and its amendment; therefore, the study was confined to other treatments.

Growth: The control amended series show significant increase in all the characters recorded and hence, the growth has been compared between sea water treated sets and tap water control.

The growth of the plants exhibits no significant effect of the treatments. But the root length is affected by the sea water dilutions except in 10,000 ppm amended series. The number and area of the leaves indicate a similar tendency, but with the exception of a greater leaf area in plants receiving 10,000 ppm amended medium. Sea water dilutions do not show pronounced depressing effect on the fresh weight of shoot. The dry weight of the shoot, on the other hand is practically affected with less significant values in plants treated with 10,000 ppm amended solution. The fresh weight and dry weight of the roots show significant differences amongst the treatments (Table 2).

In tobacco the antagonistic effect of potassium on the uptake of sodium is observed when the potassium concentration increases in the external media (Parikh *et al.*, 1957). Similarly the vegetative growth of tobacco plants decreased with the increase in the salinity and on amendments with potassium salts improved considerably, by a marked increase in the leaf area.

Soil study: The soil samples collected at 10, 30 and 60 cm depths do not tend to have any accumulation of salts within the root zone (Table 3). The salt accumulation at 60 cm depth is always higher in all

TABLE 2: Growth behaviour of tobacco Variety K-20 Irrigated with sea water dilutions
(Mean of six replications)

Treatments	*Growth in height of plant cm*	*Root length cm*	*No. of leaves*	*Area of leaf sq. cm*	*Fresh wt. of shoot g*	*Dry wt. of shoot g*	*Fresh wt. of root g*	*Dry wt. of root g*
Control								
Tap water	14·62	34·74	9·40	38·21	14·9270	4·2994	1·6613	0·6653
Tap water amended	34·10	44·04	14·60	125·26	63·6475	13·4408	5·8611	3·5744
Sea water dilutions								
10,000 ppm	10·90	20·14	6·60	28·78	10·6578	1·4222	0·6224	0·2726
10,000 ppm amended	16·88	24·78	9·60	54·08	24·0340	3·9118	1·3522	0·3398
15,000 ppm	11·10	14·52	5·40	24·66	8·0565	1·0305	0·1849	0·1132
15,000 ppm amended	12·10	22·80	6·60	29·14	8·2904	1·2512	0·3204	0·1703
LSD 5%	6·13	11·50	1·85	19·82	12·6828	2·7743	1·7689	1·5861
LSD 1%	8·36	15·73	2·53	27·03	17·2976	3·7833	2·4136	2·1622

Table 3: Degree of soil salinization and *p*H
(Average of duplicates)

Treatment	*Soil water extract of 1:1*						*Soil-water suspension of 1:2·5 pH values*		
	Ece mmhos/cm. Soil depth in cm			*Calculated NaCl per cent Soil depth in cm*			*Soil depth in cm*		
	10	30	60	10	30	60	10	30	60
Control									
Tap water	0·3728	0·1242	0·1177	0·0075	0·0031	0·0029	8·5	8·1	8·5
Tap water amended	1·1775	0·8831	1·1120	0·0058	0·0028	0·0033	7·9	8·3	7·5
Sea water dilutions									
10,000 ppm	1·1447	1·7681	3·1418	0·0305	0·0485	0·0740	8·8	8·8	8·6
10,000 ppm amended	1·4391	1·9625	3·7941	0·0365	0·0312	0·0637	8·2	8·2	7·8
15,000 ppm	1·5045	1·7008	3·7941	0·0725	0·0775	0·1250	8·2	8·4	8·4
15,000 ppm amended	2·1587	4·2520	5·2333	0·0630	0·1400	0·2300	8·8	7·8	8·0

TABLE 4: Chlorophyll and nicotine contents of tobacco variety K-20 irrigated with sea water dilutions

Treatments	Chlorophyll mg/100 gm of the fresh wt. of leave				Nicotine percentage of leaves on oven dry basis
	Total chlorophyll	α Chlorophyll	β Chlorophyll	Ratio α/β	
Control					
Tap water	16·82	7·51	9·31	0·81	0·268
Tap water amended	36·04	15·77	20·30	0·78	0·548
Sea water dilutions					
10,000 ppm	20·24	9·06	11·19	0·81	0·748
10,000 ppm amended	33·31	14·48	18·85	0·77	1·048
15,000 ppm	15·68	7·14	8·53	0·84	0·458
15,000 ppm amended	25·66	11·38	14·30	0·79	0·609

the cases. Boyko and Boyko (1959) stated that accumulation of salts at the root zone need not be feared even under oceanic water irrigation, if the soils are highly permeable and sufficiently deeper. The soil salinity in this experiment shows an increase in the salt concentration at 60 cm depth which can be attributed to the prevention of further leaching of salts in the pots.

The *p*H of the soil solutions do not have marked differences either in different depths or at the different salinity levels, while the *p*H of the sea water amended media was on the acidic side. The *p*H of the soil is not markedly influenced at different depths of the various treatments despite the low *p*H values of the amended media; probably due to attaining equilibrium with the calcium carbonate of the soil.

Chemical composition: Salinity affects the chemical composition of the plants grown on salt affected soils or irrigated with saline solutions. It is noteworthy that with increase in salinity of sea water dilutions the chlorophyll content decreases, but on the contrary the ratio of α/β chlorophyll tends to increase with increase in salinity. The amendments overcome such effects.

It is observed that higher nicotine percentage is obtained in all the series and particularly in the 10,000 ppm amended group when compared with the control (Table 4). Application of sodium chloride in higher doses impairs the quality of tobacco by reducing nicotine (Peele *et al.* 1960; Gopalachari, 1961, Paul *et al.* 1963). However, Hutchenson *et al.* (1959) noted an increase in nicotine content of the leaves on supply of potassium in high concentration of sodium chloride solution. But in the present investigation the sea water dilutions and their amendments exhibit an increase in nicotine percentage of the leaves.

SUMMARY

The use of sea water dilutions on tobacco variety K-20 is described. The higher concentrations of sea water (10,000; 15,000 and 20,000 ppm) show depressing effect on the plant growth. Addition of potassium salts, to counteract the effects of Na and Cl ions, improves the growth of crop.

Chlorophyll analysis exhibit a similar trend in the total chlorophyll content, but the ratio of α/β chlorophyll increases as the sea water concentration increases. The nicotine content of the leaves showed increase with increasing concentration of salts in sea water, particularly in the 10,000 p.p.m. amended series. The degree of soil salinization at different depths recorded at the end of the experiments indicates the non accumulation of salts at the root zone.

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DISCUSSION

S. P. Raychaudhuri: Why was tobacco chosen as chloride has adverse effect on the quality of leaf ?

M. R. Narayana: The tobacco was chosen because it is a good indicator crop although chloride has an adverse effect on the crop.

S. Pels: Why do you use sea water in irrigation trials and not brackish ground water ? Is the need for irrigation not much greater inland from the coastal belt of relatively high rainfall ?

M. R. Narayana: There is need for supplementary irrigation in some coastal areas. Although the rainfall along the coast may be as high as 50 inches, the normal distribution is very erratic. Brackish water irrigation trials are also being carried out in inland areas.

EFFECT OF SEA WATER AND ITS DILUTIONS ON SOME SOIL CHARACTERISTICS[1]

by

M. R. Narayana, V. C. Mehta & D. S. Datar

Several countries have taken recourse to investigate the possibilities of bringing into cultivation the vast stretches of dune sands of coastal regions, under sea water irrigation. The results obtained in Israel, Spain and Sweden have been reviewed by Iyengar and Narayana (1964). Recently, similar experiments were conducted on some crops in India and encouraging results have been obtained with tobacco and wheat (unpublished data).

In the use of highly saline and sea water for irrigation, the main danger involved is the salinity of the soil. Bernstein (1962) has rightly pointed out that a water of poor quality may produce good results when used on permeable, well drained soils. Investigations in Israel (Boyko & Boyko, 1959) showed that no salt accumulation takes place in the root zone even when the soils are irrigated with sea water, if the soils are deep and highly permeable. The present communication describes the permeability characteristics of a sandy soil and a silty clay soil for sea water and its various dilutions, to have better understanding of the suitability of sandy soils for such irrigation.

MATERIAL AND METHODS

Sea water for the investigation was collected from Bhavnagar coast and the sandy and silty clay soils from the coasts of Mahuva and Bhavnagar (Gujarat State) respectively. Only surface samples up to a depth of 8 cm for silty clay soils and 30 cm for sandy soils are studied, since the soils of the respective profiles compared well with their surface soils.

The soils were air dried and the portion passing through 2 mm sieve was used for all the determinations. Soil *p*H was determined on 1:2·5 soil water suspension using Beckman electronic *p*H meter with glass electrodes. Soils were equilibrated with various dilutions of sea water by continuous leaching for a minimum period of about 5 hours. The salt content in the soils was gravimetrically determined in 1:2 soil water extract. Dispersion coefficient was measured by determining the percentage of clay by the pipette method after leaving the soil in contact with water for 24 hours (referred to as the dispersion factor) and expressing it as percentage of the total clay content of the soil obtainable on complete dispersion (Puri, 1949). For the determination of dispersion factor, 1 per cent and 10 per cent soil-water suspensions were used respectively for the silty clay and sandy soils. Set up of the constant head permeameter as described by Christiansen (1944) was used for the permeability determinations. The permeameter consisted of a glass tube of 28 cm length and 4 cm diameter. Glass wool was put at the base in the tube, over which 20 gm quartz, 20 gm soil and 15 gm quartz were put in the sequence. Compaction was effected by dropping the tube 20 times on a soft wood from a height of one inch. Viscosity corrections were applied to the permeability results.

Silt was separated from the sea water by filtration and the total salt content in sea water was gravimetrically determined. Conductivity was recorded using Serfass conductivity bridge. Analysis for Ca and Mg was carried out by the versenate titration, Na and K by the Flame photometer and CO_3, HCO_3, Cl and SO_4 by the conventional methods.

RESULTS AND INTERPRETATION

Of the various classifications proposed from time to time to categorize water for irrigation, the one developed by the United States Salinity Laboratory is widely followed wherein the waters are classified into salinity grades in terms of specific conductance and alkalinity grades in terms of sodium adsorption ratio (S.A.R.). The conductivity, composition and S.A.R. values of sea water (Table 1) reflect in the first instance, as absolutely unsuitable for irrigation purpose. The values for sea water dilutions have also been presented in the table.

The mechanical analysis of the soils is presented in Table 2. The *p*H of the soils (Table 3) tends to fall with increasing salinity of the water used in preparing the suspension. The fall is well marked in the initial levels of salinity. The practical importance of this observation would be that the *p*H of a soil as determined in the laboratory with distilled water would not be the same as it exists in the field, particularly under saline water irrigation, and the *p*H of a soil would vary in a profile depend-

1. Contribution from the Central Salt & Marine Chemicals Research Institute, Bhavnagar, Gujarat

TABLE 1: Conductivity, composition and S.A.R. values of sea water and its dilutions

Sea water and its dilutions	*Total salts me./l*	*Conductivity micromhos/cm at 25°C*	*Ionic composition me./l*								*S.A.R. values*
			Na	*K*	*Ca*	*Mg*	*Cl*	SO_4	CO_3	HCO_3	
Sea water (36,322 ppm)	1253·2	56·849	504·4	7·3	19·5	102·8	560·1	56·1	0·4	2·6	64·7
30,000 ppm	1035·6	47·760	416·7	6·1	16·1	84·9	462·9	46·4	0·3	2·1	58·6
20,000 ppm	690·4	32·890	277·8	4·1	10·8	56·6	308·6	30·9	0·2	1·4	47·9
10,000 ppm	345·2	17·222	138·9	2·1	5·4	28·3	154·3	15·5	0·1	0·7	33·9
5,000 ppm	172·6	8·371	69·5	1·0	2·7	14·2	77·2	7·7	0·05	0·35	23·9

TABLE 2: Mechanical composition of the soils (Expressed as per cent on oven dry basis)

Constituents	*Soil type*	
	Sandy	*Silty clay*
Moisture	1·72	11·58
Total soluble salts	0·0172	2·0089
$CaCO_3$	18·03	4·13
Coarse sand	1·55	—
Fine sand	71·66	13·61
Silt	3·68	24·77
Clay	3·52	53·02

TABLE 3: *p*H and salt content of soils with sea water dilutions

Sea water & its dilution	*pH*	*Sandy soil*		*Silty clay soil*	
		pH	*Salt content ppm*	*pH*	*Salt content ppm*
Sea water (36,322 ppm)	8·00	7·90	11,228	8·30	15,350
30,000 ppm	7·95	7·90	8,492	8·30	14,550
20,000 ppm	7·85	7·90	6,068	8·30	9,180
10,000 ppm	7·50	7·90	3,040	8·40	4,785
5,000 ppm	7·30	7·95	1,608	8·50	3,000
Distilled water	5·80	8·1	—	8·60	—

ing on the addition of salts and the rate of evaporation of water, apart from such other factors as carbon dioxide concentration of the soil air, etc.

Permeability curves (Fig. 1) for the two soil types indicate that the permeability increases with increase in the salinity of the water. Due to the high permeability of sandy soils, any salt left out by irrigation with saline water will be easily washed down into deeper layers during subsequent irrigations. The water holding capacity of the sandy and silty clay soils was found to be 33 and 48 per cent respectively and the salt content of the soils should accordingly approximate to about one third and half the salt concentrations of the irrigation water. This is confirmed by the values of salt content (Table 3) in the soils equilibrated with sea water of various dilutions. Boyko and Boyko (1959) observed that the salt concentration in the soils was only 0·2 per cent even after 100 times irrigation with sea water containing 3·4 per cent salts. The soils used by them contained, more of stones and coarse sand and very low silt and clay. The high permeability and very low water holding capacity of the soils might account for the residual low salt content in the soils.

The predominance of sodium in sea water is reflected in its high S.A.R. value and a soil irrigated with such water would be left with a high exchangeable sodium percentage (ESP). But, the extent of deflocculation of clay that can be brought about by the high ESP is controlled by the salt content of the soil-water system and the effect of deflocculation on soil tilth would obviously be determined by the amount of clay present in the soil.

Dispersion coefficient is a measure of the percentage of total clay that can pass into the suspensoid state by simple contact with water, and its value varies from 0 to 100 per cent, depending on whether the soil is completely flocculated or completely dispersed. The dispersion coefficient for the soils equilibrated with waters of different salinity levels and dispersed, after drying, in distilled water shows that as the salt content in the soil decreases, the dispersion coefficient increases. These results indicate that, in nature, if a heavy textured soil is either irrigated or flooded with sea water, it comes into dispersed state as soon as the excess salts are removed by rain or fresh water irrigation. The soil loses its structure and remains in puddled condition and becomes very hard on drying. Such observations on clayey soils flooded with sea water have been recorded by Dymond (quoted by Russel, 1953). On the contrary a sandy soil would maintain good tilth, since the low amount of dispersed clay will be insufficient to bring the soil to any unfavourable physical condition.

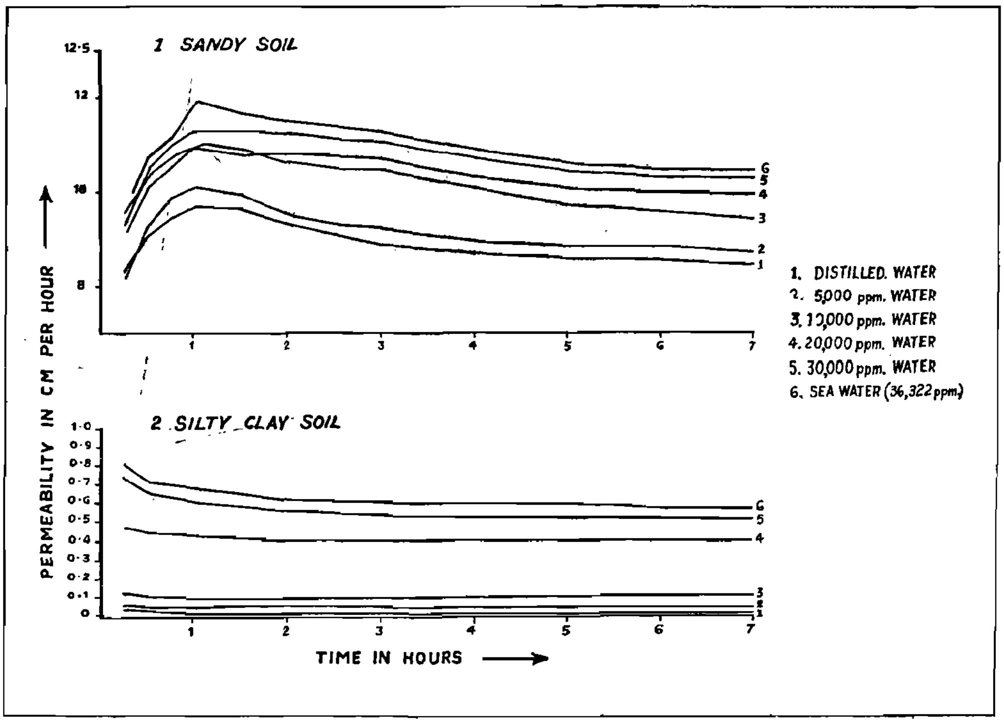

Fig. 1 — Permeability-time curves of soils with various dilutions of sea water

SUMMARY

The paper presents the total dissolved salts, conductivity ionic compositions, sodium adsorption ratio and the *p*H of sea water and its various dilutions from Bhavnagar coast. The relative influence of these waters on soil *p*H and permeability is reported. The effect of high salinity of the waters is minimized in sandy soils and their high S.A.R. value has also no ultimate effect on these soils due to the low clay content. The high permeability results for sandy soils prove their suitability for such irrigation with saline waters and this prevents any salt accumulation in the root zone.

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DISCUSSION

S. P. Raychaudhuri: Dr Boyko mostly worked with gravel soils and not with sandy soils which contain clay. We should be very careful in carrying out work with soils containing some clay. Long term effects of the use of sea water and its dilutions are needed to study the effect on the soil.

M. R. Narayana: It is true that Dr Boyko worked with gravelly material. Sandy soils on which these studies have been conducted have very low amount of clay.

IMPROVING IRRIGATION IN THE ARID ZONE[1]

by

M. R. Bajpai & A. M. Michael[2]

Irrigation is a means of maintaining a continuous supply of available moisture in the plant root zone. Successful irrigation requires adequate supply of water of suitable quality; application of proper amount of water at proper intervals, suitable methods of water application, and facilities for drainage. Judicious, irrigation results in increased yield and conservation of soil resources, maintenance of productivity and economic utilization of water. Over irrigation, however, results in soil erosion, leaching added fertilizers, impeded drainage and salt accumulation.

Careful utilization of water resource is an important item in the arid zone farming. Some of the important irrigation problems of the arid zone are: (1) inadequate source of ground water supply; (2) inefficient water lifting devices; (3) excessive conveyance losses in irrigation channels; (4) inefficient methods of irrigation and (5) inadequate drainage in canal irrigated tracts.

Successful irrigation farming in the arid zone depends on identifying these problems and combating them at various levels.

GROUND WATER RESOURCES

Ground water supply is comparatively poor in the arid zone. In the areas not reached by canals, wells are the main source of irrigation. Yield of wells varies greatly from place to place. Tube wells are not successful in areas near salt lakes and in places with rocky substratum. However, at places good water bearing confined aquifers have been tapped by tube wells in Jaisalmer district and other localized area. Moisture conservation and consequent reacharge of ground water is essential. The low rainfall combined with highly permeable soils affords excellent potential for maximum conservation of rain water. Properly designed contour bund system and conservation farming practices afford suitable means of conserving rain water. Exploration of ground water resources in the confined stratum below the surface aquifer is necessary to ascertain the suitability of tube wells in specified areas in the arid zone.

WATER LIFTING DEVICES

The farmer generally uses the age old rope and bucket system (*Charsa*) for lifting water from wells. Though a dependable one, the method is very costly. It cost from Rs. 40 to 50 per acre of irrigation and the area that can be controlled is comparatively small from 0·1 to 0·3 acres per day. The low discharge of the *Charsa* prevents adoption of efficient methods of water application in the field. Labour saving water lifting devices are to be adopted to increase irrigation efficiency. Where animal power is to be used, Persian wheels for lifts up to 30 ft, circular *Charsa* for lifts up to 15 ft, and Egyption Screw for lifts up to 4 ft, have proved efficient. Centrifugal pumps coupled to electric motors are the most suitable means of lifting water from open wells in areas where electric power is available. Engine driven centrifugal pumps are not efficient when the static lift exceeds about 40 ft. In deep wells and tube wells, where electricity is not available, engine driven turbine pumps are most suitable.

SEEPAGE LOSSES IN IRRIGATION CHANNELS

Mainly earth channels are set up for conveying water to irrigate the fields. Excessive seepage loss from earth channels, particularly in sandy tracts, is often a problem in irrigated areas, which is increased manyfolds in fields infested with rodents and burrowing animals. Often it is difficult to convey water even through short distance.

Lining of channels will reduce the amount of seepage loss and prevent the channel from eroding. Many types of materials have been employed in lining. The primitive practice of mixing alkaline clay at the source of irrigation water in the channels is not uncommon in Rajasthan. Such a lining results in developing undetected salinity in the fields. Lining with grass is not always easy to carry water as it obstructs easy flow. Concrete, however, is the most widely used lining material. Concrete lining is costly and is often beyond the capacity of an ordinary farmer. The clay tiles developed at this College, and the lining with bituminous material developed by the Council of Scientific & Industrial Research, New Delhi, provide cheap lining materials and are satisfactory

1. Contribution from S.K.N. College of Agriculture, Jobner, Rajasthan.
2. Professor of Agronomy and Professor of Agricultural Engineering, respectively.

under the soil and climatic conditions obtaining in Rajasthan.

METHODS OF IRRIGATION

At present the farmers still use the age old check flooding or compartment system of irrigation which in most cases does not give the desired irrigation efficiency. Improved methods of irrigation like border strips and furrow methods of irrigation have been tried and are found quite suitable in this region. A uniform grade of fields is necessary for adopting those improved irrigation methods. On steep slopes the border strips or furrows may be laid across the slope of the land with a gentle slope lengthwise. There should be no cross slope in border strips. Desirable grade (longitudinal) in border strips and furrows ranges from 0·3 to 0·6 per cent in this region.

Border irrigation is particularly suitable in close growing grain crops, hay and pasture, while furrow irrigation is advantageous in row crops like potatoes and vegetables. While furrow irrigation is suitable even in small sources of water, a minimum discharge of over 3,000 gallons per hour is desirable for the successful adoption of border irrigation.

TABLE 1: Advance of water in section and feet per minute

Length along border ft	*Cumulative time min.*	*Time of advance in sectiou min.*	*Rate of advance ft/min.*
0	0	0	0
10	0·25	0·25	40
20	1·00	0·75	13
30	2·00	1·00	10
40	2·75	0·75	13
50	3·50	0·75	13
60	4·25	0·75	13
70	5·00	0·75	13
80	6·00	1·00	10
90	6·75	0·75	13
100	7·75	1·00	10
110	9·00	1·25	8
120	10·25	1·25	8
130	11·00	0·75	13
140	13·00	2·00	5
150	15·50	2·50	4
160	18·00	2·50	4
170	20·00	2·00	5
180	23·00	3·00	3·3
190	25·00	2·00	5
200	26·50	1·50	7
210	28·00	1·50	7
220	30·00	2·00	5
230	32·50	2·50	4
240	35·00	2·50	4
250	38·00	3·00	3·3
260	41·00	3·00	3·3
270	45·00	4·00	2·5
275	47·00	2·00	2·5

A series of trials were conducted in 1963-64 at Jobner to test the suitability and to evolve design criteria for border irrigation. The various hydraulic criteria like the intake rate of soil prior to each irrigation, advance and recession rates along border, and time of ponding required to apply adequate moisture to the root zone of the crop throughout the length of border were studied for different lengths and slopes of border strips. The size of the border strip was 275′×10′. It had a slope of 8·75 per cent. Number of irrigations applied were six. The depth of irrigation applied was 2·4 inch. The ideal irrigation stream is based upon parallelism of border stream advance and recession relationships and a water application of 50 per cent of the total available moisture of the soil.

Results of the trials conducted during 1963-64 with wheat crop indicate that the optimum length of border strip is about 200 ft.

TABLE 2: Recession along border, and time of ponding

Length along border ft	*Cumulative time min.*	*Time of recession in section min.*	*Rate of recession ft/min.*	*Time of ponding min.*
0	57·00	—	—	57·00
10	57·50	0·50	20	57·25
20	58·00	0·50	20	57·00
30	58·00	0·50	20	56·50
40	58·83	0·33	30	56 00
50	59·50	0·77	15	56·00
60	60·25	0·75	13	56·00
70	61·00	0·75	13	56·00
80	62·00	1·00	10	50·00
90	62·75	0·75	13	56·00
100	63·75	1·00	10	56·00
110	65·00	1·25	8	56·00
120	66·50	1·50	7	56·25
130	68·00	1·50	7	57·00
140	68·75	0·55	13	55·00
150	69.75	1·00	10	54·25
160	71·00	1·25	8	53·00
170	72·00	1·00	10	52·00
180	73·50	1·50	7	53·50
190	74·75	1·25	8	49·75
200	76·00	1·25	8	49·50
210	77·50	1·50	7	49·50
220	79·50	2·00	5	49·50
230	82·00	2·50	4	49·50
240	84·00	2·00	5	49·00
250	87·50	2·50	4	49·56
260	90·00	2·50	4	49·50
270	92·00	2·00	5	47·00
275	93·50	1·50	3·3	46·50

The cumulative time need to traverse each 10 ft length increased at the rate of less than a minute up to 140 ft length and thereafter time lag successively increased. The time of ponding saved the reverse order of the time of recession in sections with increasing length along the border.

DRAINAGE OF IRRIGATED LANDS

The practice of irrigation and drainage in arid and semiarid areas are often inseparable. The excessive use of irrigation water under canal irrigation is the chief cause of water logging in irrigated areas. Excessive evaporation rate and low rainfall are responsible for the accumulation of harmful salts on the field surface in these areas. Many large and costly irrigation schemes have failed or are threatened with failure due to rising water table and salt accumulation. Improving irrigation methods and thus reducing excess water applications will reduce drainage requirements. However no large scale irrigation scheme can be assured of more than short success unless drainage requirements are met.

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DISCUSSION

B. Ramamoorthy: Whether pre-irrigation surveys are carried out or not, the introduction of Canal irrigation has brought about salinity in the U.S.A., India and Pakistan, unless it is combined with irrigation with ground water. This is what West Pakistan is now doing to reclaim such saline soils. This should be taken up even at the stage of introduction of canal irrigation in future in this country.

M. R. Bajpai: Drainage by installing tube wells is possible where the aquifer has sweet water. The discharge from the perched water table is small. Thus this practice cannot be uniformly adopted to reclaim saline soil by maintaining salt balance in the soil by introducing irrigation and drainage simultaneously.

PASTURE ECOLOGY (AGROSTOLOGY)

SELECTION OF GRASSES & LEGUMES FOR ARID ZONE PASTURE[1]

by

A. K. CHAKRAVARTY[2]

NATURE OF THE PROBLEM

THE arid zone of Rajasthan is composed of an area of about 1,92,000 sq. kilometres. Bose (1961) classified the area into grazing and permanent pasture 3·2 per cent, culturable waste 21·7 per cent and fallow land 15·1 per cent. Thus about 40 per cent of the gross area in the desert region is available for grazing of livestock.

The soils and climate of the arid zone are well adapted to grassland husbandry. The measures to be adopted for improving the animal husbandry largely depend on the improvement of native grasslands and cultivated fallow lands. It is, therefore, necessary to introduce grass to raise cultivated pastures on a very extensive scale adapted to renovate range lands. For this purpose, superior strains of grasses and legumes are in great demand.

Breeding of high-yielding pasture plants and the distribution of certified seeds of selected strains to the farmer is one of the principal objectives of grassland research. To fulfil this objective the Agrostology section of the Resources Utilization Division initiated research on some of the promising desert grasses in 1958. The results are summarized in the present paper.

REVIEW

The work on pasture grasses initiated at Poona, Coimbatore and Sirsa was mainly confined to isolation of types or strains from indigenous species of grasses and legumes. At the Indian Agricultural Research Institute, work on grasses and legumes was started in 1945 with particular reference to their role in soil conservation and soil fertility. Dabadghao (1951) reviewed this work *in extendo*. Later, Dabadghao and Gandhi (1952) described 16 grasses and 18 legumes which may be useful for fodder, soil conservation and crop rotation. Whyte (1957) reviewed the Indian work on grasses from the aspect of breeding of pasture species. At I.A.R.I. breeding and selection of pasture species of grasses was started in 1953. Intensive research was conducted on *Dichanthium annulatum* at Dharwar. Trials of prominent exotic and indigenous fodder and pasture species of grasses were conducted at Sirsa, Chakravarty (1961) evaluated the fodder value of 20 indigenous species of grasses and 15 legumes and observed that highland grasslands consisted mainly of *Dichanthium annulatum* and *Brachiaria setigera*. These provide a good supply of fodder to the grazing stock. Mehra (1962) reported the existence of four distinct morphological types in the *Dichanthium annulatum* complex. Patil and Singh (1963) observed a positive correlation between seed and forage yield among the different strains of *Cenchrus setigerus* and suggested the possibility of selecting strains having both these characters combined with leafiness.

RECENT INVESTIGATIONS

(a) *Occurrence of the grass species* — Blatter and Halberg (1920) reported the occurrence of 68 grasses, 65 indigenous and 3 introduced, in the Indian desert. In addition 60 species of legumes, 47 indigenous and 13 introduced, were reported. Seshagiri Rao and Kanodia (1963) included 61 grasses in their account of the desert flora of Rajasthan. It seems, therefore, that the arid and semi-arid zones of Rajasthan are rich in grasses which supply the bulk of forage to grazing stock. A short account of some of the pasture grasses is presented in Table 1.

From the account in Table 1, it will be observed that the species are widely distributed in the tropical and sub-tropical parts of the world and some are restricted to North-West India, Arabia and North-East Africa, i.e. in the typical desert regions. Chromosome numbers in the different species varies from 18 to 54 (Darlington & Wylie 1955). This is still to be determined in some others. There are tall densely branched perennials like *Lasiurus sindicus*, densely tufted *Dichanthium annulatum* and prostrate prolifically branched *Eleusine compressa* and so on. Among the annual grasses, the presence of densely tufted *Aristida* spp. the much branched *Brachiaria ramosa*, and tall species of sweet grass *Chloris virgata* add to the richness of the desert flora.

(b) *Ecology* — From the ecological study on succession of pasture grasses and legumes conducted at various places of Western Rajasthan desert it has been observed that several annual and perennial grasses contribute more than 10 per cent of the

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Agrostologist at the Institute.

TABLE 1: Grasses of the Rajasthan Desert

Sl. No. 1	*Species* 2	*Local or common name* 3	*Chromosome number* 4	*Geographical distribution* 5	*Growth characteristics* 6
1	*Aristida adscensionis* Linn	Lumpra	23	Widely distributed in the Old & New Worlds	Annual, average height 40 cm. densely tufted, very slender, erect or ascending
2	*Aristida funiculata* Trin.& Rupr	Lumpra	Not known	N.W. India, Arabia, North Africa	Tufted small annual, very slender, average height 20 cm
3	*Brachiaria ramosa* Stapf	Kuri	Not known	Tropics of the Old World	Annual, stems about 50 cm long, erect or ascending much branched from the base up-wards
4	*Cenchrus biflorus* Roxb	Bharut	Not known	India, Africa	Erect, spiny tufted annual, leafy, branched from the base, about 25 cm tall
5	*Cenchrus ciliaris* Linn	Dhaman or Buffel grass	32, 34, 36, 40 54	Trop. & South Africa, India	Stout, tough branched perennial grass, leafy, about 70 cm tall
6	*Cenchrus prieurii* Maire	Not known		N.W. India, Trop Africa	About 40 cm tall, erect annual with stout pale bristles
7	*Cenchrus setigerus* Vahl.	Anjan	34, 36	N.E. Trop. Africa, India	Tufted branched perennial, leafy, about 50 cm tall
8	*Chloris virgata* S.W.	Gharania Ghas	20, 26, 40	Widely distributed in tropics	Tall, annual grass, about 50 cm high
9	*Cymbopogon jwarancusa* Schult	Burada	Not known	India	Perennial, tufted on a creeping rootstock, roots aromatic, height about 1 metre
10	*Dactyloctenium sindicum* Boiss	—	48	N.W. India, N.E. Africa	Perenial, culms creeping or ascending, rooting at nodes, 20 cm high, richly branched
11	*Desmostachya bipinnata* Stapf	Kush	Not known	Trop. Asia, N.S. trop. Africa	Perennial rigid grass, with resetted very long leaves. Coarse grass, about 45 cm high, with thick creeping rhizomes
12	*Dichanthium annulatum* Stapf	Karad or Marvel grass	40	Trop. Asia, N. Trop. Africa	Densely tufted perennial, stem erect or ascending, very slender, 60 cm high
13	*Digitaria adscendens* Henr	Crab grass	34, 36 ,48, 54	Tropical & sub-tropical regions	Tall or low purplish annual grass in waste places & fields branching from nodes, about 50 cm high
14	*Eleusine compressa* Asch ex chw	Tantia	45	N.W. India, N. Africa	Perennial, prostrate, prolifically branched, stem smooth, stiff, rooting at the distant thickened leafy nodes and widely spreading
15	*Eragrostis ciliaris* R Br	—	40	Tropical & sub tropical regions	Small, erect annual, stems 20 cm long, tufted
16	*Eremopogon foveolatus* Stapf	Junjli	40	Trop. Asia, N. Africa	Slender, richly branched perennial grass, erect, about 60 cm high
17	*Elyonurus royleanus* Nees ex A	—	Not known	India, Arabia, Trop. Africa	Annual, stems 15 cm high, slender, leafy
18	*Lasiurus sindicus* Henr	Sewan grass	Not known	N.W. India, Arabia, S.E. Africa	Perennial, rootstock woody, densely branched stems about 1 metre high
19	*Panicum antidotale* Retz	Gramna or blue panic	18	Trop. Asia	Tall perennial grass reaching 1·5 metre high, root stock creeping, stoloniferous stem solid, nodes thickened, lower sometimes rooting
20	*Panicum turgidum* Forsk	Murut	Not known	West Asia, Trop. Africa	Perennial tussocky grass, stem hard, solid, leaves few, height about 1 metre
21	*Perotis indica* O. Ktze	—	Not known	S.E. Asia	Annual, stems tufted, sub-erect, 15 cm high
22	*Sehima nervosum* Stapf	Seran	34, 40	S.E. Asia, East Africa, Australia	Tall, erect slender perennial, about 70 cm high
23	*Sporobolus helvolus* Duret Sching	—	Not known	N.W. India, Trop. Africa	Tall, erect, perennial, slender, stems about 40 cm high, densely tufted
24	*Tragus biflorus* Schult	—	40	S.E. Asia, East Africa	Small, erect, perennial tufted grass, about 10 cm, high

*Compiled from (1) Chromosome atlas of flowering plants, by Darlington C. D. and Wylie, A. P. 1955, (2) Grasses of Burma, Ceylon, India & Pakistan by Bor N. L. 1960, (3) The flora of the Presidency of Bombay by Cooke T. 1904.

TABLE 2: Grass species contributing more than 10 per cent of vegetation at different centres of Western Rajasthan

Centres of observation: Rainfall MM: Soil Type					
Pali 450 *heavy*	*Sardarshahr* 250 *sand dune*	*Beechwal* 200 *sand dune sandy plain*	*Gadra road* 125 *sand dune*	*Kailana* 300 *rocky*	*Jodhpur* 300 *light sandy*
		Annuals			
Aristida spp. *Chloris virgata*	*Aristida* spp. *Cenchrus biflorus*	*Aristida* spp.	*Aristida* spp. *Cenchrus biflorus* *Elyonurus royleanas*	*Aristida* spp. *Malanocheris abyssinica* *Oropetium thomium*	*Aristida* spp. *Brachiaria ramosa* *Eragrostis ciliaris* *Perotis indica*
		Perennials			
Eleusine compressa *Cenchrus ciliaris* *Cenchrus setigerus* *Dichanthium annulatum* *Eremopogon foveolatus*	*Eleusine compressa* *Cenchrus ciliaris* *Lasiurus sindicus* *Cymbopogon jwarancusa* *Dactyloctenium sindicum*	*Eleusine compressa* *Dactyloctenium sindicum*	*Eleusine compressa* *Cenchrus ciliaris* *Cenchrus setigerus*	*Eleusine compressa* *Tragus biflorus*	*Eleusine compressa*

TABLE 3: Agro-botanical Characters of prominent desert grasses

Sl. No.	*Species*	*Plant height in cm*	*Tiller No.*	*Plant diam in cm*	*Leaf to stem ratio*	*Flowering time**	*Root development per cent beyond 1 m, depth of soil*	*Increase in forage yield over control by application of N.P. expressed in percentage*	*Forage yield in tonnes ha*	*Seed yield in kg ha*
1	*Lasiurus sindicus*	70	35	17	46:54	July-Sept.	59	34	8·4	112
2	*Cenchrus ciliaris*	48	22	11	50:50	,,	59	36	3·5	134
3	*Cenchrus setigerus*	47	27	19	48:52	,,	27	17	3·4	126
4	*Panicum antidotale*	73	21	15	42:58	,,	27	17	2·1	35
5	*Dichanthium annulatum*	73	103	9	48:52	,,	11	10	1·8	9

*Flowering at other times of the year under irrigation.

vegetation. The list of such grasses is given in Table 2.

Nine annual and nine perennial species contribute more than 10 per cent of the vegetation. The bulk of the forage is supplied by the perennial species, *Cenchrus ciliaris*, *Cenchrus setigerus*, *Lasiurus sindicus*, *Cymbopogon jwarancusa*, *Dichanthium annulatum* and *Eleusine compressa*, which is much higher than the contribution of the annuals.

(c) *Variation of characters and selection* — As a first step to selection a systematic study on five important perennial species was conducted. The results are reported in Table 3.

Lasiurus sindicus is the highest yielder of forage, with a deep penetrating root system; responds to the application of nitrogenous and phosphatic fertilizers. Among the other species, *Cenchrus ciliaris* is more leafy than the former species and compares favourably with it in the other characters. The variation which has been noted among the five species is also expected to exist among the other perennial species of the desert.

In order to study in detail various characteristics of desert grasses, a collection of species has already been built up and are under observation in the grass legume nursery of the Institute (see Table 4).

TABLE 4: Collection of important grasses

Sl. No.	Species	No. of indigenous strain collection	No. of strains introduced	Total
1	*Lasiurus sindicus*	21	1	22
2	*Cenchrus ciliaris*	48	17	65
3	*Cenchrus setigerus*	18	1	19
4	*Panicum antidotale*	41	8	49
5	*Dichanthium annulatum*	5	21	26
6	*Panicum coloratum*	nil	2	2
7	*Panicum maximum*	nil	1	1
8	*Panicum turgidum*	1	nil	1
9	*Cymbopogon* spp.	16	nil	16
10	*Sporobolus* spp.	5	nil	5
11	*Sehima nervosum*	2	nil	2

This material forms the nucleus for selection. On the basis of trials conducted with 10 different strains of *Cenchrus ciliaris* at the Central Research Farm, Jodhpur, and Research Farm, Pali, strains No. 357 and 358 have been found to be suitable for sandy soil in low rainfall areas and strains No. 226 and 362 for heavy soil in higher rainfall areas of Rajasthan desert. Similar trials will be undertaken on strains of *Lasiurus sindicus*, *Cenchrus setigerus*, *Panicum antidotale* and *Dichanthium annulatum* to select strains which will give high forage production in different agroclimatic regions.

There are hardly any perennial legume species in the desert to enrich the pasture. Some promising legumes are *Dolichos lablab* var. *Lignosus*, *Atylosia scarabaeoides*, *Clitoria ternatea*, *Canavalia ensiformis*, *Mucuna cochinchinensis*, *Indigofera spicata*, *Vigna catjang*, *Alysicarpus longifolius*, *Dolichos hamarii*, *Teramnus uncinatus*, *Stylosanthes gracilis*, *Centrosema pubescens*, *Calopogonium muconoides*, *Indigofera sumatrana*, and *Glycine javanica*; of these *Dolichos lablab* var. *lignosus*, *Atylosia scarabaeoides* and *Clitoria ternatea* have proved to be drought resistant to some extent. Their potentiality as pasture legumes is being tested.

(d) *Polymorphism* — *Cenchrus ciliaris* exhibits marked polymorphism in nature. Some observations which are linked with habitat factors are presented in Table 5.

TABLE 5: Percentage of plants of *Cenchrus ciliaris* with coloured earhead, stigma and node in different habitats

Sl. No.	Locality	Habitat	Black head	Coloured stigma	Coloured node
1	Gadra Road	Sand dune	4·0	64·9	24·7
2	do	Flat land at foot of dune	98·6	nil	0·7
3	Chandan	Low dune	25·6	53·7	86·6
4	Pokaran I	Flat sandy soil	9·6	—	—
5	Pokaran II	Flat compact soil	84·3	—	—
6	Pali	Heavy soil	100·0	37·1	83·8

A high percentage of black-headed plants generally occur in the heavy and compact soil of Gadra Road flat land, Pokaran II and Pali. Sand dunes, and loose sandy soil encourages white-headed plants to grow; the proportion of plants with coloured heads was less in sand dunes than in compact soils. The proportion of plants with coloured stigmas was rather high in this habitat. Node colour seemed to have no such relation. Such studies on populations of various grass species need to be conducted in detail to decide whether any of the genetical characters are linked with the habitat factor or not. This information will be useful in breeding and selection of grasses.

FUTURE RESEARCH

The research programme may be divided into (1) short-term and (2) long-term categories. Work in the short-term programme may be confined to the collection of strains of perennial desert grasses from indigenous sources, followed by selection of ecotypes and strains to suit the different agro-climatic regions; large-scale seed production of improved types or strains of grasses for pasture development; study of the compatible forage legumes to be grown in association with the perennial grasses and selection of types or strains of legumes which can withstand the grazing stress. The long-term programme should include detailed study of the grasses and legumes from the fundamental aspects of resistance to drought frost and saline and alkaline conditions of the soil; physiological studies on growth and reproduction of the promising grasses with reference to environmental factors; introduction of herbage species of grass and legumes from the homologous agroclimatic regions or "Homoclimes" of the world to utilize their superior characters for strain-building and isolation of types or strains for irrigated pastures.

SUMMARY

The improvement of animal husbandry in the arid zone is largely dependent on the improvement of its natural grasslands and on fodder production on the fallow lands which form about 40 per cent of the total area of Rajasthan desert. Supply of seed of the improved types of grasses and legumes in large quantities is necessary to have sown pastures and to renovate the range lands. A short account of the annual and perennial grasses of the Rajasthan desert has been presented, which includes ten annual and fifteen perennial species. There are nine annual and nine perennial species which contribute more than 10 per cent of the vegetative cover in different habitats.

A study of the agro-botanical characters of *Lasiurus sindicus*, *Cenchrus ciliaris*, *Cenchrus setigerus*, *Panicum antidotale* and *Dicanthium annulatum*, have shown that *Lasiurus sindicus* is the highest yielder of forage, with its deep penetrating roots. It also responds favourably to the combined application of nitrogenous and phosphatic fertilizers. *Cenchrus ciliaris* is more leafy than the former species and possesses a deep penetrating root system. It gives a higher response to the application of nitrogenous and phosphatic fertilizers than *Lasiurus sindicus*.

A collection of 208 strains belonging to promising perennial species has been built up. *Cenchrus ciliaris* strains No. 357 and 358 have been selected for introduction in light sandy soil in a low rainfall (125-300 mm) region and strains No. 226 and 362 for heavy soil in the high rainfall (300-500 mm) areas of the arid zone. Among the introduced legumes *Dolichos lablab* var. *lignosus*, *Atylosia sacrabaeoides* and *Clitoria ternatea* have proved to be drought-resistant to an appreciable extent.

From a population study on *Cenchrus ciliaris* in different habitats, black-headed plants were found more frequently on heavy, compact and flat soils than on sandy, loose soils and sand dunes. Plants with coloured stigmas are usually associated with sandy loose soils or sand dunes. This study has a bearing on future breeding and selection of grass species.

ACKNOWLEDGEMENT

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DISCUSSION

S. P. Raychaudhuri: In formulating the future programme of work on the breeding of grasses, evolution of varieties which are good soil binders with good root system and also tops with good nutritive value may be kept in view.

A. K. Chakravarty: Records are maintained on the root system and nutritive value of grasses. Attempts will be made to evolve strains with good root system and high nutritive value.

U. N. Chatterji: With regard to the study of root system it may be kept in view that the depth and horizontal spread of the roots would differ in soil binding capacities.

A. K. Chakravarty: Studies are in progress with regard to vertical and horizontal spread of roots of different desert grasses in different soils.

S. P. Chatterjee: To which year the land use figures relate to ? What is the source of information regarding percentage of grassland area you mention ?

A. K. Chakravarty: The figures were reported from a published work which has been cited.

Ranbir Singh: Has any mixture of grass and legume been tried ? If so what is the recommendation for the arid areas of Rajasthan ?

A. K. Chakravarty: Experiments on grass and legume mixtures have been started recently. No recommendation is possible at the present state of our knowledge.

STUDY OF GRASSES & SEDGES OF CERTAIN AREAS IN JHUNJHUNU DISTRICT, RAJASTHAN[1]

by

M. C. JOSHI & C. B. S. R. SARMA

INTRODUCTION

IN the context of the scant attention paid to the agrostological studies of the Rajasthan desert, an investigation into the grasses and sedges is thought to be necessary. The areas chosen for the study include the various environs of Pilani, Ratan Shahar, Mandrela, Singhana and Khetri of Jhunjhunu district.

ENVIRONMENTAL FACTORS

The various environmental factors influencing the grasses and sedges are as follows:

The physiography of the area comprises of the following ecosystems:

(1) *Low-lying areas* — These include low-lying hard ground plains, ditches, puddles, pools, temporary ponds and Ajit Sagar Bundh area near Khetri.

(2) *Sandy areas* — These include sandy plains, embryonic, barchanoid, fusing-barchanoid, longitudinal ridged, hummocky and stabilized dunes of mainly Pilani, Mandrela and Singhana.

(3) *Hilly areas* — These include about a dozen hillocks. A few important ones are: Pahari of Pilani, Narhar hillocks, Nari Khetri Ki Pahari, Marot Ki Pahari, Kali Pahari, Jai Pahari, Makhar Salampur Ki Pahari etc., of Ratanshahr, Singhana and Khetri.

The terrain of the investigated areas is thus not flat. The undulating plain consists of three main topographic zones. While most of the low-lying areas are man-made, the sand of the sandy areas is aeolian. Cross winds, dust and sand storms, common in the area result in the annual changes in the topography of the sandy habitats. The consequent geomorphological changes depend upon the velocity and direction of the wind. Sheet erosion is quite common in all sandy areas. The spasmodic hilly tracts are the offshoots of the Aravalli ranges. These are usually surrounded by huge sand deposits of barchan type. Most of the hillocks are of granite and associated types of variable texture. In this case the weathering of rocks into small balancing boulders is typical. Apart from exfoliation, frost action, frost hearing, temperature changes, biological and chemical factors also cause weathering. Gully erosion is common in these hilly areas. Rain water flows down the slopes making channels as a result of which the rocky substratum has become exposed at many places. Katli is the solitary rain-fed stream. The extent of the river regime depends upon the intensity of the rainfall. However, it is soon lost in the sandy areas.

The climate of the area is semi-arid typical of many other regions of Rajasthan. The extreme type of climate is characterized by diurnal, seasonal and annual fluctuations. Figure I shows the meteorological data for the years 1961 and 1962 which were obtained from Pilani observatory. The minimum temperature (3·3°C) during the two years has been recorded in December while the maximum (44·0°C) occurs in June. Relative humidity is maximum (88% in 1961) during August and minimum (13% in 1962) in May. In 1961 the maximum rainfall (171·5 mm) was received in August while 1962 showed unusual fluctuations (283·0 mm in July, 98·5 mm in August and 115·7 mm in September). The maximum wind velocity (18·6 km/hr) was in June in 1961 as well as in 1962 (22·5 km/hr). Dew, mist and fog offer a source of moisture during winter months when rains are rare. This helps in the sprouting of certain grasses. Cold waves in January and February and dust and sand storms in summer are quite frequent. Frost is very rare.

Grasses and sedges never reach climax as these are subjected to intense biotic disturbance and destruction at various stages of their development. However, the growth and spread of the grasses and sedges on "warfooting" make their vulnerability and susceptibility to biota less recognizable and less appreciable.

Termites usually damage the grass cover in hard ground areas where these are also seen carrying the seeds of *Dactyloctenium aegyptium* and *Brachiaria ramosa*. Ants offer the dispersal media for the spiny involucels of *Cenchrus* spp., colourful spikelets of *Eragrostis uniloides* and *E. tremula*, and seeds of *Dactyloctenium aegyptium*, *Aristida mutabilis* and *Pennisetum typhoides*. The cultivated crop plants

1. Contribution from the Department of Botany, Faculty of Science, Birla Institute of Technology and Science, Pilani, Rajasthan.

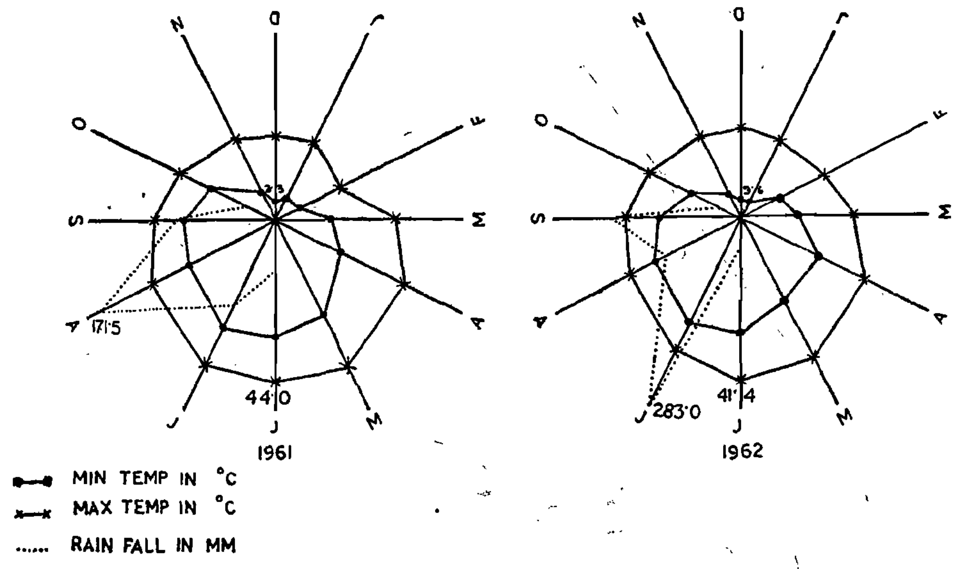

Fig. 1 — Showing temperature and rainfall

TABLE 1: Soil analyses of various habitats

Habitat	*Depth at which soil samples are taken*	*Mechanical nature*				*Chemical nature*	*pH*
		% fine gravel	*% coarse sand*	*% fine sand*	*% silt & clay*		
Low-lying areas	Surface	4·4	7·6	79·1	8·9	Chloride-carbonaterich	8·5
	10·0 cm	2·2	5·1	83·2	9·5	,,	8·5
	20·0 cm	2·2	4·2	87·8	9·5	,,	9·0
	30·0 cm	2·5	1·2	87·5	9·8	,,	9·0
	Surface	0·5	5·5	89·4	4·6	Chloride-nitrate rich	7·0
	10·0 cm	0·3	4·4	85·5	9·8	,,	4·0
Sandy areas	20·0 cm	0·2	5·6	94·0	1·2	,,	6·0
	30·0 cm	0·2	9·3	88·0	1·9	,,	6·0
	Top	10·2	59·9	12·2	17·7	,,	8·0
Hillocks	Middle	9·5	66·8	12·8	11·9	,,	7·0
	Base	5·5	66·2	14·4	14·9	,,	7·5

like *Pennisetum* and *Zea mays* are highly vulnerable to the oft-repeated danger of locust invasion.

The common birds like peacocks, patridges, pigeons, etc., damage the nurselings of some grasses like *Brachiaria ramosa*, *Panicum antidotale* and *Chloris barbata*.

The extensive fibrous root system of the sand-binding perennial grass *Saccharum bengalense* mars the effect of the burrows which testify the venomous role of rats, rabbits and hedgehogs which otherwise bring about the eclipse of other plant life.

The livestock browse and graze on all fodder grasses. At times these are even completely uprooted by them. However, *Saccharum bengalense* escapes from this danger. The spiny involucels of *Cenchrus biflorus* and other escaping devices of *Setaria verticillata* and *Echinochloa crusgalli* combat the impending danger from these animals from which they have survived by chance during their juvenility.

Man is mostly responsible for disturbing the grass climax by removing the pioneering grass cover. The uprooting of many grasses and even of some sedges like *Cyperus compressus*, *C. iria* and *C. niveus* leaves behind a denuded and exposed habitats. The excellent sand binding perennial *Saccharum bengalense* is often cut for its economic use.

Soil and plant are strongly influenced by each other owing to the intimacy of contact. Table 1 gives a summary of preliminary analyses of soil from various habitats and from different depths carried out during 1962.

HABITAT PREFERENCES

Habitat preferences of these plants are as follows: *Aristida mutabilis, Brachiaria ramosa, Cenchrus biflorus, Dactyloctenium aegyptium* and *Cyperus niveus* inhabit all the three habitats, viz. lowlying, sandy and hilly areas. Plants like *Cenchrus ciliaris, Tragus biflorus, Eremopogon foveolatus Kyllinga monocephala, K. triceps* are inhabitants of hills as well as low-lying areas, while *Perotis indica, Cyperus rotundus* are denizens of low-lying and sandy areas. On the other hand *Eragrostis riparia* and *E. tenella* occur on dunes as well as on hills. Some are secluded to low-lying areas such as *Digita ia sanguinalis, Echinochloa colonum, Poa annua, Setaria verticillata, Cyperus compressus* while *Eragrostis tremula* occur only on dunes. Plants like *Melanocenchris jacquemontii, Cymbopogon parkeri, Tetrapogon tenellus* prefer exclusively hilly tracts. *Apluda mutica, Digitaria sanguinalis, Echinochloa colonum, Polypogon monspeliensis, Cyperus compressus* and *C. iria* are moisture lovers whereas *Setaria verticillata* and *Chloris barbata* are sciophytes.

Grass and sedge communities are varied. Many reconnaissance trips in the fields covering all the three habitats were undertaken during 1961-1962. The percentage presence of grasses and sedges as obtained within their communities is presented in Table 2. Forbes have not been considered.

Further in each of the habitats, the grasses and sedges have been grouped based on their relationship to one another, i.e. whether, (a) isolated and pure, or (b) segregates of two or three species, or (c) conglomeration of many species, as in Table 3.

TABLE 2: Percentage distribution of grasses and sedges in different habitats

Name of the plant	*Low-lying area*	*Sandy area*	*Hilly area*
Aristida adscensionis Linn.	7	—	—
A. mutabilis Trin., et. Rupr.	2	5	2
Brachiaria ramosa (Linn.) Stapf.	5	4	4
Cenchrus biflorus Roxb.	12	22	4
C. ciliaris Linn.	6	—	—
C. prieurii (Kunth) Maire.	—	8	—
Chrysopogon gryllus (Linn) Trin.	—	—	4
Cymbopogon parkeri Stapf.	—	—	17
C. martinii (Roxb.)	—	—	7
Cynodon dactylon (Linn) Pers.	4	2	2
Dactyloctenium aegyptium (Linn) P. Beauv.	15	7	10
D. sindicum Boiss.	4	3	—
Desmostachya bipinnata (Linn) Stapf.	2	2	—
Digitaria sanguinalis (Linn) Scop.	3	—	—
Eragrostis ciliaris (Linn) R. Br.	2	1	4
E. riparia (Willd) Nees.	—	—	2
E. tenella (Linn) P. Beauv.	—	5	—
E. tremula Hochst.	—	9	—
Melanocenchris jacquemontii Jaub. et. Spach.	—	—	5
Perotis hordeiformis Nees.	—	—	4
P. indica (Linn) O. Ktze.	—	7	—
Saccharum bengalense Totz.	—	4	2
Tetrapogon tenellus (Roxb) Chiov.	—	—	3
Tragus biflorus Schult.	2	1	4
Bulbostylis barbata Kunth.	—	—	3
Cyperus arenarius Retz.	—	4	—
C. compressus Linn.	3	—	—
C. iria Linn.	4	—	—
Kyllinga monocephala Rottb.	7	—	—
K. tricepsa Rottb.	4	—	—
Other species	18	16	25

TABLE 3: Mode of occurrence of grasses and sedges in different habitats

Habitat	*Pure communities*	*Seggregation*	*Mixed communities*
Low-lying areas	*Cenchrus ciliaris*	*Cyperus iria* *C. compressus*	*Cenchrus biflorus* *Dactyloctenium aegyptium*
	Dactyloctenium sindicum		*Digitaria sanguinalis* *Aristida adscensionis*
	Desmostachya bipinnata	*Kyllinnga triceps*	*Kyllinga monocephala* *K. triceps*
		K. monocephala	
	Cynodon dactylon		*Brachiaria ramosa* *Sporobolus coromandelianus*
Sandy areas			*Dactyloctenium sindicum*
	Cenchrus biflorus	*Eragrostis tremula*	*Perotis indica*
	C. prieurii	*E. tenella*	*Tragus biflorus* *Brachiaria ramosa*
	Saccharum bengalense		
Hilly areas	*Bulbostylis barbata*	*Tragus biflorus* *Melanocenchris jacquemontii* *Eragrostis ciliaris*	*Dactyloctenium sindicum* *Tetrapogon tenellus* *Perotis hordeiformis*
	Aristida mutabilis	*E. riparia* *Chrysopogon gryllus*	*Brachiaria ramosa*
	Saccharum bengalense	*Cymbopogon parkeri* *C. martinii*	

Cymbopogon parkeri, *Cymbopogon martinii* and *Chrysopogon gryllus* form longitudinal belts over the hilly slopes. But certain grasses like *Cenchrus biflorus*, *Perotis indica*, *Perotis hordeiformis* and *Dactyloctenium aegyptium* grow in all the varied fashions, as narrated above.

ECOPHENES

The differential growth habit of several of the plants warrant to distinguish these into certain ecophenes. *Brachiaria ramosa*, *Cenchrus* spp., and *Dactyloctenium aegyptium* exhibit highly variable morphological characters from habitat to habitat. On the low outcrops of hills, *Brachiaria ramosa* and *Dactyloctenium aegyptium* are crustose and diminutive. *Cenchrus biflorus*, *Brachiaria ramosa* and *Dactyloctenium aegyptium* plants of low-lying areas show distinct characteristic features than those of hills and dunes. It is probable that there might be ecotypes.

INDICATORS

Their role as indicators of the nature of soil and the biotic influence is noteworthy. Certain exclusives to hills such as *Melanocenchris jacquemontii* and *Bulbostylis barbata* when found elsewhere indicate a very hard ground akin to hilly soil. Similarly wherever *Polypogon monspeliensis*, *Cyperus compressus*, *C. iria* occur in other than their characteristic habitats, are indicators of moist subsoil. *Saccharum bengalense* indicates thin vegetation and the prevalence of rodents, around it. *Cenchrus biflorus* is the indicator of the absence of intense biotic influence. *Brachiaria ramosa*, *Digitaria sanguinalis*, *Acrachne racemosa* and *Perotis indica* indicate severe grazing.

SAND BINDERS

Grasses by their tenacious fibrous roots hold the earth in its place either by their profuse tillering growth, viz. *Cenchrus ciliaris* and *Desmostachya bipinnata* or by extensive underground system as in *Cyperus rotundus*, *C. arenarius*, *Panicum antidotale* and *Cenchrus biflorus*. The most efficient sand binder in all respects is *Saccharum bengalense*.

RECLAMATION AND SELECTION OF GRASSES FOR STABILIZATION

Grasscover binds the soil against wind, accumulates moisture and increases soil fertility. Keeping the necessities of the livestock in mind, Satyanarayan (1958a) suggests a drought resistant, stoloniferous sand binder with a rapid growth and branching, for stabilization. We believe that moisture value, mortality rate and carrying capacity are also important in the selection of species. Moreover, mere stabilization of the sandy areas will not suffice the need as they comprise only a part of the desert. The hilly areas, which are mostly nude will have to be stabilized by suitable grasses and sedges before they completely disintegrate and add to our perennial problem. Keeping all these, in mind the following grasses are suggested for field trials.

Saccharum bengalense — A perennial, drought resistant sand binder with an enormous root system which survives even the combined onslaught of man and rodents, should be extensively cultivated and be given paramount importance.

Cenchrus ciliaris — Another sand binding perennial, if successfully grown on dunes, cannot be easily swept out. The involucels of this plant offer a very good dispersal mechanism. This plant is also noted for its pasture and moisture value.

Cymbopogon parkeri, *C. martinii* and *Chrysopogon gryllus* — Belts of these can be widely employed on denuded parts of the hills along with *Melanocenchris jacquemontii*, *Aristida mutabilis* and *A. adscensionis*.

Desmostachya bipinnata — Another important grass for loose sand areas.

Cyanodon dectylon and *Dactyloctenium sindicum* — These stoloniferous perennials have few parallels in their " vegetative reproductive capacity " and efficient dispersal mechanism. They are very good sand binders.

Cenchrus biflorus — This occurs in all the habitats through out all the seasons with efficient propagule mechanism, Moreover its spiny involucels are a sort of inhibitors to major biotic influences. That is why good fodder grasses, sand binders and others capable of extensive growth, if grown along with this plant, may have to endure only a little biotic retardation. Further, this only sand-dweller among the grasses of Rajasthan is the first invader of the embryonic dunes. Thus, this can be compared with Russia's *Aristida pennata* var. Karelini (Satyanarayan, 1958b) which was employed for stabilization due to its ability to be alive even when almost burried.

A fair field trial of the afore-mentioned grasses will certainly yield fruitful results in stabilizing the eroding habitats.

SUMMARY

The present paper deals with a study of grasses and sedges of certain areas of Jhunjhunu district, Rajasthan. Environment, in general, is described. Habitat preferences, communities, ecophenes, and sand binders among grasses and sedges are dealt with stress on their indicator value and utility to man and cattle. Keeping all the above in mind the role of certain grasses in stabilizing the barren areas is discussed and some of them are suggested for the purpose.

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ADDENDUM

Since the paper was presented at the symposium (1964) further information has been added by the authors.

The grasses and sedges of the areas of Jhunjhunu district, that form the locale of the present work, have been studied by Joshi & Sarma (1966) and Sarma & Joshi (1967a) respectively. Presence of 51 grasses — 22 of the sub-family Panicoideae and 29 of the Pooideae was recognized, Eragrosteae, belonging to the latter, occurring more frequently. Ten sedges have been reported. Preliminary morphological and ecological notes of grasses as well as sedges have been incorporated and their floristic data were compared with those of other investigated areas of the state.

Sarma (1965) studied the percentage seed germination and relative growth of root and shoot systems under different conditions of light and darkness for three species of *Cenchrus* and *Dactyloctenium.* It was found that continuous darkness enhances both seed germination and seedling growth. It was suggested that the seeds may first be germinated under continuous darkness and then transplanted to the field for better growth of the species. Sarma & Joshi (1967b) further, determined the seed outputs, reproductive capacities and mortality rates of various species of the genera *Cenchrus* and *Dactyloctenium* on different habitats like the dunes, the hillocks and the low lying areas. Attempts to correlate the data with the habitat factor have been made. Further work on grasses is in progress.

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DISCUSSION

C. P. Bhimaya: Is *Saccharum bengalensis* different from *S. munja* and *S. spontaneum* ? Has the generic name changed to *Erianthus* ?

M. C. Joshi: *S. bengalensis* is the present name of *S. munja.*

C. P. Bhimaya: Could you find *Sehima* spp on the hills ?

M. C. Joshi: The hills being low no *Sehima* could be found.

K. S. Sankhala: Kindly give us the method of propagation of *S. munja* for fixation of sand dunes ?

M. C. Joshi: The rootstock may be planted at a distance of one metre on bare dunes after a good soaking rain.

ECOLOGY OF GRASSLANDS OF WESTERN RAJASTHAN[1]

by

R. B. DAS & C. P. BHIMAYA[2]

IN arid or semi-arid regions, under the influence of man and his domestic animals, climate may in various degrees modify the trend of plant succession. The denudation which is frequent and extensive in these regions has, in some cases converted fertile tracts into deserts. The continued removal of the cover of trees and shrubs and the practice of uncontrolled grazing have caused this denudation. Some tracts already denuded of trees have under favourable climatic conditions tended to evolve permanent grassland covers of good value, which are called natural grasslands or rangelands, and which are sometimes interspersed with trees or more often with shrubs. These associations represent a sub-climax stage, which becomes stable under a complex of environmental factors favouring its existence and development. An evolution of this nature has taken place in Western Rajasthan, where in historical times there were forests inhabited by elephants and rhinoceros existed (Hora, 1952). Now, in places, in this region where human and animal activities are restricted, we find vast sandy or gravelly tracts with an excellent stand of good, palatable and nutritious grasses, on the other hand, in areas where biotic action has been intensive are to be found overgrazed and almost barren sandy or gravelly deserts.

In the recent past, there has been a general awakening among land and stock owners about the need for an improvement of the deteriorated pastures, in order to maintain a uniformly high level of production through management practices based on the accepted principles of pasture ecology.

The following may be listed as the most important:

1) The concept of plant succession as influenced by different classes of grazing and growing animals.
2) The application of "proper use" factor for key species in grasslands.
3) The concept of the relative potentialitis of individual species in a grassland community from the point of view of grazing capacity and utilization.

In this paper a correlation is made between the ecology of vegetation in relation to its management, utilization and development under the influence of grazing.

RANGE REGENERATION UNDER GRAZING

Clements (1916) was a pioneer in the establishment of the field of dynamic ecology as a unified science. Sampson (1917, 1919, 1952) stressed the importance of ecological principles in relation to range management. Dyksterhius (1949, 1951, 1958), Hanson (1957), Costello (1939), Parker (1952, 1954) and Renner (1948) further developed and applied the concept of range and pasture ecology in various vegetational and grazing studies. Trumble (1938, 1949) rightly emphasized the fact that, with the elucidation of the relation between pasture species and the soil and climate the influence of biotic factors assume increased importance.

Studying the influence of grazing on range vegetation from the aspect of pasture ecology, Weaver and Darland (1948), Weaver and Tomanek (1951), Tomanek (1948), Clark, Tisdale and Skoglund (1947), and Campbell (1931) have indicated trends in plant succession and forage production in different habitats.

Klipple and co-workers (1960, 1961), Paulsen and Ares (1961), Lange (1955), Rogler (1944) and Hopkin, Albertson and Reigel (1952) have recommended light grazing of deteriorated rangelands for its positive advantages in terms of better animal performance and progressive increases in forage production, and at the same time for its economic importance when compared with even moderate and heavy stocking of the ranges.

Studies on regeneration of range under the influence of grazing were conducted by the Central Arid Zone Research Institute at it's farm Pali on an area of 2·43 hectares of natural grassland, where mature wethers of the Marwari breed were allowed to graze from 1957 to 1961. They were grazed for 16,227 sheep days, on a yearlong basis, giving a grazing capacity of 6·17 wether per hectare. Table 1 illustrates the effect of grazing on the botanical composition.

In the initial stage, annuals constituted 71·02 per cent the dominant species, *Aristida funiculata* and *A. adscensionis*, together contributing 54·8 per cent. After 3 years of grazing, the percentage of perennial grasses, *Eleusine compressa*, *Cenchrus ciliaris*, *C. setigerus* and *Eremopogon foveolatus*,

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Assistant Agrostologist and Head of the Division at this Institute.

TABLE 1: Effect of grazing on botanical composition (1957-1960)

Species	*Percentage composition*		*Percentage differences*
	Before grazing 1957	*After grazing* 1960	
Aristida spp.	54·8	49·5	−5·3
Eleusine compressa	19·3	27·2	7·9
Melanocenchris jucquemontii	9·7	0·8	−8·9
Eremopogon foveolatus	3·9	3·2	−0·7
Cenchrus spp.	5·6	11·1	5·5
Schoenfeldia gracilis	2·4	—	−2·4
Brachiaria ramosa	2·1	—	−2·1
Tetrapogon tenellus	0·9	—	−0·9
Oropetium thomaeum	0·5	8·1	7·6
Dactyloctenium sindicum	0·2	—	−0·2
Sehima ischaemoides	0·2	—	−0·2
Heteropogon contortus	0·2	—	−0·2
Sporobolus spp.	0·2	—	−0·2
Total	100·0	100·0	—

TABLE 2: Effect of grazing plant cover from 1957-60

Species	*Percentage plant cover*		*Percentage variation under grazing*
	Before grazing 1957	*After grazing* 1960	
Aristida spp.	2·81	4·71	1·96
Eleusine compressa	2·09	9·07	6·98
Cenchrus spp.	1·04	0·60	−0·44
Eremopogon foveolatus	0·01	3·15	3·14
Oropetium thomaeum	0·01	0·77	0·76
Melanocenchris jacquemontii	0·30	0·12	−0·18
Non-grasses	2·86	9·00	6·14
Others	0·97	—	0·97
Total	10·25	28·27	18·02

increased by 12·7 per cent. Individual *Eleusine compressa* increased by 7·9 per cent while *Cenchrus* spp. recorded an increase of 5·5 per cent. It is thus clear that under the light intensity of grazing practised during the experimental period, the grassland was maintained at a higher level of botanical composition and showed positive trends of regeneration as compared with the initial stage.

Plant density cover increased under the influence of sheep grazing from 10·25 to 28·27 per cent during the same period. The contributions of the individual species are presented in Table 2. The increase in percentage plant cover by 18·02 per cent over the initial shows that, under the grazing regime followed, the grassland maintained an upward trend in succession.

Similar studies were made by the Institute from 1960 to 1963 on rocky ranges near Jodhpur, using one-year-old heifers as the experimental animals at Kailana (12 km from Jodhpur) and breeding ewes of the Marwari breed at Beriganga. Data were recorded on changes of vegetation floristic composition and plant cover (Tables 3 and 4).

Where heifers were allowed to graze only after seed fall, the plant cover increased from 16·6 to 23·78 per cent. The perennial grass cover increased from 8·7 to 14·82 per cent in 3 years. It is also evident that forage production tended to increase in quality as well as quantity under controlled utilization. The increase of about 72 per cent in forage production is substantial in spite of the fact that there was less rainfall during 1962-63 than in 1960-61.

Investigations at Beriganga, 15 kilometres from Jodhpur, have shown similar trends in variations of plant cover, but a reduction in forage yield

TABLE 3: Effect of grazing on variations in percentage plant cover and forage yield between 1960 and 1963 at Kailana

Composition	*Percentage plant cover*		*Forage yield*		*Variation*	
	Before grazing 1960	*After grazing* 1963	*Before grazing kg/ha*	*After grazing kg/ha*	*% of plant cover*	*Yield kg/ha*
I. *Edible species:*						
A. Grasses						
i. Perennial species	8·7	14·82	362·5	659·8	6·12	297·3
ii. Annual species	4·8	7·42	28·3	29·8	2·62	1·5
B. Non-grasses & Forbs	1·5	1·2	Traces	1·8	−0·29	1·8
II. *Non-edible species*	1·6	0·33	9·7	3·1	−1·27	−6·6
Total	16·6	23·78	400·5	694·5	7·18	294·0

TABLE 4: Effect of grazing on variations in percentage plant cover and forage yield between 1960 and 1963 at Beriganga

Composition	*Compartment No. 2*						*Compartment No. 3*					
	Percentage plant cover			*Forage yield kg/ha*			*Percentage plant cover*			*Forage production kg/ha*		
	Before grazing 1960	*After grazing* 1963	*Variations*	*Before grazing* 1960	*After grazing* 1963	*Variations*	*Before grazing* 1960	*After grazing* 1963	*Variations*	*Before grazing* 1960	*After grazing* 1963	*Variations*
I. *Edible species*												
A. Grasses												
i. Perennial species	9·31	16·60	7·29	543·74	382·03	−161·71	9·99	13·90	3·91	344·6	234·96	−109·64
ii. Annual species	8·21	6·16	−2·05	11·71	104·30	92·59	8·64	8·1	−0·54	65·98	76·12	10·14
B. Non-grassland forbs	Trace	0·11	0·11	32·36	7·01	−25·35	0·22	0·40	0·18	23·88	29·20	6·70
II. *Non-edible species*	0·22	0·77	0·55	49·99	47·82	−1·17	0·66	0·80	0·14	78·54	37·83	−40·71
Total	17·74	23·64	6·90	637·80	541·16	−95·64	19·51	23·20	3·69	513·00	378·11	−134·89

under sheep grazing. Here the sheep flock grazed also after seed had been shed during each year from 1960 to 1963. The total sheep grazing days were 53,741 and 86,083 in compartments No. 2 and No. 3 respectively. The data recorded before and after grazing in terms of plant cover and forage yield are given in Table 4. The percentage plant cover of perennial grass species increased in both compartments No. 2 and 3 by 7·29 and 3·91 per cent respectively under sheep grazing. The total increase in percentage plant cover was 6·90 and 3·69 respectively when stated in the same order. Forage production fell by 95·64 and 134·89 kg per hectare in compartments No. 2 and 3 respectively, possibly because sheep graze close to the ground, and because perennial species such as the low growing. *Eleusine compressa* was grazed short and was slow in recovery. Fluctuations in forage production show the need for constant adjustment in grazing capacity of arid zone ranges in order to enable correct regeneration of the vegetation.

PROPER USE FACTOR

For correct grassland management in the arid zone, grasslands have to be maintained at their highest level of production from both the qualitative and quantitative point of view, particularly by regulating the degree of utilization of the key species to the desired extent. For developing such standards of utilization for the key species in a range or pasture land, there is a need to have quick, easy and accurate indices or guides so that under proper use the two major objectives may be achieved. Springfield (1961) used the grazed plant method for judging the utilization of crested wheat grass pastures, as suggested by Stoddart (1935) and further applied by Hurd and Kissinger (1953) and Roach (1950). Pechanec (1936) found this method insufficiently accurate when applied to the measurement of utilization of *Agropyron dasystachyum* grassland. Pechanec and Pickford (1937), Pickford and Reid (1942) and, Reid and Pickford (1941) advocated the ocular-estimate-by-plot-method using a 9·6 sq. foot circular plot.

In order to develop the concept of the "proper use factor" for the range vegetation of Western Rajasthan, studies were made on height-weight relations of the key species, using the Lommasen and Jensen (1938, 1942, 1943) technique which was also accepted by Campbell (1943) for arid and semi-arid ranges. These studies were concerned with the species, *Lasiurus sindicus*, *Cenchrus ciliaris*, *C. setigerus*, *Panicum antidotale* and *Dichanthium annulatum*.

Regression studies were made on the data obtained regarding percentage height clipped (x) and percentage weight removed (Y) and by fitting the orthogonal polynomial (Fisher, 1950). Thus the quadratic curves of the form represented by the equation $Y = A+B + Cx^2$ were fitted separately for each of the grass species. The values of the fitted curves are

(a) *Lasiurus sindicus* $Y=0{\cdot}136-0{\cdot}005x+0{\cdot}241X^2$
(b) *Cenchrus ciliaris* $Y=2{\cdot}610-2{\cdot}137X+0{\cdot}329X^2$
(c) *C. setigerus* $Y=2{\cdot}069-1{\cdot}695X+0{\cdot}327X^2$
(d) *Dichanthium annulatum* $Y=1{\cdot}097-1{\cdot}186x+0{\cdot}312X^2$
(c) *Panicum antidotale* $Y=2{\cdot}437-1{\cdot}728x+0{\cdot}311X^2$

It will be observed that in all the species the weight is not evenly distributed throughout the height of the plant. For example, when only 20 per cent forage is grazed, then 45, 58, 54, 61 and 53 per cent of the height is removed from *Lasiurus sindicus*, *Cenchrus ciliaris*, *Panicum antidotale*, *Dichanthium annulatum*, and *Cenchrus setigerus* respectively. Again, stating in the same order, 40 per cent utilization is achieved when 63, 73, 71, 75 and 85 per cent height is grazed or clipped. Thus these studies help in achieving correct grassland utilization.

RELATIVE COMPATIBILITY OF SPECIES

In arid or semi-arid regions it is important that land considered marginal or sub-marginal for crop production should be put under grass, from both the economic and resources point of view. This significant step would greatly reduce the hazards of erosion and the further spread of desert like conditions.

The ecology of reseeded dry land pastures has been studied by Launchbaugh (1958), Rogler (1944), Wegner (1943), Hurd (1948), McTaggart (1935, 1937) and Williams and Post (1941). These investigations covered aspects such as comparative yields, adaptability, performance of various species different climatic and edaphic habitats, and their reactions to grazing.

Thus, a knowledge of the ecological behaviour of the key species in an arid grassland community is very important. The relative performances of each of the individual species with respect to growth, forage yield, grazing capacity and persistency are indications of its adaptability to specific under conditions of soil and climate. The potentialities of *Lasiurus sindicus*, *Cenchrus ciliaris*, *C. setigerus*, *Panicum antidotale*, and *Dichanthium annulatum* have been studied at the Central Research Farm, Jodhpur, and at the Research Farm, Pali, representing two contrasting habitats.

At each place, 0·404 hectares of dryland seeded pastures of each of the above species (first four named at C.R. Farm and last four named at Pali) were subjected to grazing by initially comparable sheep (wethers) flock of five animals each over a period of 3 years. Observations were recorded on forage yield, grazing capacity and reaction to grazing (Table 5). With a change of soil and climate, the ecological behaviour of the each species varies significantly. At Pali, where the soil is sandy loam and has a slightly better moisture regime, *Cenchrus ciliaris*, *C. setigerus* and *Panicum antidotale* gave increased yields and hence higher grazing capacities as compared to their performance on sandy soils at the Central Research Farm, Jodhpur. In *Cenchrus setigerus*, the grazing capacity at Pali is more than double that at the C.R. Farm.

APPRAISAL OF PROBLEMS OF PASTURE ECOLOGY

In the arid and semi-arid conditions of Western Rajasthan, the livestock factor, although an essential part of the environmental complex in grassland ecology, has not yet been the subject of much critical investigation. With recent advances in knowledge of the relations between grassland species and their soil climate environment, and with the evolution of persistent, stable and productive species for seed mixtures, investigations on the influence of relevant factors would give results of great significance for the efficient management of pastures. Further studies are needed on the ecological interrelations of species in a grassland community, so as to show how each species function and how they react to stresses and influences of various factors of the habitat. Investigations are required on the adaptability of different species and strains to the conditions existing on overgrazed and otherwise mismanaged lands in these arid zones.

TABLE 5: Comparative data of performance of grass species at C.R. Farm, Jodhpur and Pali. (Average of 3 years grazing)

Species	*At C.R. Farm, Jodhpur*			*At Pali*			*Variations*		
	Av. No. of sheep days	*Av. forage production kg/ha*	*Av. grazing capacity*	*Av. No. of sheep days*	*Av. forage production kg/ha*	*Av. grazing capacity*	*No. of sheep days*	*Forage production kg/ha*	*Grazing capacity per ha*
Cenchrus ciliaris	661	629·2	4·46	1115	1496·6	7·53	454	867·4	3·07
Cenchrus setigerus	321	353·6	2·53	889	1137·4	6·04	568	783·8	3·51
Panicum antidotale	606	880·2	4·06	737	1621	4·90	131	840·8	0·84
Lasiurus sindicus	1049	1276·8	6·92	—	—	—	—	—	—
Dichanthium annulatum	—	—	—	1022	1331·3	6·86	—	—	—

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DISCUSSION

J. P. Hrabovszky: What adjustments are made in the number of animals from season to season to suit variation in the rainfall and resulting feed production ?

C. S. Christian: The variation in nutrient supply to the animals does not vary as greatly as amount of dry matter. Most of the nutrients are taken up in the early stages of growth. So even in a year of moderate rainfall the value of the pasture is not much less than in a year of high rainfall. In years of very high rainfall the total yield may be high but the quality of feed may be lower. Hence there is less variability in annual grazing capacity than there is in rainfall, although years of very low rainfall of course do reduce the carrying capacity.

T. N. Srivastava: What type of controlled grazing was introduced ? Was an optimum area per animal fixed or the grazing was closed during part of the year ?

R. B. Das: The controlled grazing was in accordance with the grazing capacity of the pasture where 60 per cent utilization was aimed at. As soon as this level of utilization was attained the grazing was stopped. The grazing capacity was fixed according to the total forage available and the rate of daily consumption by the animals on the range.

ANIMAL GRAZING, MANAGEMENT AND ADAPTATION

NUTRITIVE VALUE OF *ANJAN* (*CENCHRUS CILIARIS* LINN) GRASS HAY FROM GRAZING AREAS OF RAJASTHAN FORESTS[1]

by

V. MAHADEVAN, P. S. GUPTA AND M. M. JAYAL

ANJAN is a perennial grass. It grows in plains and low hills throughout western India from Kashmir to the upper Gangetic plain and is fairly common in south India and Rajasthan. Once established, it is not killed by drought. This is the famous *Kolakattai* grass of Coimbatore district (Achariar, 1921). Other scientific names of this grass are *Pennisetum cenchroides*, *C. digynus*, Schrele and *C. anjania*, Ham (Hooker, 1897). It is an excellent fodder grass in young stage for both cattle and sheep. The nutritive values of *Anjan* hay from the Punjab, Uttar Pradesh and Madras (Sen, 1946) indicate wide differences in its chemical composition and nutritional quality. Since such scientific data in respect of *Anjan* grass from semi-arid grazing areas of Rajasthan forests, where the grass grows naturally in abundance, were not available, it was considered desirable to conduct feeding trials on *Anjan* grass, cut and dried into hay at the flowering and post-seeding stages.

EXPERIMENTAL

Two samples of *Anjan* hay, one at the flowering stage and the other at the post-seeding stage, collected from the same grazing area of Rajasthan forests were received through the courtesy of Chief Conservator of Forests, Rajasthan.

For conducting feeding experiments eight adult *Kumaoni* bullocks were divided into two comparable groups in respect of age and live weight, etc. The flowering stage hay was fed to one group and the post-seeding stage hay to the other group. Both the samples were fed *ad libitum* and formed the only source of nutrient intake of the test animals. A free choice of water twice at 11·00 A.M. and 4·00 P.M. and one *oz* of common salt daily were given to each animal. The feeding regime covered 32 days of which the last 10 days constituted the metabolic period when excreta at twenty-four hourly periods were collected. The left-overs of each animal during the metabolic period were collected and analysed.

The methods of analysis by A.O.A.C. were generally followed. The minerals, calcium and phosphorus were estimated according to the modified methods of Talpatra, Ray and Sen, (1940).

RESULTS AND DISCUSSION

Chemical composition — The chemical composition of the two samples of *Anjan* hay, on dry basis, is set out in Table 1 and compared with those from the Punjab, Uttar Pradesh and Madras (Sen 1946).

1. Contribution from the Division of Animal Nutrition, Indian Veterinary Research Institute, Izatnagar.

TABLE 1: Percentage composition of *Anjan* hay at various stages of growth

Feeding stuff	*Crude protein*	*Ether ext.*	*Crude fibre*	*Nitrogen-free extract*	*Ash*	*Calcium (Ca)*	*Phosphorus (P)*
Anjan hay							
(i) Flowering stage (Rajasthan)	5·520	0·822	35·590	40·412	17·656	0·428	0·210
(ii) Post-seeding stage (Rajasthan)	4·590	0·777	38·430	42·382	13·821	0·344	0·160
Anjan hay (Punjab)	5·730	1·500	36·690	44·250	11·910	0·140	0·140
Anjan hay (Uttar-Pradesh)	4·870	1·420	32·910	51·210	10·180	0·310	0·180
Anjan hay (Madras)							
(i) Young	16·890	1·140	28·490	40·780	12·700	—	—
(ii) Prime	10·010	1·160	35·330	42·600	10·900	—	—
(iii) Ripe	6·380	0·680	33·300	49·710	9·930	—	—

TABLE 2: Dry feed consumption of the experimental bullocks under the two feeding trials. Dry matter consumption per day

Stage of Anjan *hay*	*Animal No.*	*Body weight on dates* 22-3-1959 (*kg*)	11-4-1959 (*kg*)	22-4-1959 (*kg*)	*Average body wt during the metabolic period* (*kg*)	*Feed consumption per day* (*gm*)	*Consumption of hay in kg per 100 kg body wt per day* (*kg*)
Flowering stage	182	192	187	185	186	2860·68	1·54
	75	192	187	185	186	3191·40	1·72
	37	227	225	223	224	3377·08	1·51
	28	218	218	211	212	3135·97	1·48
	Average	207·25	203	201	202	3141·28	1·56
Post-seeding stage hay	70	194	191	189	190	2781·37	1·46
	35	192	185	183	184	2971·93	1·61
	33	226	221	219	220	3173·54	1·44
	176	216	211	209	210	3142·24	1·50
	Average	207·00	202	200	201	3017·27	1·50

The data expressed in Table 1 show that not only the two samples of *Anjan* hay from Rajasthan forests but those from U.P. and the Punjab also are poorer in crude protein than those from Madras. The hay in ripe stage appears to be low in crude protein irrespective of the place where it grows.

From Table 2 it will be seen that the experimental animals consumed an average of 1·5 kg hay of the flowering stage and 1·50 kg hay of the post-seeding stage on dry basis per 100 kg body weight per day. For a palatable roughage the figures of consumption are somewhat low for both the samples of *Anjan* hay.

Digestibility and nutritive value: The digestibility coefficients of *Anjan* hay at the flowering and post-seeding stages of growth are shown in Table 3.

TABLE 3: Digestibility coefficients

Stage	*Animal No.*	*Crude protein*	*Ether ext.*	*Crude fibre*	*Nitrogen-free extract*
Flowering stage	182	27·88	44·85	58·25	48·33
	75	27·76	33·71	55·20	51·78
	37	28·57	35·48	55·68	51·85
	28	29·76	39·98	55·98	58·08
Average		28·49	38·99	56·28	50·99
Post-seeding stage	70	21·05	35·72	52·03	48·17
	35	22·35	31·49	49·41	35·64
	33	21·71	40·11	57·95	56·41
Average		22·41	35·59	52·29	45·83

The digestibility coefficients for all the organic constituents were found to be higher in the hay at the flowering stage than those recorded for the hay at the post-seeding stage. The digestibility coefficients, especially of crude protein and ether extract, are of a low order for both the samples of *Anjan* hay, whereas those of crude fibre and nitrogen-free extract may be considered satisfactory.

The percentage digestible crude protein and total digestible nutrients of the two samples of *Anjan* hay from Rajasthan are expressed in Table 4 and compared with the values of *Anjan* hay from U.P., Punjab and Madras (Sen, loc. cit.).

TABLE 4: Percentage digestible crude protein, ether extract and carbohydrates

Feeding stuff	*Digestible nutrients in kg per 100 kg of dry material* *Crude protein*	*Ether ext.*	*Carbohydrates*	*Total*	*Nutritive ratio*
Anjan hay from Rajasthan:					
(i) Flowering stage	1·57	0·32	40·64	42·93	1 : 26·34
(ii) Post-seeding stage	1·03	0·28	39·52	41·18	1 : 38·98
Anjan hay (Meerut, U.P.)	1·71	0·25	49·41	51·68	1 : 29·30
Anjan hay (Punjab)	2·01	0·43	47·54	50·51	1 : 24·20
Anjan hay (Hosur, Madras):					
(i) Young stage	11·17	0·32	47·56	59·44	1 : 4·30
(ii) Prime stage	5·49	0·48	49·56	56·13	1 : 9·20
(iii) Ripe stage	2·97	0·16	49·46	52·78	1 : 16·80

The data given in Table 4 indicate that the values of digestible crude protein and total digestible nutrients in the flowering and post-seeding stage of *Anjan* hay from Rajasthan are lower than those of *Anjan* hays from the other parts of this country. The nutritive ratio in the test samples of *Anjan* hay is fairly wide which shows that the proportion of digestible protein to that of non-nitrogenous nutrients is low. Such feeds, therefore, are unsuitable for growing animals where the object is to produce best rate of gain of live weight. In general, rations having a narrower nutritive ratio than 1: 5 are considered suitable to ensure optimum growth rate in the calves. The hays in the flowering and post-seeding stages from Rajasthan are rather poor in digestible protein as neither of them could maintain the adult *Kumaoni* bullocks in nitrogen equilibrium. Instead the experimental bullocks recorded negative balances for nitrogen (Table 5) and loss in body weight (Table 2).

The nitrogen, calcium and phosphorus balances displayed by the experimental bullocks fed *Anjan* hay from Rajasthan in the flowering and post-seeding stages are given in Table 5.

The experimental animals in both the feeding trials remained in negative nitrogen balance al-

TABLE 5: Nitrogen, Calcium and Phosphorus balances in gm per day

Stage	*Bullock No.*	*Offered in hay*	*Left in residue*	*Consumed from hay*	*Excretion*			*Balance*
					Faeces	*Urine*	*Total*	
				Nitrogen Balance				
Flowering stage	182	34·38	4·41	29·97	20·80	10·00	30·80	−0·83
	75	34·38	2·80	31·58	22·00	10·48	32·48	−0·90
	37	34·38	1·89	32·49	22·40	11·04	33·44	−0·95
	28	34·38	8·07	31·31	21·00	10·72	31·92	−0·61
	Average	34·38	0·84	31·34	21·60	10·56	32·16	−0·82
Post-seeding stage	70	27·21	3·79	28·42	18·50	8·80	27·30	−3·88
	85	27·31	3·01	24·20	18·50	9·82	28·12	−3·92
	33	27·21	2·18	25·03	19·60	9·64	29·24	−4·21
	176	27·21	2·31	24·90	18·80	10·12	28·92	−4·02
	Average	27·21	2·82	24·39	18·93	9·47	28·40	−4·01
				Calcium Balance				
Flowering stage	182	16·12	3·00	13·12	11·19	0·73	11·92	+1·20
	75	16·12	1·91	14·21	12·50	0·73	13·23	+0·98
	37	16·12	1·29	14·83	13·04	0·84	13·88	+0·95
	28	16·12	2·09	14·03	12·51	0·57	13·08	+0·95
	Average	16·12	2·07	14·05	12·31	0·72	13·03	+0·02
Post-seeding stage	70	12·75	2·54	10·21	12·78	1·25	14·03	−8·82
	35	12·75	2·01	10·74	13·46	1·07	14·53	−3·79
	83	12·75	1·46	11·29	12·40	1·71	14·11	−2·82
	176	12·75	1·55	11·20	12·40	1·78	14·18	−2·98
	Average	12·75	1·89	10·86	12·76	1·45	14·21	−3·85
				Phosphorus Balance				
Flowering stage	182	7·91	1·54	6·37	4·92	0·03	4·95	+1·42
	75	7·91	0·98	6·93	5·13	0·01	5·14	+1·79
	37	7·91	0·66	7·25	5·45	0·03	5·48	+1·77
	28	7·91	1·07	6·84	5·38	0·04	5·42	+1·42
	Average	7·91	1·06	6·85	5·22	0·03	5·25	+1·60
Post-seeding stage	70	5·93	1·02	4·91	4·00	0·02	4·02	+0·89
	35	5·93	0·81	5·12	4·62	0·04	4·66	+0·46
	33	5·93	0·59	5·34	4·07	0·05	4·12	+1·22
	176	5·93	0·62	5·31	4·39	0·04	4·48	+0·88
	Average	5·93	0·76	5·17	4·27	0·04	4·31	+0·86

though it was more marked in the case of animals fed *Anjan* hay of the post-seeding stage. The calcium balances were negative for animals fed the post-seeding stage hay and positive for those fed the flowering stage hay. The phosphorus balances were positive on both the feeding trials.

It may be concluded from the above observations that *Anjan* hay from Rajasthan forests in the flowering and post-seeding stages cannot meet the maintenance requirements of cattle grazing on them without supplements of protein-rich concentrates. In order to utilize the grass profitably, so that it supplies higher nutrients to grazing animals, it must be harvested or grazed at much earlier stages than those of the two samples reported here.

Academecian Andre Voison states as third law in his recent book '*Rational Rotational Grazing*'. " The animals with the greatest nutritional requirements must be helped to harvest the greatest quantity of the grass of the best possible quality ". As corollary 1 of the 3rd law, he states, " Grass with an average height of 6 inches (15 cm) in the case of permanent pastures (and of at least 9 inches in temporary grazings) allows the cow to harvest maximnm quantity of high quality grass."

A 500 kg cow put out to permanent pasture, where the grass was 15 cm high, harvested per day; (a) 48 kg of grass, if she was forced to graze the sward absolutely bare and yield of milk was 11 litres per day; (b) 56 kg of grass, if she had only to harvest half the grass present and yield of milk was 15 litres per day, and (c) 64 kg of grass, if she was obliged to harvest only a third of the grass present and the yield of milk was 18 litres per day.

The same would be true of gains in live weight or progress in development. The above illustrates how the production is affected by the quality of nutrients grazed by the animal which in turn depends upon the growth of grass and the manner of grazing.

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DISCUSSION

S. P. Raychaudhuri : How does the composition of " *Anjan* grass " vary in respect of calcium and phosphous for the dry climates of low rainfall region to wet climates of high rainfall region ?

V. Mahadevan : In high rainfall region in the south calcium and phosphorus content of the grass is lower to the extent of about 50 per cent. The Ca content also depends on the calcium content of the soil.

T. N. Srivastava : If grazing or grass cutting is allowed before flowering, as has been suggested for Rajasthan, will it not result in reduction of yield in future ?

V. Mahadevan : No. Proper control of cutting at frequent intervals, say, 4 weeks, after the first cut at 8 weeks' growth, in Rajasthan forest has shown to yield more quantity, about 50 per cent more, than cutting at 11 weeks' and 15 weeks' intervals.

R. B. Das : Five promising desert grasses cut at the interval of 30 days at 10-15 cm height would yield the highest quantity of forage.

H. Nath : Was any study made on the biological value of the proteins of the grass made either for maintenance or for growth ? Was any study conducted to find out the low digestibility of the protein ? What are the methods for finding out the supplementary values of other grasses ?

V. Mahadevan : The apparent digestibility coefficient of protein gives indirectly a measure of its biological value for maintenance and growth according to the physiological status of the animals used in the experiment. In the case of ruminants the microbial population uses the vegetable protein and turn it into high biological value bacterial protein in the rumen to be used by the host animal. The B.V. of all proteins reach a constant value of about 55-60 per cent in cattle or sheep. It is not necessary to study the improvement of protein by supplementing with amino acid in adult ruminants because of the ability of the rumen organisms to synthesize all amino acids. The low digestibility of protein is due to higher fibre and lignin content of the fodder. The associative effect of one grass on others is present but not studied in detail.

LIVESTOCK MANAGEMENT OF RANGELANDS IN WESTERN RAJASTHAN[1]

by

L. D. AHUJA[2]

INTRODUCTION

THE livestock of westen Rajasthan is reputed for the inherent high production capacity and hardiness. Cows of Tharparkar, Rathi, Gir and Kankrej breeds possess high milk production capacity varying from 1500 to 2500 litres per year, and bullocks of Nagauri, Hariana and Kankrej are reputed for excellent draft capacity. Carpet wool of Bikaneri breed of sheep helps in earning a large amount of foreign exchange for the country. However, the native rangelands, the major source of livestock feed supplies, have very much deteriorated due to overgrazing and improper management. The economy of the dry zone, where rainfall is scanty and erratic, is highly interlinked with the raising of cattle, sheep and goats and the improvement of these rangelands should receive high priority.

Sampson (1951), Stoddart and Smith (1955), Cook and Haris (1950), Cook and Stoddart (1961) and Anonymous (1957) have reviewed the literature concerning range management and range production in the U.S.A. and elsewhere. Grassland types of western Rajasthan have been classified by Dabadghao (1960) as *Lasiurus* (*Elynous*) — *Cenchrus-Dichanthium* type and these have further been categorized by Raheja (1963) in different pasture types. Patel (1961-1963) believes that grasses from ranges in Rajasthan are richer in nutritive components than those of Saurashtra. Ray (1958) and Mahadevan (1959, 60, 61) conclude that the high forage-producing grasses of Rajasthan contain fairly high crude protein content.

Stocking rate on a rangeland is dependent upon its production, floristic composition and intake of different forage species by different kinds and classes of farm animals. Requirements of ration by farm animals under stall feeding conditions have been reported by Morrison (1957), Maynard and Looslie; Lander (1949) and Sen (1952). The requirements of feeds and nutrients of the animals on the range are much more than under stall feeding conditions, due to larger variety of grasses, legumes, forbes, etc., Guilbert *et al* (1940) Morrison (1957) Watkins (1937) Stoddart & Smith (1955) Sampson (1951) Woodman *et al* (1937). Donahue *et al* (1956) have suggested stocking rate for ranges in the U.S.A. under different rainfall conditions. Das *et al* (1963) have suggested the stocking rate for a rocky range of western Rajasthan.

Wheeler (1962) reviewed the work of grazing management under continuous, rotational and strip grazing systems. Grazing studies for a short term period have been reported by Cook *et al* (1961), Stoddart and Smith (1955), Dabadghao *et al* (1962-1963) and Das *et al* (1963).

Negi and Mullick (1960), Morrison (1957), Kaura (1950), Tablot (1926), Thompson (1949), Stanley (1938), Ignam (1930) and Hutchings (1946), have reported drinking water needs of various farm animals; but the water needs of animals on the range have not been reported. With a view to determine body weight of cattle for computing rations and planning feed storage, different regression equations and formulae suiting different breeds have been reported by Johnson (1944), Wanderstock and Salisbury (1946), Ragsdale and Brody (1935), Davies *et al* (1938), Thornton (1960), Ross (1958) and Mullick (1950). Mahadevan (1961) has suggested that a separate regression question for estimation of live weight of cattle in western Rajasthan may be evolved.

EXPERIMENTAL

A project on range management as applicable on field scale was conducted in 44 peddocks each of 60-80 hectares distributed over 10 districts of western Rajasthan. The different treatments are given below:

Main Treatments:

a. Rainfall conditions i) High (over 375 mm per year)
ii) Low (under 375 mm per year)

b. Soil types i) Light soils
ii) Heavy soils

c. Condition classes of rangelands
For cattle: i) Poor
ii) Fair
iii) Good
For sheep: i) Poor
ii) Fair

The range condition classification is based upon the botanical composition of the grassland.

1. Contribution from the Resource Utilization Studies Division, Central Arid Zone Research Institute, Jodhpur.
2. Livestock Officer.

Sub-treatments: Each of the range management paddocks is divided into six equal parts for studies of the following pastoral treatments:

PT_1—Continuous grazing at controlled rate from 1st July throughout the year.

PT_2—Closed to grazing throughout the year with different experiments on reseeding and fertilization.

PT_3—Deferred to grazing from 1st July for 8 weeks preceeded and followed by grazing at controlled rate.

PT_4—Deferred to grazing 1st July for 16 weeks, preceeded and followed by grazing at controlled rate.

PT_5—Deferred to grazing from 26th August for 8 weeks, preceeded and followed by grazing at controlled rate.

PT_6—Deferred to grazing from 26th August for 16 weeks, preceeded and followed by grazing at controlled rate.

Number of replications: There were four replications for 'Poor' and two each for 'Fair' and 'Good' condition classes of ranges for cattle, and two replications each for 'Fair' and 'Poor' rangelands for sheep as experimental animals except the treatment of animals for "heavy soils" under "low rainfall".

The observations recorded consisted of the following:

1. *Performance of farm animals under different pastoral treatments on various range conditions classes*: Adult cows and sheep formed the experimental animals during 1961-62, and in 1962-63, young growing stock, i.e. heifers of 12-15 months in age and ram lambs 9-12 months old, served as experimental animals. The body weights of animals were recorded at biweekly intervals. In the case of cows it was determined by regression equation evolved by Mullick (1950) and for the growing stock by the formula evolved by Ahuja (1962). Sheep were weighed with a spring balance. Following stocking rate was followed:

TABLE 1: Stocking rate of farm animals on different range condition class. Adult cow weight-272 kg; heifer weight-96 kg; sheep-20-30 kg

Condition class of rangeland	*No. of hectares per animal*		
	Cattle		*Sheep*
	Adult	*Young stock*	
Good	4·86	2·4	0·81
Fair	8·09	4·1	1·33
Poor	12·14	6·1	2·00

Same animals continued to graze under each pastoral treatment for the entire working year (1st July to 30th June). New sets of animals were taken for study each year. The stocking rate was fixed on the basis of botanical composition, forage yield of rangelands and allowing for the two factors of trampling and maintenance of ground cover to overcome erosion. Looking to the needs of livestock of this part of the country and the area suggested by Morrison (1957) and Donahue (1956) of 2-16 hectares per mature sheep, 24-81 hectares for adult animal in rainfall of under 127 mm and 1·2-4·8 hectares in ranges with rainfall of 672 mm per adult beast, the one followed in the experiments is reasonable.

The sheep were sheated twice a year, i.e. once during February-March and the second time during September-October.

2. *Observations on intake of water by animals recorded at biweekly intervals by offering water three times a day, i.e. morning, noon and evening*: In order to evolve regression equations to determine body weight of cattle from heart girth measurements observations on body weight of each of the animals under study were recorded from October 1961 to June 1962 at monthly intervals, and the data were analysed by the technique of analysis of covariance.

For the purpose of the present study, the year was divided into six seasons, viz. early monsoon (1 July to 26 August); late monsoon (27 August to 21 October); autumn (22 October to 2 December); winter (3 December to 10 February); spring (11 February to 24 March), and summer (25 March to 30 June).

RESULTS AND DISCUSSIONS

(a) *Cattle*: The data of changes in body weight of cattle are summarized in Table 2.

In adult cows, the maximum gains in body weight have been recorded under "continuous controlled grazing system" on a yearlong basis in all types of rangelands. The body weight gains on an average in 'Good', 'Fair' and 'Poor' ranges were 56·7, 35·5 and 25·8 kg per cow respectively. Due to unexpected heavy rains during the last week of June 1961, resulting in unsettled condition of stock owners, animals were introduced in 'Good' ranch 4 weeks later than 1st July. Hence gains in body weight on 'Good' category of range were below expectation.

There are substantial increases in body weight of cattle during 'early monsoon' and less in 'late monsoon' period. This is chiefly due to high nutritive value and high digestibility of forage during this period. Christensen *et al* (1932), Cook and Haris (1950), Cook and Stoddart (1961) have reported very high nutritive value of grasses during early stages of growth. The nutritive value declined with the increase in maturity of the plant. Patel (1961) reported that the protein content of grasses in Rajasthan during flowering stage was

TABLE 2: Progressive gains in body weights (in kg) of cows in different range condition class areas under various seasons 1961-1962

Particulars of grazing treatments	Good							Fair							Poor						
	A	*B*	*C*	*D*	*E*	*F*	*Total*	*A*	*B*	*C*	*D*	*E*	*F*	*Total*	*A*	*B*	*C*	*D*	*E*	*F*	*Total*
No. of areas studied							1							16							15
I PT_1	7·7	19·5	14·1	5·4	0·0	10·0	56·7	20·4	14·1	5·0	4·5	0·9	−9·5	35·5	12·7	11·3	4·1	−4·1	2·7	−0·9	25·8
III PT_3	—	15·9	25·9	5·4	1·8	−1·8	47·2	—	13·2	4·1	4·5	0·9	−5·9	16·8	—	10·4	6·8	−0·5	4·1	1·8	22·6
IV PT_4	—	—	10·9	11·4	−5·4	1·8	19·1	—	—	3·6	3·6	−1·8	−4·5	0·9	—	—	5·9	3·2	−0·5	7·3	15·9
V PT_5	—	—	11·8	−5·9	2·3	−8·2	0·0	21·8	—	5·4	7·3	1·4	−6·4	29·5	15·4	—	2·3	4·9	4·1	−0·9	25·8
VI PT_6	1·8	—	—	13·6	−5·9	6·4	15·9	12·1	—	—	5·4	−2·3	−8·6	13·6	18·6	—	—	2·3	6·4	3·2	30·5
Total	9·5	35·4	62·7	30·3	−7·2	8·2	138·9	61·3	27·3	18·3	25·3	−0·9	34·9	96·3	46·7	21·7	19·1	5·8	16·8	10·5	120·6
Average	3·2	17·7	15·7	6·1	−1·4	1·6	27·8	20·4	13·7	4·5	5·1	−0·2	−7·0	19·3	15·6	10·9	4·8	1·2	3·3	2·1	24·1

Note: A, B, C, D, E & F denote early monsoon period, late monsoon period, autumn, winter, spring and summer season respectively.

nearly double than that during maturity. Cook and Stoddart (1961) reported that D.C.P. content of forage from seeded crested wheat grass ranges was 7·8 per cent during early stages of growth (28 May) and 1·0 per cent after maturity (19 July), respectively. Therefore, the gains in body weight of animals were high during early growth period of vegetation. In spite of forage on the range getting fibrous, and dry from November onwards and being completely weathered and dried from spring onwards, the animals carried on fairly well and did not reduce in body weight. The top feed from species like *Zizyphus nummularia*, *Prosopis cineraria*, *Acacia species* which have a high protein content (Ganguli *et al*, 1963) and are green during dry weather, add substantially to the animal nutrition in the range during lean periods of the year. Twigs of *Cappris aphylla*, leaves of *Salvadora species*, *Calligonum pollygonoides* and, to a limited extent, *Calotropis procera*, which are unpalatable to bovines, form useful top feed for sheep during dry weather (Ahuja, 1961). Leaves of forage-cum-shade trees like *Albizzia lebbek* and *Azadirachta indica* add to the stock feeds on the range substantially. Ray *et al* (1962) have reported that feeding of green together with dry forage increases the digestibility of nutrients of the later. It is, therefore, likely that leaves of top feed species, in addition to providing nutritious feed, also increased the digestibility of dry forage on the range; which was perhaps responsible for maintenance of body weight of animals on the range during lean periods of the year.

The gains in body weights of heifers in different range condition classes during 1962-63 are presented in Table 3.

The highest gains in body weights of growing stock were observed under continuous controlled grazing system. The increases under 'Good', 'Fair' and 'Poor' range condition classes per heifer on the average were 45·4, 67·9 and 64·4 kg respectively. Under the treatment where the rangeland received rest for 16 weeks from 1 July (PT IV), heifers showed least gains in their body weight and these were less than those obtained under PT_1 by at least 30 kg per animal. The animals did not get succulent forage during the monsoon season and had to feed on less palatable and woody forage, which also results in less intake of forage (Gomm, 1956).

The increase in body weights of heifers is highest during the monsoon season (1 July to 21 October) and then the gains decline. This is due to higher nutritive value of forage during this season. The growth rate during the monsoon season amount to 2 kg per week in all types of rangelands and compares favourably with the animals of Indian breeds of cattle maintained on fairly high plane of nutrition under farm conditions.

The rate of growth of animals in 'Good' ranch is lower than that in other types from autumn

TABLE 3: Average gains in body weight of heifers (in kg) under various pastoral treatment in different range condition classes and seasons from 1-7-1962 to 30-6-1964

Particulars of ranches and pastoral treatments	*Early Monsoon*	*Late Monsoon*	*Autumn*	*Winter*	*Spring*	*Summer*	*Total*
Poor							
PT I	13·3	21·6	9·2	7·9	3·7	8·7	64·4
PT III	—	16·2	8·3	8·7	3·4	7·5	44·1
PT IV	—	—	9·5	8·4	5·4	5·7	29·0
PT V	14·4	—	9·7	7·7	6·5	6·1	44·0
PT VI	10·3	—	—	10·1	6·5	6·4	33·3
Total	38·0	37·8	36·7	42·8	25·5	34·4	
Average	12·7	18·9	9·2	8·6	5·1	6·9	
Fair							
PT I	13·8	23·3	5·4	12·2	5·5	7·7	67·9
PT III	—	16·9	7·1	11·7	4·0	6·2	45·9
PT IV	—	—	6·6	9·0	5·9	6·5	28·0
PT V	13·1	—	7·2	11·3	6·6	8·1	46·3
PT VI	12·5	—	—	8·0	6·4	3·4	30·3
Total	39·4	40·2	26·3	52·2	28·4	31·9	
Average	13·1	20·1	6·6	13·0	5·7	6·4	
Good							
PT I	16·3	17·7	9·0	3·2	1·1	−1·9	45·4
PT III	—	12·5	8·0	3·7	1·9	−0·9	25·2
PT IV	—	—	6·3	0·3	1·1	−3·4	3·7
PT V	17·2	—	7·0	3·1	0·2	−2·0	25·5
PT VI	14·2	—	—	5·3	0·1	−2·1	17·5
Total	47·7	30·2	30·3	15·0	4·4	−10·3	
Average	15·9	15·1	7·6	3·0	0·9	−2·1	

onwards and is mainly due to the outbreak of foot and mouth disease from November onwards in most of these areas, and tussecky grasses like *Dichanthium annulatum* and *Lasiurus sindicus* which dominate in 'Good' rangelands become woody and fibrous from November onwards and these are less palatable which results in less intake of forage by animals.

The growth rate of Indian breed cattle is inherently slower than that of European breeds of cattle. Chandiramani *et al* (1957) reported an increase in body weight of 25 kg (56 lb) in yearling heifers of Hariàna breed in a farm during the second year of their age. The growth rate of the heifer on range condition appears to be favourable compared to that under farm conditions.

The data of the body weight gains in heifer per 100 hectares are presented in Table 4.

The maximum animal growth was obtained under continuous controlled grazing system (PT_1) on all types of rangelands, and the least under treatment PT IV. The high forage producing grasses with better nutrient contents dominating in 'Good' rangelands have shown high net gains in PT_1 treatment, but somewhat less under other pastoral treatments. This is due to the reasons already explained above.

TABLE 4: Mean gains in body weight (kg) of heifers per 100 hectares in different condition class ranges

Range condition class	*Pastoral treatments*				
	PT I	*PT III*	*PT IV*	*PT V*	*PT IV*
Poor	1055·8	722·9	475·8	727·8	545·3
Fair	1656·1	1119·5	682·9	1129·3	739·0
Good	1891·7	1050·0	154·2	1062·5	729·1

(b) *Sheep*: The data of the body weight gains in ram lambs in different pastoral treatments on various rangelands are presented in Table 5.

As in the case of heifers maximum gains in body weights of ram lambs have been obtained under 'continuous controlled' grazing under all types of rangelands and least gains are put on under the treatment where range received rest for 16 weeks from 1 July (PT IV). In 'Fair' rangelands the gains in body increase steadily up to the beginning of winter and then decline in winter and spring

TABLE 5: Average gains in body weights of ram lambs (kg) under various pastoral treatments and seasons, on different ranges: 1962-1963

Particulars of range type and pastoral treatments	*Gains in body weights in kg during different seasons*						
	Early Monsoon	*Late Monsoon*	*Autumn*	*Winter*	*Spring*	*Summer*	*Total*
Fair							
PT I	3·18	2·49	2·99	0·77	0·09	0·48	10·0
PT III	—	1·86	2·68	1·04	0·36	0·18	6·12
PT IV	—	—	2·63	1·18	0·09	0·59	4·49
PT V	3·13	—	2·63	1·00	0·36	1·08	7·48
PT VI	2·99	—	—	0·50	0·14	0·50	4·13
Average	3·1	2·1	2·7	0·9	0·1	0·6	
Poor							
PT I	2·27	2·36	1·95	1·86	0·23	3·03	11·70
PT III	—	2·90	1·50	2·31	—0·09	1·92	8·52
PT IV	—	—	1·72	1·86	0·18	1·95	5·71
PT V	2·72	—	1·77	2·18	0·73	1·45	8·25
PT VI	2·08	—	—	2·36	0·14	1·59	6·17
Average	2·4	2·6	1·7	2·1	0·2	1·99	

and slowly improve in summer season, whereas in 'Poor' ranges the maximum decline in gains in body weights is observed only during the spring season. During spring the gains in body weights were the least in both 'Poor' and 'Fair' rangelands. Due to the presence of perennial tussocky grasses in higher frequency in 'Fair' rangelands than in 'Poor' ones (Prakash *et al* 1964) which become woody and fibrous and less palatable, resulting the growth responses in 'Fair' ranches from autumn onwards less than in 'Poor' range class pastures.

The data of increase in body weight of ram lambs per 100 hectares under different pastoral treatments are presented in Table 6 below:

TABLE 6: Gains in body weights (kg) of Ram lambs under different pastoral treatments per 100 hectares of rangelands

Condition class of rangelands	*Pastoral treatment*				
	I	*III*	*IV*	*V*	*VI*
Poor	585·0	426·0	285·5	442·5	308·5
Fair	751·9	460·1	337·6	562·4	310·5

The net gains per unit area of a rangeland in ram lambs are higher in 'Fair' rangelands than on 'Poor' ones. Continuous controlled grazing system (PT_1) gives the highest animal production and PT IV gives the least animal growth.

Comparing the net gains in body weight of heifers and sheep (lambs) on a unit area of rangeland, it is evident that heifers gain much more (nearly double) than lambs in body weight (Table 7)

TABLE 7: Comparative gains (kg) in body weights by heifers and ram lambs per 100 hectares in pastoral treatment PT I

Condition class of rangeland	*Heifers*	*Ram lambs*
Poor	1055·8	585·0
Fair	1656·1	751·9

(c) *Wool production in lambs*: The data are presented in Table 8.

The yield of wool under PT IV for first clip is not given as the animals were introduced on 21 October, i.e. after these were shorn in September, as per schedule of the experiment. The average yield of wool per yearling ram lamb in 'Fair' and 'Poor' rangelands is 1·16 and 1·66 kg respectively. The higher wool production in 'Poor' rangelands may be due to breed differences. Detailed data reveal that the highest average wool produced by Chokla breed of lambs in 2 clips is 1·75 kg.

Morrison (1957), quoting Spencer concluded that the yield of wool increases as the age advances and it is heavier in 2 to 3-year-old sheep than in yearlings. Narayan (1959) noted that the yield of Indian sheep is 0·9-2·7 kg per animal and is much lower than that of Australian Meriano. Narayan and

TABLE 8: Average yield of fleece per ram lamb grazing under pastoral treatments (kg)

Pastoral treatment	Poor ranges			Fair ranges		
	1st Clip (Sept clip)	2nd Clip (March clip)	Total	1st Clip (Sept clip)	2nd Clip (March clip)	Total
PT 1	0·74	1·02	1·76	0·49	0·71	1·20
PT 3	0·69	0·95	1·54	0·50	0·51	1·01
PT 4	—	0·78	0·78	—	0·63	0·64
PT 5	0·71	1·05	1·76	0·48	0·65	1·13
PT 6	0·75	0·88	1·63	0·52	0·62	1·14
Average	0·72	0·94	1·66	0·50	0·66	1·16

TABLE 9: Drinking water consumed by farm animals on the range per animal per day (litres)

Kind of stock	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
A. *Adult & dry*												
i. Cows	—	—	—	—	—	—	19·3	26·5	28·6	32·8	35·0	41·1
ii. Sheep	—	—	—	—	—	—	2·1	2·1	2·7	3·2	3·8	4·5
B. *Growing stock* (Yearlings)												
i. Heifers	10·6	11·1	12·6	12·9	11·3	9·0	10·2	12·1	13·5	15·0	15·9	17·0
ii. Ram lambs	2·4	2·4	2·1	1·9	2·1	1·6	1·8	2·2	2·5	3·2	3·8	4·0

Sapre (1961) reported average wool yield from an adult ram, ewe, yearling ram lamb, and ewe lambs of Chokla breed as 1·02, 0·86, 0·51 and 0·46 kg respectively. The wool output from the yearling lambs on range feeding is very satisfactory.

(d) *Drinking water requirements*: The data on drinking water consumed per animal per day by adult cow and sheep and growing heifers and ram lambs under range feeding conditions are presented in Table 9.

The daily drinking water requirements of animals are appreciably lower during monsoon season, autumn and winter, but increase with rise of temperature during summer season when humidity is low, in all classes and kinds of farm animals. These in adult cows increase from 19·3 litres in January to 41·1 litres in June and from 2·1 to 4·5 litres in adult sheep. In case of young stock (heifers) the water needs in December are 9·0 litres and 17·0 litres in June and for ram lambs 1·6-4·0 litres per animal. The water consumed by young stock from July to November does not differ appreciably. During monsoon season the fresh succulent green grass contains appreciable amount of water and hence the intake is less. Besides, the humidity rises and temperatures fall. In consequence water is required to a lesser extent for temperature regulation in the animal. Stanley (1938) also reports that the water requirements of farm animals on the range increase considerably with the rise in temperature and reduction in humidity. The water intake of dairy cattle increases by 50 per cent when temperature rises from 15·5°C to 32·2°C (Thompson, 1949). The higher intake of water during summer season is obviously due to high temperatures and low humidity in this tract.

Water is the crying need in this part of the desert where water-table is very low and well waters are highly saline and stock have to go miles together to quench their thirst. Even the best and highly productive ranges will be of no use if adequate arrangements for stock water do not exist. Mahendra Prakash and Gopinath (1962) after a detailed study suggested utilization of surface water by its collection in underground water reservoirs locally called 'Tankas'. A 'Tanka' was constructed on the range where nearest water source is about 5 km. It has a capacity of 1,36,379 litres and has given good performance. The cost of construction was Rs. 30·43 per 1000 litres. The maintenance and repair cost of the reservoir works out to Rs. 1·18 per 1000 litres while the transport of water from the nearest open tank in the region is Rs. 11·37 for the same quantity of water.

(e) *Regression equations for estimation of body weight in cattle from heart girth*: Observations recorded from October 1961 to June 1962 on yearling heifers and bull calves of local breed in Pali district and adult Kankrej and local cattle revealed that there was a very high coefficient of correlation between heart girth and body weight in the above classes of animals. Detailed statistical analysis revealed that there does not exist any significant variations between monthly regressions within any class of animals. In case of adult cows there were no significant differences in the coefficient of regression, between adjusted means between Kankrej cows and local cows. But in case of male and female calves there were significant differences between their adjusted means of elevations. The data pooled are summarized in Table 10.

TABLE 10: Regression equations for estimation of body weight in cattle from heart girth observations

Class of animals	*Total number of observations*	*Regression equation*	*Coefficient of correlation*
Male calves	195	$Y=3{\cdot}053\ X-220{\cdot}9736$	0·9534**
Female calves	163	$Y=2{\cdot}8798\ X-204{\cdot}3452$	0·8989**
Adult cows	544	$Y=5{\cdot}1189\ X-479{\cdot}7$	0·9050**

**Highly significant.

Where Y is the estimated body weight in Kg and X is the observed heart girth in cm.

With the increase in age (up to a certain period) the rate of change of body weight is proportionate to that in heart girth, as the cattle having age between 15 and 30 months or having girth measurements between 85 and 140 cm the rate of increase of 3 kg per unit increase heart girth in cm and for adult cows with girth from 131 to 179 cm the rate of increase of 5 kg per unit increase of 1 cm of heart girth is reliable.

The deviations between predicted and observed body weights for male calves, female calves and adult cows are of the order of 8·3, 8·7 and 18·1 per cent respectively. Deviations of such order have been observed by Ragasdale and Brody (1935), Ross (1958b), Thronton (1960), Mullick (1950). Besides, Wandorstack and Salisbury (1946) observed that the Aberden angus steers were lighter than the Hereford steers in relation to their heart girth. Similar differences have been reported by Mullick (1950) between Murrah buffaloes and Hariana cows and in Jersay and Holistein cows by Ragasdale and Brody (1935). Significant difference between regression lines of male and female calves have been observed in the present study. Apparently there are slight differences in regression lines of Kankrej and local cows (adult), but those differences are not significant.

SUMMARY

With a view to improving animal production through improvement of native rangelands in western Rajasthan, Range Management project was started in 1958. The results achieved in the adequately fenced rangelands wherein controlled grazing based upon the forage production and floristic composition was practised are summarized below:

1. Amongst the different pastoral treatments highest average gains in body weight of adult cows, with initial body weight of 272 kg were obtained under continuous controlled grazing on a yearlong basis. These were 25·3, 35·5 and 56·7 kg respectively in 'Poor', 'Fair' and 'Good' range condition class areas. The least gains in body weight were observed under the treatment where the rangeland received rest for 16 weeks from 1 July to 21 October.

2. Gains in body weights of growing heifers which had average initial body weight of 92-95 kg indicated the same pattern under the continuous controlled grazing on a yearlong basis. In this treatment, the gains were 64·4, 67·9 and 45·4 kg for 'Poor', 'Fair' and 'Good' condition class ranges respectively. Deferment for 16 weeks during the growing period, on an average, decreased the animal production by more than 30 kg per heifer.

3. The average body weight gains of ram lamb initially weighing 19·1 kg in 'Fair' and 'Poor' condition class ranges were 10·0 and 11·7 kg respectively under continuous controlled grazing system. Where the grazing was deferred during grass-growing season for 16 weeks, the respective gains averaged to 4·5 and 5·7 kg. The highest gains in body weight of lambs, were noticed on 'Fair' condition class ranges in the high rainfall region on light soils under the treatment of controlled grazing on a yearlong basis.

4. Animal production per 100 hectares is nearly double in heifers than in the ram lambs irrespective of range condition class and pastoral treatment.

5. Wool production in 1962-63 from two clips from ram lambs of local breeds averaged 1·66 and 1·16 kg for 'Poor' and 'Fair' condition class ranges respectively.

6. Drinking water consumed per day by an adult cow weighing 272 kg increased from 19·3 litres in January to 41·1 litres in June. On average a heifer consumed from 9·0 to 17·0 litres, an adult sheep from 2·4 to 4·5 litres, ram lamb from 1·6 to 4·0 litres during the above-mentioned months of the year.

7. The construction cost of underground water reservoir 'Tanka', which is the most efficient means for storage of sweet water for human and stock consumption in desert range, works out to Rs. 30·43. per 1000 litres while the transport cost alone from the nearest open tank in the region is Rs. 11·37 for the same quantity.

8. Regression equations for estimating body weight of cattle with the help of heart girth have

been evolved. These for different classes of animals are as under:

BULL CALVES $Y=3{\cdot}053\ X-220{\cdot}9736$; HEIFERS $Y=2{\cdot}8798\ X-204{\cdot}3452$;

ADULT COWS $Y=5{\cdot}1189\ X-479{\cdot}7$

where Y is the estimated weight in kg and X is the heart girth in cm. No seasonal variations in regression coefficient were noticed in all classes of animals.

9. With adequate fencing, continuous controlled grazing, range production increased substantially which was reflected in increased animal production.

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DISCUSSION

H. Nath : Is any information available on the performance of animals as related to loss in body weight to dehydration by reduced water intake ?

L. D. Ahuja : No quantitative work has been carried out on this particular aspect, but it has been observed that when there is a lack of water there is less milk yield which is manifested in 24-48 hrs.

Mahendra Prakash : What will be the optimum utilization of a pasture ? Have any studies been made on palatability of the range ?

L. D. Ahuja : If the grazing is to be conducted on yearlong basis, optimum utilization is 70 per cent. Data on relative palatability have been summarized in the paper.

ADAPTATION OF LIVESTOCK TO ARID CLIMATE[1]

by

G. C. TANEJA[2]

GENERAL

ANIMALS in the arid zone, although well adapted, are less productive than those of temperate climate. However, the latter unfortunately do not thrive well when imported into the arid areas. There is, therefore, a need for developing breeds which are productive yet well adapted, to arid conditions.

In nature animals have become adapted to different environments by natural selection, so that in artificial selection and improvement of livestock for different environmental conditions we have to find the physiological effects on the animals of different factors which make up that environment. The fact that animals adapted to arid climate differ markedly from those developed in humid regions was recorded as early as 1958, when it was observed that the Zebu cattle of India, unlike European cattle, seldom seek shade in the intense tropical sun (Lydekker, 1912). However, the main advances in climatological physiology are of recent origin.

In order to evolve breeds of highly productive type and most suited to arid areas or to select within breeds for adaptability to arid climate, it is necessary that the reactions of animals to high temperatures which are characteristic of arid regions should be determined. Findlay (1950) indicated that under natural conditions, animals are influenced by the aggregate effect of various climatic components. Under laboratory conditions it has been possible to study the effect of individual components on various physiological reactions both in man and animals and this has yielded useful information.

Effects of artificially created arid climate on body temperature, respiration rate and pulse rate have been studied in man (Gregory & Lee, 1936; Lee, 1940; Lee & Boissard, 1940), sheep (Lee & Robinson, 1941; Lee, 1950), cattle (Kibler & Brody, 1950b; 1951; Seath & Miller, 1946a, b; Regan & Richardson, 1938; Freeborn, Regan & Berry, 1934; Bonsma, Scholtz & Badenhorst, 1940; Riek & Lee, 1948a, b; Robinson & Klemm, 1953; Kibler & Brody, 1953; Beakley & Findlay, 1955a, b, c; Findlay, 1955 and others), pig (Robinson & Lee, 1941a; Heitman Jr & Hughes, 1949), pregant sows (Heitman Jr., Hughes & Lee, 1941b), domestic fowls (Yeates, Lee & Hines, 1941) and rabbits (Lee, Robinson & Hines, 1941). In fact, in cattle and other livestock, rectal temperatures and respiratory rates are most sensitive and simple indices of thermal stress. Probably the thermal stress is reflected in the whole body including nerves, endocrines, enzymes, metabolites and metabolic rates (Brody, 1948). With rise in air temperature, the rectal temperature and respiration rates begin to rise, followed by depression of food consumption, milk production, pulse rate, blood CO_2 combining power and ascorbic acid and increase in blood creatine (Worestell & Brody, 1953).

EFFECTS OF ARID CLIMATE ON PRODUCTIVITY IN CATTLE

Regan and Richardson (1938) assessed the effect of controlled environmental temperatures at constant humidity and air movement on the milk yield and composition of the milk of Jersey cows. The changes in composition and yield were noticed with ambient temperatures above 80°F. The milk yield declined and there also appeared to be a slight decrease of 0·2 per cent in the butter fat percentage between 60° and 80°F. At 85°F the fat percentage had risen, but this would be expected since the milk yield had declined. Riek and Lee (1948a), from experiments in psychrometric room, did not confirm all these results. With Jersey cows they could find no effect on the butter fat content of the milk, either percentage or total, which could be ascribed to rise in temperature. With rise in dry bulb temperature at higher humidities they found that the specific gravity of the milk increased by 0·69 per cent.

Ragsdale, Brody, Thompson and Worstell (1948) in experiments with Holstein and Jersey cows under psychrometric room conditions, investigated the effect of temperatures from 50 to 105°F on milk production and feed consumption in dairy cattle. The range of critical high temperature at which the depressing effect on milk production, feed consumption and body weight become evident was 75-80°F for Holsteins and 80-85°F for Jerseys. Increasing environmental temperatures above these temperatures rapidly decreased feed consumption and milk production till at 105°F both ceased. Reducing the temperature to 50-60°F restored normality.

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Head of the Animal Studies Division of the Institute.

Ragsdale, Worstell, Thompson and Brody (1949) studied the effect of various temperatures on body weights of Jersey and Holstein cows and reported that with temperature rising from 50 to 95°F, there occurred a sharp decline in body weight above 80°F. The larger the animal, the more sensitive it was to rising environmental temperature.

Ragsdale, Thompson, Worstell and Brody (1950) studied the influence of rising temperature, 50°F up to 105°F, on milk production of European-evolved (Jersey and Holstein) and Indian-evolved (Texas-bred Brahman) cattle. The milk yield bagan to decline appreciably at about 75°F in European and 95°F in Indian cattle. The percentage decline in milk yield is greater in the Holstein cows; less in the Jersey and least in the Brahman. The milk yield of European-evolved cows begins to decline above 70°F and below 40°F, the optimum temperature for milk production being 50°F. The Jersey and Holstein cows lost body weight at temperatures above 75°F while the Brahman cattle maintained their weight.

Temperature conditions critical to milk production in Holstein cattle at Beltsville (U.S.A.) have been investigated by Lee, McMullan and McDowell (1954), who reported that production in cows kept in open barns declines significantly when local mean shade temperature exceeds 71°F for two successive days. To conclude, arid climate has a deleterious effect on the milk production in cattle and this subject has been fully dealt with by Findlay (1950) and Hancock (1954).

PROBLEMS OF HEAT TOLERANCE IN ZEBU AND EUROPEAN CATTLE

There is considerable evidence that Zebu cattle (*Bos indicus*) and their relatives are superior to European cattle (*Bos taurus*) in their ability to withstand arid climate. When exposed to high air temperature, the rectal temperature and respiratory rates of Zebu cattle do not rise to the same degree as those of European cattle, (Rhoad, 1936, 1938, 1940a; Bonsma, 1940; Bonsma, Scholtz & Badenhorst, 1940; Klemm and Robinson, 1955 and others).

There are also marked differences in the grazing habits of tropical and temperate breeds of cattle. The seeking of shade and a voluntary reduction in food intake by the cessation of grazing are physical homeothermic mechanisms which ease the burden of heat load upon the animal (Findlay, 1950). The grazing habits of both tropical and temperate breeds of cattle have been studied by various workers (Rhoad, 1938, Bonsma, Scholtz & Badenhorst, 1940; Kelly, 1943), and the general opinion is that the Zeby and Zebu cross cattle will remain out in bright sunlight, either resting or grazing, where British cattle seek the shade.

The differences in heat tolerance of Zebu inhabiting the arid and semiarid areas of Indian and European cattle have attracted the attention of various workers and a number of explanations have been offered. These are:

(i) Zebu cattle possess greater body surface from which heat can be dissipated, such as the hump, large ears, and pendulous dewlap. Kibler and Brody (1950b) have estimated that Zebu cattle possess about 12 per cent greater surface area than Jerseys of the same weight. European cattle, on the other hand, have hairy fat, tight hides, undeveloped dewlaps and relatively small ears. This theory, however, seems no longer to hold since Mc Dowell, Lee and Fohrman (1953) have found Sindhi ×Jersey crossbreds to have much the same surface area as Jerseys of the same weight.

Yeates (1955a) suggested that large surface areas should, theoretically, be an advantage to a beast if that surface is reasonably well vascularized and one from which evaporation takes place. He points out that the actual benefit derived by certain breeds of arid areas from their large ears, dewlaps, naval folds and prepuces is undetermined and has probably been over-estimated in the past, since Lee, Robinson, Yeates and Scot (1945) demonstrated that poultry derive no appreciable benefit from their head appendages. Brody (1945) suggested that heat production is proportional to external surface rather than body weight. Surface area per unit weight declines with increasing body weight and, therefore, the metabolism per unit weight in small animals is many times greater than that of large animals. Greater heat production per unit weight in small animals is due to the fact they have relatively larger metabolism controlling organs. Worstell and Brody (1953) and Wright (1954) suggested that small animals are more heat tolerant than large animals, because they have greater surface areas per unit weight.

(ii) Differences in coat colour have been associated with differences in heat tolerance. Rhoad (1940b) reported that lighter cattle reflect more of the rays of the sun, and, therefore, absorb less heat. For example, white Zebu cattle, light fawn Jerseys, dark fawn Jerseys and Black Aberdeen cattle ranked in that order in the amount of sunlight reflected. Similar results were obtained by Bonsma (1943) who studied the amount of sunlight reflected from Afrikander and Jersey cattle, animals of several shades being included from each of the two breeds. Comparisons were also made of animals of various breeds with contrasting colours. Wide variations were observed and the lighter animals reflected the most sunlight.

Riemerschmid and Elder (1945) approached this problem by a different method. These workers determined the 'mean effective absorptivity' of cattle coats of different colours. The mean effective absorptivity is a measure of the relative amount of heat produced at the surface of the hairy coat by conversion of radiant energy into heat. This is expressed as percentage, and is always less than 100 since the animals' body is cylindrical and light hits only a portion of an exposed side at right angles. The mean effective absorptivity was found to be 49 per cent for a white Zeby animal, 78 per cent for a red Africander and 89 per cent for a black Aberdeen Angus. Thus more heat is retained at the surface of the darker-coloured animal.

Bonsma (1949) suggested that resistance to different types of solar radiation is affected by particular combinations of skin and coat colour. Thus a white, yellow or red coat with a dark hide is the ideal combination for resistance to high temperature and intense radiation of infra-red or heat-rays and of ultra-violet rays. Black cattle are best adapted to regions where the latter only is intense, e.g. at high altitudes. Smooth-coated types of cattle will reflect heat more effectively than woolly coated ones.

(iii) The rate of hair growth may also be an important factor in determining adaptability to arid climate. French (1946) investigated rate of hair growth on Zeby, Ankole, $\frac{3}{4}$ Ayrshire $\frac{1}{2}$ Zebu, and $\frac{3}{4}$ Holstein $\frac{1}{4}$ Zebu animals, all of comparable ages. The slowest rate of hair growth was observed on Zebu, though there was little difference between them and the indigenous Ankole stock. The rate of growth was considerably higher in $\frac{3}{4}$ European animals. There was little difference between the animals having Ayrshire and Holstein blood, but in the few animals studied their was an indication that Ayrshire cattle might grow hair faster than Holstein; this point needs confirmation by study of larger numbers of animals. French (1946) also observed a tendency to faster hair growth in animals having woolly coats.

Thickness of the coat has been suggested to be the cause of differences in heat tolerances of European and Zebu breeds (Bonsma, 1943; Brody, 1948), Seasonal changes in coat thickness have also been related to heat tolerance in cattle (Bonsma, 1943, 1948; Yeates, 1955b). These authors have concluded that animals with sleek and glossy coats are more resistant to heat than those with dull and woolly coats. In psychrometric room studies in Brisbane, Yeates (1955b), assessing the heat tolerance of both woolly and smooth-coated cattle, found the woolly animals to be at a grave disadvantage in the heat, a thick curly coat constituting a threat to the animal's lives in an atmosphere of 105°F dry bulb and 92°F wet bulb. That the coat as such was responsible, and not some other factor with which woolly-coatedness might be associated, was shown by immediate clipping of animals, which then maintained satisfactory heat regulation. The experimental breeding by Bonsma (1952) of a wooly coated strain of Afrikander cattle also provides evidence that smooth coats are necessary to ensure adaptability in the sun the respiration rate of his woolly individual was 148 per minute and the body temperature 106·6°F against 47 and 102·6°F respectively, in smooth-coated Africanders. The physiological feature of heat transfer from the body by conduction is that still air has an extremely low conductivity and that hair and feathers contain much air and are, therefore, excellent non-conductors or insulators (Brody, 1948).

Yeates (1954, 1955b) clearly demonstrated that the light environment exercises an important influence on the seasonal coat changes. A rising plane of light initiates shedding of long hairs and in the Polled Shorthorn calves the shedding commenced after approximately twelve weeks of increasing light.

The coat of Africanders is approximately four times as heavy in winter as in summer. The average coat of 6 Africander heifers weighing on an average 600 lb each, was 29 gm in summer, while the coats of the same 6 heifers six months later, during winter, averaged 129 gm (Bonsma, 1943). The average weights of the summer coats of 6 two-year-old Africander heifers and 6 two-year-old Shorthorn heifers were 29 gm and 303 gm respectively in summer their winter coats weighed 129 gm and 505 gm respectively. Differences were also observed in the thickness of hair. In case of hairs of Shorthorns, the thickness was 26 y while the figure for Africanders was 50 y (Bonsma, 1943).

The hairs of animals with glossy coats not only have a more uniform thickness, but are also shorter and have a much higher fat content than those of animals with dull coats. From analysis made of large numbers of samples taken from the two classes of bovines, viz. those with glossy coats and those with dull coats, other ether extract (fat) content of the hair of the former was 4·2 per cent while that of the latter was 2·9 per cent (Bonsma, 1943).

Turner (1955) reported some interesting results on coat characteristics of European cattle. He observed that coat score and weight of hair per unit area are fairly well related, though not as well as might be expected. Coat score and felting are well related, because one of the important components of felting appears to be length of hair; felting also seems to be influenced by curvature and diameter of hair. A surprising relationship is that between hair diameter and depth of colour among red Shorthorn and Hereford cows. He recorded that in roan coats the white hairs are of smaller diameter than the red hairs and that lactating cows have lighter colour and lower coat score than dry cows. The correlations between coat score and skin temperature ranged from 0·6 to 0·8, with rectal temperature 0·5-0·6 and respiration rate 0·4-0·6. The same coefficients for felting score were 0·6-0·7, 0·5-0·6 and 0·4-0·5, respectively. He suggested that there are important differences in coat among animals in a relatively uniform herd of Herefords or Shorthorns, and that these differences have a considerable effect on heat regulation.

(iv) Another factor which has been suggested as a cause of the difference in heat tolerance between Zebu and European cattle is that Zebu cattle of arid regions sweat, while European cattle apparently do not, or sweat but slightly, so that their evaporative cooling from the skin is mostly, if not entirely, of 'osmotic moisture' or diffusion mosi-ture.

Cutaneous water losses in cattle and the increase in this loss under hot conditions has been measured (Rhoad, 1940a; Riek and Lee, 1948a, b; Robinson & Klemm, 1953; Thompson, Robinson, 1954; McDowell, Lee & Fohrman, 1954; Klemm & Robinson, 1955). These estimates are higher than would be expected from diffusion moisture alone.

Some observations have been recorded suggesting the activity of the sweat glands. Kibler and Brody (1950a) observed that the sudden rise in skin moisture vaporization in cattle at temperatures between 65° and 80°F is analogous to 'breaking out in sweat' in man at about 80° to 90°F. Worstell and Brody (1953), however, concluded that cattle do not sweat in the same sense than man does. McDowell, Lee and Fohrman (1954) suggested that the maximum amount of water evaporated from the skin (660 g/sq m/hr) is more than the diffussion through the epithelium, and that it is true secretory process.

There is no doubt that cattle skin is abundantly supplied with sweat glands (Gurlt, 1835; Ellenburger, 1906; Muto, 1925; Kelley, 1932; Yamane & One, 1936; Findlay & Yang, 1950; Dempsey, 1946; Carter & Dowling, 1954; Dowlina, 1955). However, the activity of sweat glands has been a subject of great controversy. Experiments of Findlay and Yang (1950) suggest that cattle sweat glands have a poor blood supply, and that these glands do not function as efficiently in heat regulation as human sweat glands. Recent studies carried out in the University of Queensland have conclusively proved that cattle sweat and that their sweating is controlled adrenergically. The amount of sweat secretion is, however, fairly small. These studies have also shown that the Zebu cattle sweat more than the European cattle (Taneja, 1958a; 1959a, b, c, d; 1960; 1963).

(v) Kibler and Brody (1950b) studied the effects of air temperature between 50 to 105°F on heat production in Brahman Jersey and Holstein cows. These authors found that the heat production at 50°F (control temperature) varied between 800 and 1000 Cal/hr in the Holsteins, 600 to 700 Cal/hr in the Jerseys and 450 to 500 Cal/hr Brahmans. Brahmans and Jersey cows, had nearly the same body weight but the Brahman had the lowest heat production. Elevating the environmental temperature from 70 to 100°F decreased heat production by about 35 per cent in the Jerseys and Holsteins but only by about 10 per cent in the Brahmans. Kilber and Brody (1950b) suggested that probably the Indian cows have an inherently lower basal metabolic rate than European cows. This point was further elucidated by these authors (Kibler and Brody, 1951) who observed that at an air temperature of 100 to 105°F, the heat production per unit surface was about 40 per cent higher in the Brown Swiss than in the Brahman (both non-lactating), when the feed consumption was greater in the Brahman. Kibler and Brody (1950b) suggested that the lower heat production in the Brahman than in Jerseys on the same weight in an optimal temperature zone is probably due to the fact that Brahman have relatively (in comparison to the high milking Jerseys) lower thyroid activity.

The decline in heat production with increasing temperature may also be partly due to declining thyroid activity with increasing temperature as has been demonstrated on rats (Dempsey and Aswood, 1943). Biological factors controlling energy metabolism have been studied by various workers and in this connection differences in the level of creatine (Bilincoe and Brody, 1951), alkaline phosphatase (Kunkel, Stokes Jr., Anthony and Futrell, 1953), and thyroid function (Bilincoe and Brody, 1951) have been reported.

Mullick and Kehar (1952) studied the seasonal variation in heat production of cattle and buffaloes in India. These authors found that Indian cattle require 25 per cent less protein and about 20 per cent less calories for maintenance than the standards advocated by Morrison (1947). Heat production was measured on 12 Hariana cows, three imported crossbreds and three Murrah buffaloes exposed to varying air temperatures (50 to 1000°F). The heat production (KCal) per hour of Hariana and cross cows and buffaloes decreased with the increase in air temperature. The mean values with their standard deviations were 386 ± 37 (Hariana), 394 ± 37 (European cross) and 485 ± 31 (Buffaloes) and the mean differences were significant. The total number of calories per hour per square meter of body surface showed a negative correlation with air temperature and the differences were highly significant. The mean values with standard deviations were $98{\cdot}0 \pm 8{\cdot}8$, $107{\cdot}0 \pm 8{\cdot}7$ and $107{\cdot}0 \pm 5{\cdot}1$ for Hariana, imported crossbred cows and buffaloes, respectively.

This evidence of a difference in metabolic intensity indicates differences in heat tolerance. The hypothesis is advanced that it implies important differences in efficiency of energy utilization, the conversion of metabolizable energy to useful energy; and possible differences in digestive ability, the conversion of feed energy to metabolizable energy, do not enter into this question (Turner, 1955). It is known (Kleiber, 1945) that certain nutritional deficiencies impair efficiency of energy utilization, more waste heat being produced in the course of converting energy to essential purposes, with consequent elevation of basal metabolism.

Apart from these points mentioned above, which account partly or wholly for the differences in the heat tolerance of the Zeby and European cattle, it had been observed that Zeby cattle are more immune to ticks, flies, mosquitoes and other pests (Brody, 1943; Kelly, 1943; Hammond, 1949). The incidence of Tuberculosis however, appears to be high in Hariana (Zebu) cattle of India (Taneja, 1955a).

INHERITANCE AND REPEATABILITY OF HEAT TOLERANCE TESTS

Limited information is available on the heritability and repeatability of rectal temperature and respiration rates in cattle (Seath, 1947; Gaalaas, 1947a; McDowell, Matthews, Lee and Fohrman, 1953 and Turner, 1955).

Yeates (1955a) assumed that if the differences between individuals with regard to rectal temperature have to be located, the animals must be subjected to atmospheric temperature, severe enough to raise their rectal temperature. The results of Taneja, Negi and Satish Kumar (1964) have shown when the rise in rectal temperature is taken into consideration, the differences between sires are significant; thus allowing selection to be practised on the basis of sire differences. They estimated heritability of rectal temperature which varied from 19 to 20 per cent (19 per cent for morning temperature and 20 per cent for differences between morning and noon temperature). Other workers, Seath (1947) and Gaalaas (1947a, b) reported heritability of 15 to 30 per cent. Considering these results there is a reason to believe that this character is heritable.

Seath (1947), and McDowell, Lee, Fohrman and Anderson (1953) reported the results of repeatability of body temperature of cattle. Seath (1947) tested Jersey and Holstein involving 52 cows by 7 sires in 1952 and 68 cows by 8 sires in 1945. In his data, 21 cows included in the study for both the years gave a repeatability of 0·37 for body temperature. Turner (1955) estimated the repeatability of body temperature as 0·45. McDowell, Lee, Fohrman and Anderson (1953) reported that the repeatability of body temperature was fairly high when data were analysed on seasonal basis. The estimate of repeatability for rectal temperature determined by Taneja, Negi and Satish Kumar (1964) for the morning observations was 0·31 and it was higher than the values estimated for the noon temperature or for the difference between morning and noon temperature.

PROBLEMS OF SELECTION FOR ADAPTATION TO ARID CLIMATE

The solution to many problems of adaptability can be expected only through the carrying out of breeding experiments under conditions in which the animals involved are to be produced. Hammond (1947) recommended that the required character is best selected under environmental conditions which favour its fullest expression, and that once developed it can also be used in other environments, provided that other characters, specially required by that new environment, are also present in the animal. However, Falconer and Latyszewski (1952) demonstrated experimentally that while selecting for body weight in rats, there was a significant genotype-environment interaction. The improvement of the genotype for rapid growth on a high plane, while improvement of the genotype for growth on a low plane did carry with it a considerable improvement for growth on a high plane. Results of Taneja (1955b) carried out on growth rate of sheep support these findings. Hancock (1954) conducted similar experiments with identical twin pairs of calves feeding them on different levels of nutrition. It appeared unwise to attempt to select dairy cattle in good environmental conditions if they are to perform in much poorer conditions. His results agree with those of Falconer and Latyszewski (1952). Recent studies of Taneja and Negi (1964) shown that the effect of change of temperature on the level of production (high, medium and low) is not uniform. This has, therefore, a direct bearing on the problems of selection for these characteristics while selecting stock in one environment for breeding in another environment. The portion of stock with the level of production that is going to be adversely affected by the change of environment shall have to be excluded in the selection programme for a successful and economic prodcction of stock.

Lee and Phillips (1948) and Phillips (1949) suggested that the breeding procedures fall into the following categories; (i) Selection within native types; (ii) Grading-up with already improved types or breeds from other countries; and (iii) Development of new types out of animals that are graded only part of the way up to the improved types.

Selection within a native type has certain advantages. The native types are already adapted to the local environment, which may not be true of types brought in from other countries, and there is no problem of selection and importation of foreign stock. The disadvantage is that progress is much slower than grading-up with already improved types, provided the improved types meet local needs and are adapted to the environment.

Grading-up has the obvious advantage of rapid improvement, through the use of improved males on large numbers of native females. It is the logical method in all cases whereas there are existing types in other countries that meet a country's needs and which are likely to perform satisfactorily under the conditions in question. If this method proves satisfactory, foreign breeds or other improved herds need be maintained only as sources of males to continue the grading-up programme, while the bulk of animals in the area or country would become high grade as the programme progressed.

In many cases it may be found that imported pure bred animals cannot perform satisfactorily under existing environmental conditions. Grades with a certain amount of improved breeding may withstand the environment satisfactorily and produce at higher levels than the native stock. In such cases, the obvious procedure is to determine the extent to which the improved breeding can be introduced, then develop a new type animal with this breeding background, (Hammond, 1932; McDowell, Fohrman and Lee, 1952; Fohrnam, McDowell and Lee, 1953; McDowell, McMullan, Lee and Fohrman, 1954).

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DISCUSSION

H. Nath: Does the acclimatization in animals against heat once achieved persists ?

G. C. Taneja: No, sir.

NOMADISM

PROBLEM OF NOMADISM IN THE ARID ZONE OF RAJASTHAN[1]

by

A. B. BOSE, S. P. MALHOTRA & P. C. SAXENA[2]

THE SETTING

WESTERN Rajasthan comprising an area of 2,14,039 sq. km is bound by 24·5° and 30·5°N latitude and 69° and 78°E longitude. It is the eastern extremity of the North Tropical Desert Belt which extends from the Atlantic coast of Africa through the Sahara, parts of Arabia, South Persia and Baluchistan to India.

The climate is characterized by hot summers (maximum temperature of 49°C) and cold winters (minimum temperature of 19°C). Humidity is low throughout the year. A short erratic precipitation of 100 to 450 mm occurs during the monsoon season. Hot dry winds and dust storms from southwest and west, common in summer, accentuate wind erosion.

One-third of the total area is cultivated every year. This provides some fodder and by-products for the livestock. The fallow area which covers 23·6 per cent of the land provides some grazing and fodder for the lean period of the year. Permanent pastures occupy only 3·2 per cent of the geographical area. The grazing lands have useful indigenous grasses like *Lasiurus sindicus*, *Dicanthium annulatum*, *Cenchrus setigerus* and *Cenchrus ciliaris* all of which are superior fodder species. *Prosopis spicigera* and *Zizyphus nummularia* provide nutritious top-feed especially in hot summer months. Agriculture is the chief source of livelihood of the people in this region. Animal husbandary occupies a secondary place.

NOMADIC GROUPS

Nomadism is one of the oldest forms of adaptation to an arid environment. Krader (1959) regards it as a palaeolithic pattern of culture. Historical, political and cultural factors have often combined with climatic and geographical conditions to give rise to this way of life involving continuous movement from one place to another. Nomadic life is not chaotic nor is it culturally degenerated. Nomads have a stable social and economic organization which has been influenced by the exigencies of nomadic existence. There are definite territories which they traverse at different periods of the year. They have a definite cycle in their movements which is, of course, subject to modification depending upon the vegetative cover and availability of water for livestock and human beings. Nomadism is thus a pattern of resource use.

The nomads in this region may be grouped on the basis of their chief source of livelihood. In the first group are pastoral nomads like *Raikas*, *Parihars*, *Bilochis* and *Sindhi* cattle breeders. The former keep large flocks of sheep, goats and camels while the latter keep large herds of cattle. Most of these families are actually semi-nomadic practising cultivation for about four months and moving out in search of grass and water as soon as local supplies are exhausted. Livestock produce meets the dietary needs. Surplus livestock and livestock produce are sold or exchanged for other articles of consumption.

The second important category, designated trading nomads, comprises *Banjaras*, *Ghattiwala Jogis* and *Gawariyas*. The Banjaras trade in salt, Fuller's earth, onions, etc., for about five months. The period of their trade in these commodities and the area of operation is determined by the availability of grass and water in this region for bullocks which they keep as pack animals. *Banjaras* also trade in cattle. As soon as water and grass are exhausted they move towards Gujarat where they earn through haulage of goods. The *Gawariyas* trade in beads, bangles, mirrors, combs, etc., and cater primarily to the needs of the village women. They use donkeys as pack animals and have a fixed area of operation visiting the villages at regular intervals. The *Ghattiwala Jogis* sell grinding wheels, *chelum* (indigenous smoking pipe) and baskets to the sedentary population. Like the *Gawariyas*, their area of operation is limited. Some of the trading nomads in this region are on the move throughout the year. Others belonging to these castes have, however, sedentarized or are semi-nomadic leading a settled life as minor agriculturists or casual labourers during the cultivating season and taking up their traditional occupation for the rest of the year.

In the third category of nomads come the *Gadolya Lohars*, *Sattias* and *Sansis*, who render certain specialized services to the settled population. Of these the *Gadolya Lohars* have been the most publicized group. They are adept in fabricating and repairing iron implements and are regarded as better blacksmiths than the village *Lohars*. They also do trading in livestock, particularly bullocks to a limited extent. These nomads move in bullock carts with their families and their material possessions. This distinguishes them from other nomadic

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groups who use camels, donkeys or bullocks as pack animals. This mode of movement, however, confines the visit of *Gadolya Lohars* to villages connected by cart tracks. The *Sattias* and *Sansis* castrate the male calves maintained by the sedentary population, exchange their bullocks with the uncastrated male stock of such households who consider it irreligious to castrate the animals themselves, and trade in cattle to a limited extent. They are believed to be associated with immoral activities and stealing.

There are some other nomadic groups like the *Nats* and *Kalbeliya Jogis*. The former show acrobatics and physical feats and also beg food grains. They are widely believed to be associated with criminal activities. The *Kalbeliya Jogis* are snake charmers who move from village to village showing snakes and begging food grains in return.

Movements of these nomads are usually organized in groups of six to twenty families bound by close kinship ties. Such a movement ensures coordination, provides security, enables the nomads to assert their rights and provides a social framework for group living with all the associated advantages. Each group has a *mukhia* or headman who exercises undisputed control over the families in the unit.

The Hindu nomads in western Rajasthan are, strictly speaking, not tribes but caste groups. Some of them like the *Banjaras* and the *Raikas* occupy a high position in the caste hierarchy while others like *Sattias* and *Sansis* occupy low rungs in the social order. Various factors account for this differential caste status but the nature and type of occupation practised gives a broad indication of their position in the society.

The nomads are very conservative and tradition bound. Breach of codes of conduct or conventions is frowned upon. Heavy expenses are incurred in socio-religious ceremonies. Drinking is fairly widespread. Receptivity to technological change or the acceptance of new ideas is very slow.

PROBLEMS OF NOMADS

In the past nomads played an important role in the economy of the region. Their functions were complementary to those of the settled population. The poor means of communication helped to build up a relationship of mutual dependence. In recent years, however, they are not as welcome. The data in Table 1 show that feelings run strongest against the visit of *Raikas*, *Sindhi* cattle breeders, *Banjaras*, *Sansis*, *Sattias* and *Nats*. *Gawariyas*, *Ghattiwalla Jogis* and *Gadolya Lohars* are more welcome.

The disadvantages to the settled population from the visit of nomads are indicated in Table 2 which

TABLE 1: Response of settled population to the Visit of Nomads

Nomadic Groups	*Want* %	*Do not Want* %	*Indifferent* %	*Total* %
Raikas	4·7	92·0	3·3	100·0
Sindhi cattle breeders	12·5	83·0	4·5	100·0
Banjaras	32·1	64·5	3·4	100·0
Gawariyas	62·2	33·5	4·3	100·0
Ghattiwala Jogis	60·9	34·8	4·3	100·0
Gadolya Lohars	61·2	34·9	3·9	100·0
Sansis	1·7	95·7	2·6	100·0
Sattias	18·3	78·6	3·1	100·0
Nats	6·3	90·3	3·4	100·0

The tables are based on a sample survey conducted in five community development blocks in Jalore district in Western Rajasthan. A two stage sampling procedure was followed and a schedule was administered to the heads of sample households. The field work was completed in 1961-62.

TABLE 2: Disadvantages to settled population when Nomads visit their villages

Type of response	*Raikas*	*Sindhi cattle breeders*	*Banjaras*	*Gawariyas*	*Ghattiwala Jogis*	*Gadolya Lohars*	*Sansis*	*Sattias*	*Nats*
Their livestock destroy standing crops	82·9	69·5	80·2	4·1	8·0	2·8	0·6	0·7	3·3
Their livestock exhaust local grazing resources	84·3	68·3	79·3	3·6	6·7	2·1	0·6	0·7	2·5
Their livestock exhaust local water resources	28·9	25·6	36·1	1·4	0·9	0·1	0·1	0·1	0·9
Their livestock bring diseases and infect village livestock	11·6	5·8	9·8	0·6	0·1	0·5	0·1	0·1	0·1
They commit theft of livestock	1·5	2·3	2·2	0·1	2·3	0·5	63·3	12·7	31·2
They commit theft of crops and other articles	0·1	0·9	0·1	0·1	4·6	0·8	81·2	20·1	41·7
They commit other types of crime	0·3	0·6	—	0·6	2·8	0·1	14·2	10·7	6·9
They are immoral	—	0·5	—	0·1	1·5	0·1	2·7	17·6	1·6
They cheat the village folk in transactions	—	—	0·1	12·4	8·8	0·4	4·5	2·5	5·3
They beg and are a nuisance	—	—	0·1	1·2	4·4	0·1	0·3	1·9	9·6
Other	1·2	0·2	0·4	0·1	0·8	1·0	0·6	2·9	1·1
No harms	10·3	20·9	21·1	79·8	79·7	85·7	7·1	57·9	37·8

gives the responses of sample household heads. Most of the respondents feel that the visit of pastoral nomads and trading nomads with large herds of cattle results in the destruction of standing crops and exhaustion of local water and grazing resources thus imposing hardships on the livestock of the settled population. The problem has been aggravated on account of shrinkage of grazing lands and the extension of area under cultivation. A significantly greater percentage of respondents consider that the visit of *Gadolya Lohars, Gawariyas* and *Ghattiwala Jogis* is not disadvantageous to the settled population; some, however, feel that the livestock kept by them as pack animals cause damage to crops and exhaust water and grazing resources. It is also alleged that they charge higher prices for low quality goods. *Sansis* and *Nats* are commonly believed to be associated with thefts and other criminal activities. A significantly greater percentage of respondents feel that the visit of *Sattias* does not result in any harm to the settled population. An appreciable number, however, feel that they are associated with thefts, crimes and immoral activities.

The benefits to the settled population from the visit of nomads are given in Table 3. The data attributed to social, economic and political changes that have been going on in the region and have struck at the delicate human ecological balance. Firstly, due to increase in population and consequent reclamation of land for cultivation, the area available to nomads for grazing their livestock has been gradually shrinking. Secondly, the development of means of transport and communication has opened up the hinterland and facilitated the sale of surplus produce and purchase of necessities from outside. Through superior marketing techniques the city trader has pushed the nomad into the background and reduced the dependence of the settled population on him. Substitute and functionally more efficient goods and services are being increasingly offered by different agencies as a part of development activities. Thirdly, the Government's policy of sedentarizing nomads puts a limit on their movements. Fourthly, with the development of a strong government, the rights and obligations of various groups are now regulated by the State and security is guaranteed by the machinery created for the purpose. This has affected the social and political organization of nomadic groups and reduced the status and power of the chiefs.

TABLE 3: Benefits to settled population when Nomads visit their village

Type of response	*Raikas*	*Sindhi* cattle breeders	*Banjaras*	*Gawariyas*	*Ghattiwala Jogis*	*Gadolya Lohars*	*Sansis*	*Sattias*	*Nats*
Articles can be purchased, sold, exchanged or repaired	1·2	12·0	32·1	73·2	69·9	68·1	0·4	0·8	—
Animals can be purchased, sold or exchanged	0·6	6·2	2·1	0·4	0·3	0·3	0·1	0·8	0·1
Animal produced can be purchased or sold	—	0·3	0·1	0·1	—	—	—	—	0·1
Services like treatment of animals, castration, etc. can be available	—	0·4	—	—	—	0·4	1·7	16·8	—
Fields can be manured	1·6	0·1	0·1	—	—	—	—	—	—
Entertainment	0·1	—	—	—	—	—	—	0·3	8·3
Others	0·1	0·3	0·5	—	0·1	—	—	—	0·6
No benefit	97·1	80·9	68·7	27·9	29·7	31·3	97·8	81·3	90·9

show that most of the respondents feel that the settled population does not get any benefit from pastoral nomads, *Sansis, Sattias* and *Nats*. About the visit of *Banjaras* two-thirds of the respondents feel that this was of no benefit, while one-third feel that the settled population could purchase salt and other commodities from them. About the other trading nomads a significantly greater percentage feel that articles could be purchased, sold, exchanged or repaired.

The foregoing account indicates that nomadism is passing through a critical phase. This may be

FUTURE OF NOMADISM

It is, therefore, essential to frame a suitable policy regarding the future of nomadism. The basic issue seems to be whether to sedentarize the nomads or to extend them facilities for continued nomadic life. So far as the last three groups are concerned sedentarization should begin without further delay since they are ceasing to perform a useful function. The economy of these people should be based on agriculture and certain crafts. Facilities should be extended for water supply, housing, credit, and social welfare. They should be settled on the basis of kinship units which are compact groups for all purposes. The existing social organization with its informal machinery of administration should be utilized rather than superseded. The families should be approached through the *mukhia* (headman) who is their spokesman in all matters.

The policy that needs to be followed regarding pastoral nomads is more controversial. Some writers argue that nomadism permits the best utilization of arid lands, retention of large stocks of cattle and a higher standard of living than the settled population. They assert that since agriculture has already reached saturation point and alternative employment avenues do not exist, sedentarization of nomads is likely to result in their impoverishment. Nomadic culture would also decline (Barth, 1962; Capot Rey, 1962). Conditions in India are, however, different. The nomads themselves desire sedentarization. Recent survey data show that most of them desire to be settled (Malhotra and Bose, 1963). Since a large number of pastoral nomads move along the borders with other countries, political security demands their settlement at one place. Sedentarization would also stabilize production through improved animal husbandry practices rather than expose the nomad and his flock to the danger of annihilation through diseases or natural calamities. Administration and exercise of control becomes easy. Conflicts, which sometimes assume a violent form over the enforcement of rights by pastoral nomads on grazing and water resources, will be checked. The economy of these settled pastoral nomads should be based on animal husbandry. The survey of water resources and development will meet the water requirements of animals and human beings. Improved practices in range management will enable the retention of good quality livestock, thus increasing livestock produce. The extension of veterinary, marketing, credit, communication, education and housing facilities will substantially increase the contribution of the sedentarized nomads to the economy of the region.

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DISCUSSION

P. G. Adyalkar : An important problem relates to the policy that should be followed for sedentarizing nomads. What is the attitude of the nomads towards this ?

A. B. Bose : The nomads themselves desire sedentarization now in view of their falling incomes and difficulties in finding grazing land and water for their livestock.

N. Nath : Has any study been made of the food habits of the two groups of population ? Is there any difference in the dietary pattern of these two groups in terms of calories, proteins and other nutrients ?

A. B. Bose : No study has been made so far but it is intended to include it in future programme of work.

THE NOMADIC GADULIA LOHARS: THEIR REGION OF MOVEMENT AND THE COMPOSITION OF A BAND*

by

P. K. MISRA

INTRODUCTION

INDIA has an interesting collection of people who lead a nomadic way of life. The nature of their wanderings differ and so also their means of livelihood. There are bands of people who move round the year from place to place whereas some others move out only in certain seasons of the year either due to the rigours of the climate or for some other reasons and have permanent dwelling places or holdings to which they periodically return. The repeated shifting of habitat in search of subsistence has been termed as nomadism. The repeated movement of one group of people from one place to another is based on realistic considerations and they also have a stipulated direction and are focussed around certain centres of operation for obtaining the livelihood (Thurnwald, 1933; 390-92, Bacon, 1954; 54, Krader, 1959; 499). Nomadism assumes different forms depending upon climate, topographic conditions, resources available, the means of livelihood chosen by the wandering group and the preferences of the settled population. In India, there are several grades of nomadic groups engaged in a variety of professions like snake charmers, monkey and bear displayers, acrobats, quack surgeons; hunters and food gatherers; artisans; pastoralists, traders, beggars and labourers (Luiz, 1961; Misra, 1967). Some of them combine more than one occupation for example, they may be traders and pastoralists or traders and artisans, and so on. The different forms of nomadism have been classified as true nomads, semi-nomads and semi-sedentary depending upon the nature of movement (Bacon, 1954; 54). Bacon defines the true nomads as those people who dwell round the year in portable dwellings and who practise no agriculture.

Whatever may be the form of nomadism, the nomads particularly those who move in the Indian countryside are dependent in varying degrees upon the settled people for their subsistence. On the other hand by performing various kinds of occupations, the nomads fulfill the varied wants of the settled people and thus the latter are also dependent on the nomads to some extent particularly in regard to those services and goods which are not ordinarily available in the village or near about. The various wandering groups in India specializing in different trades are examples. They are welcome visitors to the villages (Somasundaram, 1958).

The Gadulia Lohars are one such nomadic group which comes in the category of true nomads. Their main occupation is blacksmithy. It will be seen later how the economy of the Gadulia Lohars is dependent upon the settled villagers and how their movements are affected by the latter's perferences.

The Gadulia Lohars are mainly found roaming in eastern Rajasthan, Gujarat, Madhya Pradesh, Punjab and a part of Uttar Pradesh. In some of the above mentioned places they are known by other names too. In Western Rajasthan, it is reported that many of them have settled down and the information is that in Gujarat too they have started living in houses. In Rajasthan alone, their population was 16,648[1] (Rajasthan Year Book, 1961).

The Gadulia Lohars move in their tiny bullock-carts and it is also their abode which contains all the necessities of their life. Their name is derived from their occupation of blacksmithy and their abode of carts. In vernacular, Gadulia or Gadi stands for bullock-cart and Lohar means blacksmith that is 'bullock-cart blacksmith'.

The object of this paper is to trace the region of movement of a band of the Gadulia Lohars, to show the composition of the band and to find out how far these are related to other factors, such as economy and environment.

The field work on a particular group roaming in the region of Chittorgarh was undertaken between July 1962 and February 1964.

*Contribution from the Anthropological Survey of India, Mysore.

1. *The Rajasthan Year Book and Who's Who,* 1961 do not give source from where these figures have been taken. According to the unpublished report of the committee appointed by the Government of Rajasthan in 1955 to study the question of rehabilitation of the Gadulia Lohars, the population of the Gadulia Lohars in Rajasthan was 16,672. According to 1941 Census (Webb, 1941) the population of the Gadulia Lohars in Rajasthan was 6,970. It may be noted in this connection that more areas have been included in the State of Rajasthan after the integration of Indian States in 1948 and again after the States Reorganization in 1956.

REGION

The subsistence of the Gadulia Lohars is based on blacksmithy work and the trade of bullocks. In order to find work of blacksmithy and opportunities to sell and purchase the bullocks they move from one place to another. This movement remains confined to a region. First, I will define what this region is, in terms of the Gadulia Lohars roaming around Chittorgarh, and then I will show the details of the movement together with the composition of the 'band'.

In the absence of any other suitable term, I am using the term 'band' here in a loose sense for the Gadulia Lohar families which camp and move together for a part of the year. In the remaining part of the year they move from place to place into smaller units of one, two or more families during which time they are engaged in their blacksmith work and trade of bullocks. When the work season is over, they join the larger groups. The district of Chittorgarh in the State of Rajasthan is bound by the district of Bhilwara in the north; to its south and west lie the hill districts of Dungarpur, Banswara and Udaipur. In the east it forms border with the present State of Madhya Pradesh. Chittorgarh was the seat of the kingdom of Mewar till 1568 A.D. (Majumdar *et al* 1950; 449). After the sack of Chittoor at the hands of Akbar, the capital of Mewar was shifted to Udaipur, and though it remained under Muslim domination, Chittorgarh was considered as a part of the kingdom of Mewar. The people of the former State of Mewar even to-day are popularly known as Mewaris. The dialect spoken in this area is also called as Mewari. The people living in the neighbourhood of Chittor though Mewaris are also known as Chittoris. There are many cultural similarities within the former State of Mewar, leaving the hill areas. The distribution of the various cultural traits as found in the former State of Mewar can easily be distinguished with those found in the neighbouring former States of Marwar and Malwa. Thus, a cultural region of Mewar and within that a sub-region of Chittorgarh could be roughly demarcated on the basis of various cultural similarities found in the former State of Mewar and negatively on the basis of the cultural differences from the neighbouring areas. However, now with the improved means of communication and other socio-economic changes, the distinctions between the region of Mewar and other neighbouring areas are progressively disappearing. For a Gadulia Lohar, however, the region of Chittorgarh or Mewar is not the administrative district of Chittorgarh, nor the entire former State of Mewar, nor even the area covered by the Mewari dialect or the cultural region of Mewar; it is something different from all these; but each of the factors mentioned above, though not in entirety, influences and contributes to his idea of Mewar or Chittorgarh region. His idea of the region does not have clearly defined geographical boundaries but is more concerned with the sense of belonging to a particular area. For example, the Chittori Gadulia Lohars go as far as Mandsor in Madhya Pradesh but still claim themselves as Chittori Gadulia Lohars. Nomads are usually known to belong to the place from where they start (Awad Md., 1962; 333). In respect of the Gadulia Lohars, besides the former political boundary, the linguistic and cultural similarities, the aspect of their movement and the place to which they habitually return in the summer season are also factors in determining the regional affiliations. Thus, all those Gadulia Lohars who start from the neighbourhood of Chittorgarh and again return to the same place or near about are known to belong to the region of Chittorgarh. The Gadulia Lohars who live and roam near about Udaipur, which was an integral part of the Mewar State, are not considered as Chittori or even Mewari Gadulia Lohars by the Gadulia Lohars moving out from near about Chittorgarh. The main reason for this is that those who are known as Chittori or Mewari Gadulia Lohars do not have any contacts nor any social or economic ties with those who roam near about Udaipur. So far as the Chittori Gadulia Lohars are concerned, the Udaipuri Gadulia Lohars as well do not exist; there are no social relations of any kind between these two groups which one would have ordinarily thought to be cognate. On the other hand, the Gadulia Lohars coming from Ratangarh side (Ratangarh is on the west of Chittorgarh in the State of Madhya Pradesh; the two places are separated by hills) and going upto Mandsor in Madhya Pradesh are known to belong to the region of Malwa, though not only a part of the route of these two groups is common but they also have social, economic and political ties. The reasons for referring them as belonging to the region of Malwa are that they habitually start and return to the place which is in the former State of Malwa and that they have some differences in respect of food, dress and speech.

Thus, it is seen that the different groups of the nomadic Gadulia Lohars though living in the same cultural and linguistic region, and former political boundaries are not included as belonging to the same region on account of the lack of contacts between them. On the other hand, inspite of having 'effective relations' with another group they are considered to belong to another region on account of their starting and returning place being in another cultural and linguistic region, and former political boundary. Therefore, it can be argued that the region in respect of the nomadic Gadulia Lohars is determined by taking into account, namely, linguistic, cultural, the former political boundaries, the place of starting and return, and the contacts between the different groups. This would be further elucidated in this paper by taking a concrete case of the movement of a band of the Gadulia Lohars.

CHITTORI LOHAR

The region of Chittorgarh for the Chittori Gadulia Lohars extends in the north from Chittorgarh, all along the rail and road route up to Vijainagar (District Ajmer) and Shahpura (District Bhilwara). The eastern side, all along this route, is blocked by the thick ranges of Aravali. To the western side, it extends upto Kapasan or a little farther, beyond that the tract is again difficult mountainous atleast for the easy movements of the bullock-carts of the Gadulia Lohars. In the south, it passes through the narrow streak of plain land along the rail and road route and spreads into the plains of Malwa. At this end the farthest limits are Mandsor on one side, Rampura on the other. The villages falling between this tract are the centres of their operations. Within this region the Gadulia Lohars are split up into a number of bands.

As has been already said, the Gadulia Lohars move in their tiny bullock-carts and it is not easy for them to negotiate the hilly tracts; hence their movements have been limited both in the eastern and the western side. In the north, beyond Chittorgarh and in the south below Neemuch the land is relatively plain and open and these are the two areas where the Gadulia Lohars spread and visit the interior villages for their work.

The Gadulia Lohars, contained in this geographical region, call themselves as Chittori or Mewari Lohar. They distinguish themselves from the Gadulia Lohars of other regions in respect of dress, standard of living, the tools and implements they make and the customs regarding bride-price. The Gadulia Lohars speak their own tongue and also the dialect spoken by the people of the region where they move. This to some extent affects their own tongue by way of taking in some words of the dialect spoken in that area. The Gadulia Lohars of a region also show allegiance, respect and faith in the leaders of the council or Panchayat; they seek help and advice, and requisition the services of these leaders to plead their cases, when required. The region of the council does not have precise and fixed limits but in any case it is much larger than the movement or the economic region. The line of demarcation between the members of the contiguous regions, in respect of the points as given above, is in any case very thin.

MOVEMENT

The area of movement is known as *pharnet* (Hindi, from *phirna* to move about). Now let us take the case of the band which I studied. Their movement is traced from the point which is claimed to be the starting point of the band.

A band of the Gadula Lohars reached in twos and threes around the first week of April, at Gangrar, from Neemuch side. Gangrar is 14 miles north of Chittorgarh, well connected with rail and road. They camped on an open space near the railway station of Gangrar on either side of the Chittorgarh-Bhilwara road. The number of carts* in the camp rose to 51 in the first week of May. Here and in the foregoing account the strength of the band would often be referred to in terms of the number of carts, as it is easier to assess their strength in this way. The Gadulia Lohars themselves refer the strength of their bands in terms of carts. Though, always, one cart does not mean one family, a family may have a set of two or three carts (maximum number of carts, possessed by any family was three). But usually it is two, one is their traditional typical Gadulia Lohar cart, the other is lighter and is known as *Chakra*.

In the same week, five carts left Gangrar for Hamirgarh. There were two other major camps nearby, one was at Hamirgarh and the other was at Lalans. The former is about 8 miles north of Gangrar and the other is 3 miles on the eastern side of Gangrar. There was yet another camp at Barsi which is about 12 miles east of Gangrar. In the middle of the next week, three more carts left Gangrar to join the camp at Barsi. One of them usually does not come to this side. He calls himself a Malwi Lohar and his area of movement extends in the north from Ratangarh to Mandsor and further south. This time he came to this side on account of his friend who insisted that he should be with him for a part of the summers. Now, he was going to join the members of his band. In the third week again some 6 carts left Gangrar.

Towards the last week of May, some major movements started taking place. The camp broke up into smaller units of 4, 3, 3, 10, 13 and 4 and each of the units took a different direction from Gangrar. The families of each of these units are generally closely related, as father, married sons, brothers, and so on. Only in a very few cases it was found that no direct relationship could be traced between the families of the units. The membership to these units is not fixed. Any major blacksmithy work requires the services of atleast four adult persons, though five is considered as an ideal; therefore, those families which cannot provide enough number of workers join with other such families for the purpose of work. Such unions are formed on the basis of kin or ties of friendship. They last as long as they do not develop any feud among themselves.

Each of these units continued in its errands in the interior villages to carry on its work and trade till the month of June. This period, they consider as the season for work and trade for three reasons. Firstly, the farmers in the villages start or are in the process of the preparation of agricultural fields for the rainy season crop during the month of June and hence there is demand for repairs as well as new agricultural tools and implements. Secondly,

*The word cart is being used here for bullock carts.

many of the farmers require bullocks for their agricultural operations at this time. With many of the farmers the practice is that they do not retain bullocks for the entire year; they sell the bullocks when their work is over and purchase again when the time for agricultural operations approaches. The presence of the Gadulia Lohars, for this reason, at such a time comes very easy to them as they get the dealers in bullocks at their door and they have the privilege of examining the bullocks before purchasing, as much as they like. Thirdly, the winter crop is already harvested by this time and so the grains and fodder are easily available in the villages. The Gadulia Lohars during this part of the year generally do the blacksmithy work in exchange for grains and fodder. This is particularly important for the Gadulia Lohars, because the following rainy season is a lean period for them and they must store enough of grains to keep them going till the rainy season is over and they can again visit the villages and find work. During the rainy season, the Gadulia Lohars either stay at one convenient place or they remain on road sides. They cannot enter the villages on account of the muddy paths on which it becomes difficult to ply the bullock carts.

The visit of the Gadulia Lohars to the villages during the month of late May and June, thus, is helpful to both, the nomads who are economically dependent upon the settled villagers, and the settled villagers who derive the service and the goods from the nomads. Both derive mutual benefits from each other.

In the early part of July they again assembled one by one at Gangrar, for about 15 days, and from there they proceeded to Chittorgarh. They halted at Chittorgarh for another 15 days, meanwhile some other bands operating on Kapasan-Chittorgarh-Neemuch area came and halted at Chittorgarh. This gave them the opportunity to meet both affinal and consanguineous relatives and friends of other bands. This is socially important, since they would not be able to see each other for more than seven to eight months. Therefore, they make their movement programme in such a way that the Gadulia Lohars operating on different routes meet each other at such places. The parting is rather painful to observe. The close relatives embrace each other, wailing and crying. The women, while crying, recite some parting songs.

From Chittorgarh they proceeded to Neemuch which is about 35 miles from Chittorgarh, halting on the way at Zalampura, Nimbhera and Kesarpura. Neemuch is another important meeting point and also a business centre. The Gadulia Lohars operating between Choti Sadri-Neemuch-Chittorgarh; Ratangarh-Neemuch-Mandsor-Sitamau-Suwasra-Ujjain (some of them stop at Sitamau, others proceed upto Ujjain); Ratlam-Neemuch; and the band under study reach Neemuch in the later part of the month of September or early October. But during the year of study they reached Neemuch in the middle of September. Their explanation was that in the particular year rains were late and hence they reached Neemuch earlier. The business attraction at Neemuch is that every Sunday a weekly cattle market is held there. The period around middle of October is again good for trading in bullocks, as it is around the sowing period of winter crop, and the farmers are in need of bullocks for their agricultural operations. The winter season, from middle of November to the beginning of February, is considered not good for bullock trading and this period is mainly devoted for blacksmithy work. Besides, the winter season is more suited for blacksmithy work than the summers. In winters, they start their work by eight or nine in the morning and continue to do it till four or five in the evening with a break of one hour or so in the mid-day, while in summers they have to get up early and start their work by six or seven in the morning, and by ten or eleven they have to close it, as it becomes difficult to bear the heat of the sun and forge. They again start the work in the evening, at about three or four and do it till the light permits. They are never happy to work in summers. Those Gadulia Lohars who are well off and those who have earned sufficiently in the previous season, sparingly take the blacksmithy work in summers.

Coming back to the band, after staying for 15 days at Neemuch, they proceeded towards Manasa. While they were staying at Neemuch, they attended each of the Sunday cattle markets. As they wound up the camp at Neemuch towards the end of September, once again it started breaking up into smaller units. Some of them continued to proceed along the Neemuch-Manasa road and some took the route towards the interior villages from Jwasa, a village six miles away from Neemuch.

These smaller units continue to visit the interior villages till the month of February during which time they attend the fair held, in the month of November, at Rampura, 37 miles away from Neemuch. Rampura fair is famous for cattle trading. Some of the Gadulia Lohars also attend the fair held in the month of March at Suwasra, which is about 64 miles from Neemuch. In the period between October-November they move around Neemuch and Jharla. In the latter place also a weekly cattle market is held every Monday. The distance between Jharla and Neemuch is 35 miles via Manasa but they make a short cut which would be 16 to 18 miles. The smaller units are all spread over in the villages between these two places. On the market days they leave their families at the camping sites and take the lighter bullock carts and attend the weekly cattle markets. The rest of the days in the week, they are again back to their camps which keep on shifting from one village to another. The duration of the halt at these villages is dependent upon the availability of work, facilities to stay at the village, such as open space, nearness to water

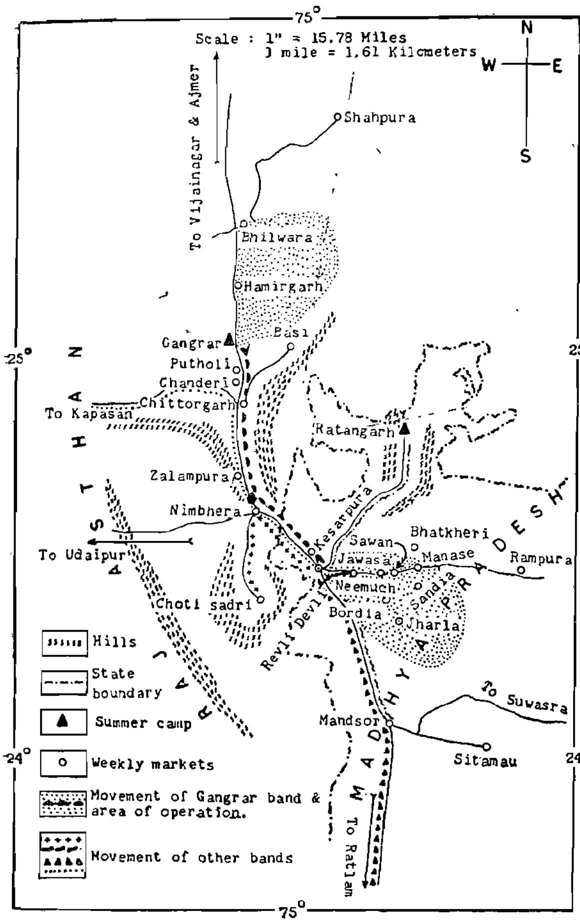

Fig. 1 — The area of movement of a band of the nomadic Gadulia Lohars of Chittorgarh region

source and grazing ground for their cattle. As for the selection of the villages to be visited they have a good knowledge of the entire area and accordingly they have a rough classification of the good and bad villages from the above points of view. They also know where work is available in plenty. The villagers also await their arrival, for the Gadulia Lohars are known for their workmanship, specially in making new things out of broken and scrap iron and for repairs. Such jobs are not taken by the settled Lohars of the villages. Then the rates charged by the Gadulia Lohars are also lower than the others in the field.

On enquiry as regards the number of villages visited by each of the units, from October to the middle of February, it was found out that on an average each of the units visits 28 villages. Often the same villages are visited twice or thrice. There are no fixed number of days of halt as has been stated above nor is there any particular order for visiting the villages.

By the middle of February they start on their back journey and are in the process of getting together from Neemuch itself. This process of assembling continues till they reach Chittorgarh or Gangrar by the middle of March. The route for the return journey is the same as for the outward journey. A rough estimate of the distance covered by them in one full cycle is between 210 and 260 miles.

Picking up the thread of this description from the place the band under study started, the members of the band stayed at Gangrar for nearly 55 days. The period of their stay at Gangrar was utilized, in negotiating and celebrating marriages (two marriages were celebrated during that time), meeting their relatives, making short business visits to the nearby villages, settling outstanding disputes, renewing relationships, fulfilling ritual promises and repairing their carts and tools. The above description, thus gives a complete cycle of movement of a band of the Chittori Gadulia Lohars (*see* map). The movement of the band described above is repeated year after year with minor changes as regards the number of villages they visit, duration of halts and the order of visiting the villages. But the route remains the same and the halts at important places such as Gangrar, Chittorgarh, Neemuch, Sawan and Manasa are also regular.

SUMMARY AND DISCUSSION

The Gadulia Lohars, trace their allegiance to a particular geographical region. The Gadulia Lohars contained in a region are split up into a number of bands. The different bands have different areas of movement within that geographical region. The movement and the halts are organized keeping several factors in view such as climate, sowing and harvesting time, availability of work, fodder for the cattle, facilities for stay in the villages and the weekly cattle markets. The period from middle of March till the end of May is considered to be off-period from the point of view of work. June is good for work and trade; July and August again is off-period for them; and during this time they mostly camp on road sides. From September onwards to late February they are again busy in their work and trade. The trade of bullocks is in its peak in the month of October and middle of November. Towards March they are again back with their earnings to their summer camps. The intervening off-periods are utilized in maintaining and renewing social and kinship ties, and in entertainment.

It has been seen that the size of the band keeps on fluctuating; the membership of a band is maximum in the off-season (for a period of two to three months in summer and rainy seasons) while in the work-season (a month in summer and the whole of winter), the Gadulia Lohars remain dispersed into small work-units of two or three or more households. There is no central authority to control or regulate movements of the individual households. The Gadulia Lohar society gives full freedom to the individual households to exercise their choice as regards movement, joining and leaving a band or camp. However, it was found out that the members of a band always belong to that region in which that band usually operates. Those who are present in a band of the region to which they do not belong, are considered as outsiders and as soon as they finish the task which brings them to a band of another region, they go back to their own region of movement. Within a region, there is no restriction as such, for a person to join one band or the other, but what is observed in this regard is that there are three kinds of bonds which tie the members of a band together. These are patrilineal, matrilineal and affinal ties. To this may be added the somewhat unpredictable factor of friendship which at times may weigh more than any of the structural ties mentioned above.

A band breaks up into smaller units at the beginning of the work-season and is formed again when the units join after the end of the work-season. The membership of a band, however is not static. It is an ongoing concern. It is augmented or depleted by natural events such as birth and death, and social events such as marriage, adoption and partition. In addition to this, feuds between members of a band, important business elsewhere and visits to close kin in other bands may temporarily affect the membership of a band.

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DISCUSSION

L. P. Bharara: Is there any rotational movement among the Gadulia Lohars ?

P. K. Misra: The Gadulia Lohars in Chittorgarh region start from a particular place in a particular season and return following almost the same route to the same place in the same season of the following year. They cover on an average about 200 miles in a year.

J. Dresch: Are there any maps giving the extent of nomadic people, their routes of migration etc. ?

P. K. Misra: Efforts are being made to collect such data and represent them on maps.

SETTLED POPULATION

SOME ASPECTS OF THE HUMAN GEOGRAPHY OF THE INDIAN DESERT[1]

by

S. M. ALI

HUMAN geography has been defined as the study of (a) the adjustment of human groups to their physical environment, including the analysis of their regional experience and of (b) inter-regional relations as conditioned by the several adjustments and geographical orientation of the groups living within the respective regions. The present paper deals primarily with the former while the latter aspect is touched upon whenever regional details are available. However, from both these points of view, there is one region and perhaps the only region of India which has received little attention so far. This region is the vast Desert of India. Considerable work has been done on the various facets of its physical environment and problems. Proceedings and Reviews of symposia held under the UNESCO's Arid Zone Programme since 1951 (Dhir, 1953) and the one on the Rajputana Desert held by the National Institute of Sciences in India in 1952 provide valuable information and comprehensive lists of references on researches done on the evolution, geology and mineral resources, hydrology, climate, animal and plant ecology, soils, geomorphology and archaeology of the Indian Desert.

A glance at the long lists of references would show that studies on the human geography of the Indian Desert as compared with those on its physical geography are practically negligible. The NIS: Symposium on the Rajputana Desert (cited above) brought out some oblique references to the human occupance of the Desert. Sankhalia, Vats and Ghosh (1952) while dealing with the archaeology of Rajputana incidentally refer to population distribution in parts of Rajputana in the past. The papers of Pithawala (1952) and Gambhir Singh (1952) on the ' Geography of the Indian Desert ' deal with its physical geography and with such extraneous topics as the origin of the desert, desiccation, geological formations etc., but scrupulously avoid reference to human activities. Bharadwaj's (1961) paper on ' Land use in the Arid Zone of India and Pakistan ' deals with an important aspect of human geography i.e. the agricultural land-use, its history, crops and cropping techniques, domestication and distribution of animals, and agricultural problems and prospects. A few papers on the Indian Desert were presented at the International Geographical Seminar held at Aligarh in 1956. Chatterjee's (1956) paper on the ' Geographical Features ' on the Indian Desert gives a brief description of its physical features, climate and geological history and mentions some points regarding the control and reclamation of the Desert. Another paper (Ali, 1956) deals with the site, location, evolution and development of urban settlements and analyses the geographical factors affecting urbanization in the Indian Desert. Bharucha (1956) analyses the ecological problem of Jodhpur and Jaisalmer and makes a case for the vegetation mapping of the Indian Desert.

Recently two or three papers have appeared in Indian journals on the Human aspect of the Arid Regions of India. Mukherjee's (1963) paper on Land Use in Mewar Village is an excellent paper on the human occupance of a limited region and considers all aspects of Man-Land relationship. Bose's (1962) note on the human geography of the Arid Zone of Rajasthan is a brief but interesting geographical interpretation of provisional population statistics of Rajasthan 1961 Census and 1956-57 land-use statistics. Sharma's (1960) paper on house types is the only study which deals with another important aspect of the human geography of this region.

THE INDIAN DESERT, ITS LIMITS AND PHYSICAL SETTING

The Indian Desert, for the purpose of the following discussion, means that part of the State of Rajasthan which lies west of the Aravallis and for the sake of convenience the administrative districts of Jaisalmer, Jalore, Jodhpur, Pali Barmer, Nagaur, Bikaner, Ganganagar, Sikar and Jhunjhunu only are considered, although the desert extends beyond their limits in all direction except towards the south-east. The total area of these districts is 80,662 sq. miles. Its outstanding common characteristics are low latitude, low level and constant drought.

The surface of the desert is sandy, scantily watered and unproductive but improves gradually from a mere desert in the far west and north-west to comparatively fertile and habitable lands towards the north-east. On the whole, the character of the region is the same everywhere. It is covered by sand-hills, shaped generally in long straight ridges (or tibbas), which often run parallel for long distances. Some of these ridges may be two miles long and from 50 to 100 feet or even more in height; their sides are eroded by water, and at a distance they look like substantial low hills.

1. Contribution from the University of Saugar.

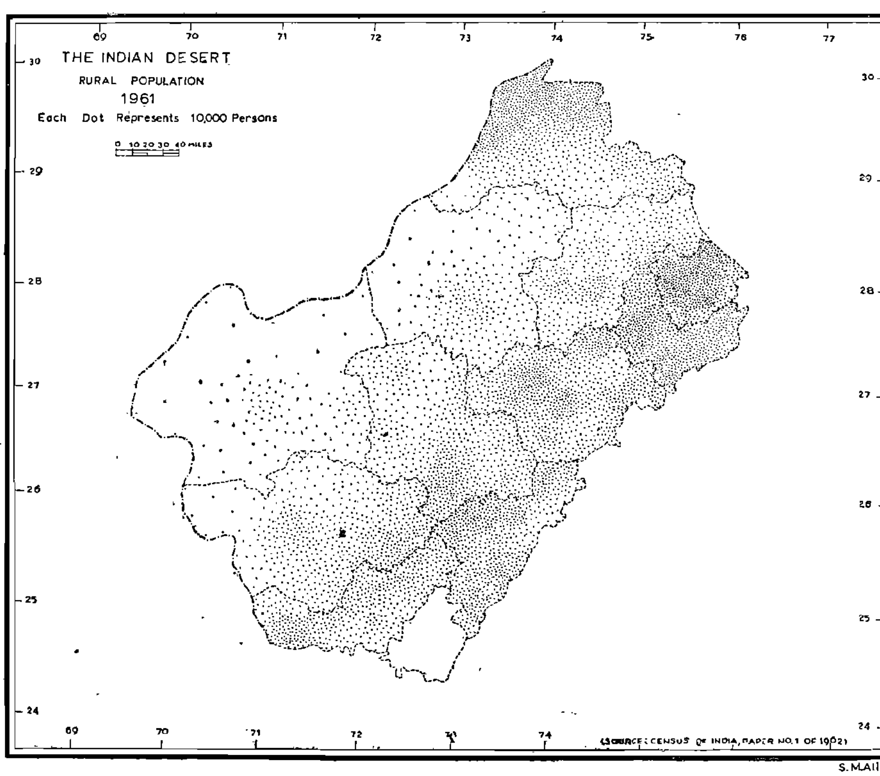
There are, however, minor variations of surface characteristics in the vast expanse of the desert. In the midst of the typical erg desert of the shifting sand-dunes (locally termed *dhrians*) which extends from the Luni to the northern and western borders of Rajasthan, there are patches of bare rocks or deserts covered with boulders and stones, extensively developed round Jaisalmer. Isolated hills of solid rocks of inselburg type varying in height from 1000 to 2000 feet are scattered all over the sandy plains. Several off-shoots of the Aravallis appear in Jalor, Jodhpur and Bikaner which sometimes reach a height of 200 to 300 feet, and command all uninterrupted view of the surrounding desert and the desert trials crossing it.

Another characteristic feature of the desert is the occurrence of wind eroded hollows or depressions of various sizes and shapes all over the area particularly in the eastern half of the region. These depressions are important for the human points of view, since they are invariably associated with settlements where population depended or depends on them for drinking water or for the manufacture of salt.

The characteristic features of the climate of the desert are its dryness and extreme ranges of temperature. The mean annual rainfall which is highly erratic varies from about 7 inches in Jaisalmer to about 17″ on the western slopes of the Aravallis. In fact, the 15 isotype roughly marks the entire eastern boundary of the desert and the rainfall decreases and its variability increases progressively as one moves towards northwest from any point on the eastern margin. Most of the rain comes in the months of July and August in brief spells but there have been years in which one or other or both of these months have been completely dry in some parts of the desert. The heaviest rainfall ever recorded in a day was 3·9 inches in June at Ganganagar, 5·5 inches in August at Bikaner, 8·5 inches in September at Jodhpur and 5·3 inches in August at Barmer. On the other hand, Jo dhpur has sometimes received only ·96″ of rain and 1·14 inches in the whole year.

THE POPULATION PATTERN

In a land where agriculture is the predominant occupation (with density of population 94 per sq. mile) and mining is still under-developed, the importance of water cannot be over emphasized. The distribution and density of population can be expressed in terms of the availability and suitablity of surface and underground water and the relation between these two is so intimate that we may reconstruct a rough population map of the whole region with the help of rainfall, drainage and water-table maps. Population density increases where the rainfall increases or the water-table approaches the surface (Map 1). The highest densities in popu-



Map 1

lation occur in the piedmont belt of the Aravallis all along its western border particularly in Sheikhawati* and a narrow zone between the Sutlej and the dry bed of the Ghaggar in the extreme north. The former widens in the south-west where the Aravallis rise to a respectable height (Mt Abu, 5650 ft) and the Luni and its tributaries raise the water level and carry the surface water during the rainy season to some distance into the desert where it is lost in the thirsty sands. The crude density of population in Jhunjhunu is 315 persons per sq. mile, in Sikar 271, in Pali 168, in Nagaur, 136, and in Jalore 111. Proceeding towards the west the densities decrease fairly rapidly from 103 in Churu, 130 in Ganganagar and 101 in Jodhpur to 64 in Barmer, 42 in Bikaner and 9 in Jaisalmer.

The relationship between the distribution of population and availability of water is obvious in an arid or semi-arid land but variations in densities of population do occur on account of differences of topography, soil, lands, occurrence of economic minerals, accessibility and other economic and social factors. In the following paragraphs some of these factors which effect agricultural activity have been considered in relation to the incidence of population, since in any geographical region, human groups adjust themselves to the environment through their predominant occupation.

As agriculture in the Indian Desert mainly depends on rains, the crop pattern is dictated by the nature of the soil and rainfall. The usual combination of crops is *Bajra*, pulses, and oilseeds. *Bajra* is the first crop and sometimes the only crop in practically all the districts of the Desert except Ganganagar and Pali where canal and well irrigation respectively make wheat, oilseeds and cotton more important than the *Kharif* crops which depend mainly on summer rainfall. If we leave out irrigated land, there is an apparent correspondence between rainfall, average of various unirrigated crops and population density. In irrigated areas, however, there is a direct relationship between population density and intensity of irrigation.

The Canal Colonies of Ganganagar are naturally fairly well-populated regions of the Desert but from the point of view of pressure of population the well- or tank-irrigated areas within the districts of Nagaur, Jodhpur, Sikar, Pali, Junjhunu and Jalore are more important than the former, since they occupy large areas with much higher densities of population. These are the areas where well or tank irrigation is possible on account of higher water-table near the foothills of the Aravallis or in the vicinity of the Luni and its tributaries.

Roughly to the west of a line joining Suratgarh, Ratangarh, Jodhpur and Gurha (on the Luni) the character of the soil changes with scantiness of rainfall and the water-table sinks abruptly so that irrigation is limited to a few favourable patches. Here, too, two main sources of supply available to the villages are wells and tanks into which water is led by means of an imperfect system of channels or ditches, but on account of the prevalence of salt in the subsoil, the water in the majority of the wells is brackish to saline, and is mostly unpalatable and undrinkable. Of the total number of wells in the Jodhpur, Bikaner and Jaisalmer districts hardly 50 per cent contain potable water; hundreds have been allowed to become derelict owing to increasing salinity since they were first sunk or because they contained only saline water originally. Wells suffer from another disadvantage as it were, viz. the immense amount of labour required to draw sufficient water for the inordinately large herds of cattle, sheep and goats possessed by the villagers. In areas of light sandy soil and a very low water-table, deficient or badly distributed rainfall results in a failure of the staple crops and in scanty grass, thus depriving both man and beast of their means of subsistence. As this is rather the rule than the exception, the people are semi-nomadic in habit and on the advent of a period of scarcity they drive off their animals to long distances, even beyond the limits of the State to the south-east and north-east, in search of grazing for the cattle and work for themselves. Since these migrations are of frequent occurrence, the villages are small and the density of population fairly low and variable. The percentage of agricultural population decreases with the percentage of net sown area (to the total area), and pastoralism becomes the secondary occupation of the people. This region includes the southern Ganganagar, Nagaur, western Sikar, Jodhpur and Barmer districts (beyond the Luni Valley). The density falls to 9 persons per sq. mile in Jaisalmer and the adjoining *tehsils* of surrounding districts where pastoralism dominates and precarious agriculture is practised in only about 2·2 per cent of the total area.

The pressure of population may best be judged by comparing the total population and the total sown area (=net sown area + area sown more than once) in the different districts of the Desert. Roughly speaking the number of persons per sq. mile of sown area is more than 400 in Pali, Jhunjhunu, Sikar, and Jaisalmer, i.e. in the wettest and driest districts of the Desert. In the former it is the intensive cultivation which sustains the high density of population while in the latter cultivated area is very limited and pastoral activities supplement agriculture. In fact the lowest density per sq. mile of net sown area occurs in Barmer (160), which has an annual average rainfall of 10·37″. As rainfall decreases below this figure this density (persons per sq. mile of sown area) increases i.e. Churu (rainfall 9·05″, density 176), Ganganagar (8·58″, 237) Jaisalmer (7·05″, 404). On the other hand where rainfall increases above this figure, the density also increases i.e. Bikaner (rainfall 11·7″,

*The two districts of Jhunjhunu and Sikar formed an old principality called Sheikhawati.

density 280), Nagaur (12·17 , 232), Jalore (1·398″, 206), Jodhpur (14·21″, 273), Pali (15·35″, 446), Jhunjhunu (15·75″, 420) and Sikar (16·95″, 404).

POPULATION CHANGES

The total population of the Indian Desert adds up to 7·6 million according to the 1961 census; it was 5·9 million in 1951. This gives a net increase of 23 per cent during the decade 1951-61. The corresponding figures for India and Rajasthan for the same period are 21·50 and 26·20 respectively.

Map No. 2 shows the percentage increase of population in each district of the Indian desert during 1951-61. The map is not very helpful since a district is too large a unit to bring out regional variations. However, one may observe from the map that:

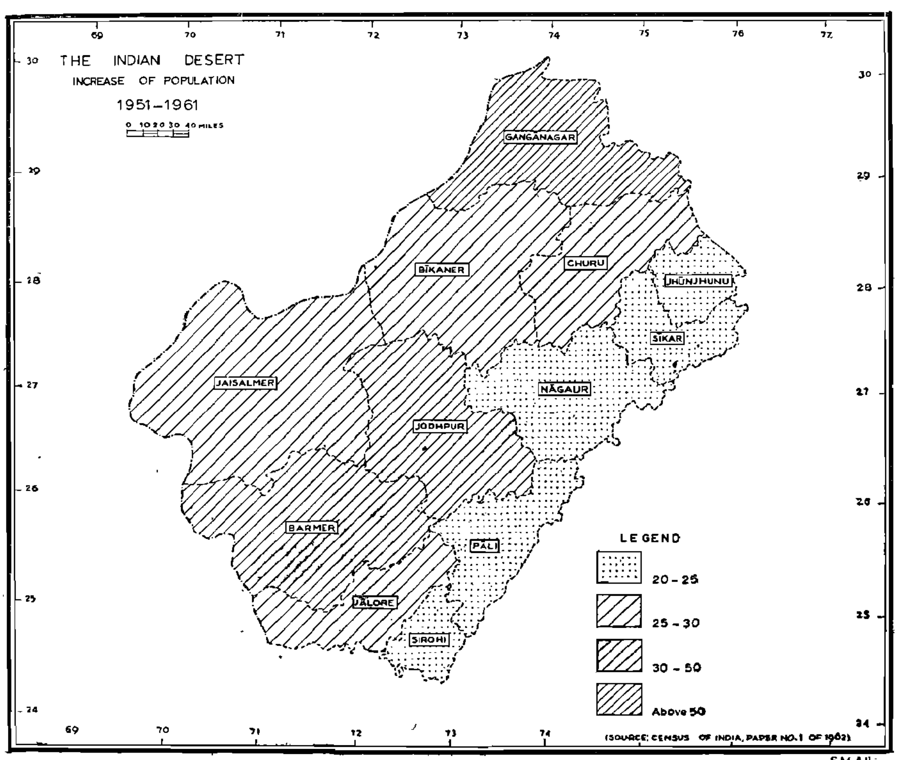
(a) The lowest increase of population (below the State average of 26 per cent) occurred in a belt of the Desert which abutts the Aravalli foothills on the west. This belt consists of the districts of Pali, Nagaur, Sikar and Jhunjhunu i.e. the land of settled agriculture where the average annual rainfall is 15-16″ and the incidence of rural population to the net sown area is fairly high as compared with districts on its west.

(b) Similar to this belt, but with a slightly higher increase of population (29 per cent) is Jaisalmer, the district which represents the core of the desert. The economy of the district is mainly pastoral and the number of sheep per person of rural population is by far the highest in the Indian desert.

(c) In between these zones lies the zone of marginal agriculture. This roughly includes the districts of Jodhpur, Bikaner and Barmer. The percentage increase of population in this zone exceeds 30. Here the increase of population, as will be seen from the following paragraphs has been highly variable in the past decade.

(d) The district of Ganganagar or rather the newly created canal colonies record the highest percentages of increase of population i.e. 65 per cent, for obvious reasons.

It may, however, be observed that the population increase during the decade 1951-61 only presents a phase of the population changes in the region. These changes are (a) short-termed and (b) long-termed. A year or period of deficient rainfall may disturb the population equilibrium and deficiency of water and fodder in this marginal zone may drive man and cattle to adjoining regions. This applies particularly to zone C mentioned above. The long-term changes in population, say, in a period



Map 2

of 50-60 years, require a closer examination. An analysis of such changes has been attempted below, with the help of the variability index of the population.

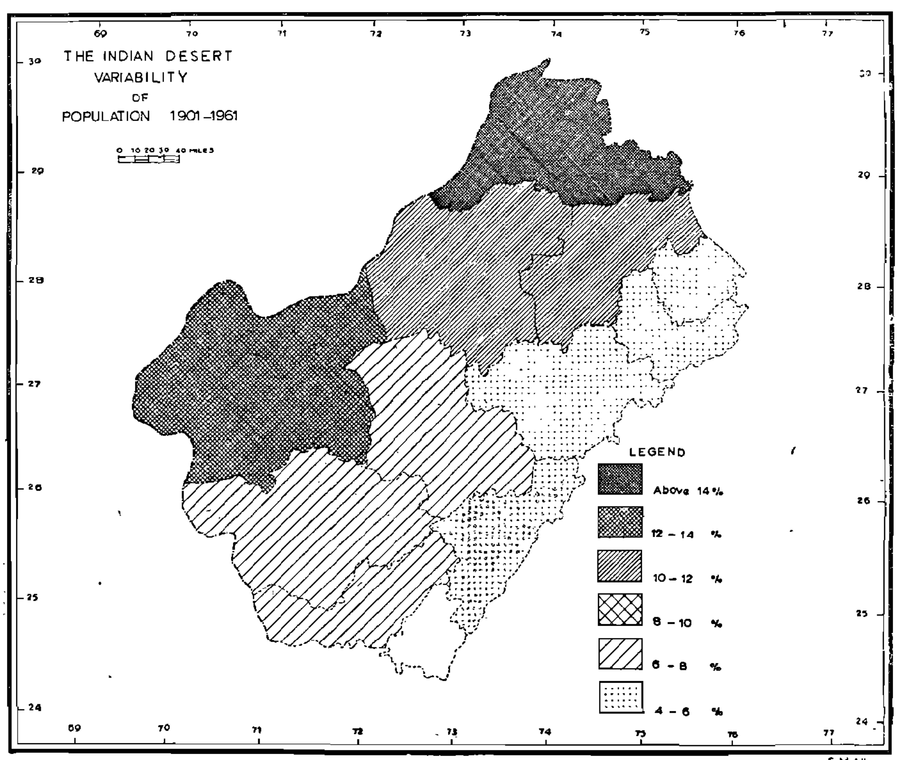
THE INDEX OF VARIABILITY OF POPULATION

The formula for the index of variability of population was devised by Dr A. C. Aitkin and was first applied by Geddes (1941a) to the analysis of population statistics in 1939 and was further elaborated by him in 1941. He argued that where a really large increase of population has taken place unaided by immigration, it can have been reached by continuous increment, but where the population is the same as fifty or sixty years before, it may mean either of two things: a recurrence of disaster, when drought and famine or epidemic declimated the population, or a condition of real stagnation. In the former case decennial rates will show extreme variation in the latter they will hardly vary. Such contrasts are brought out by the index of variability.

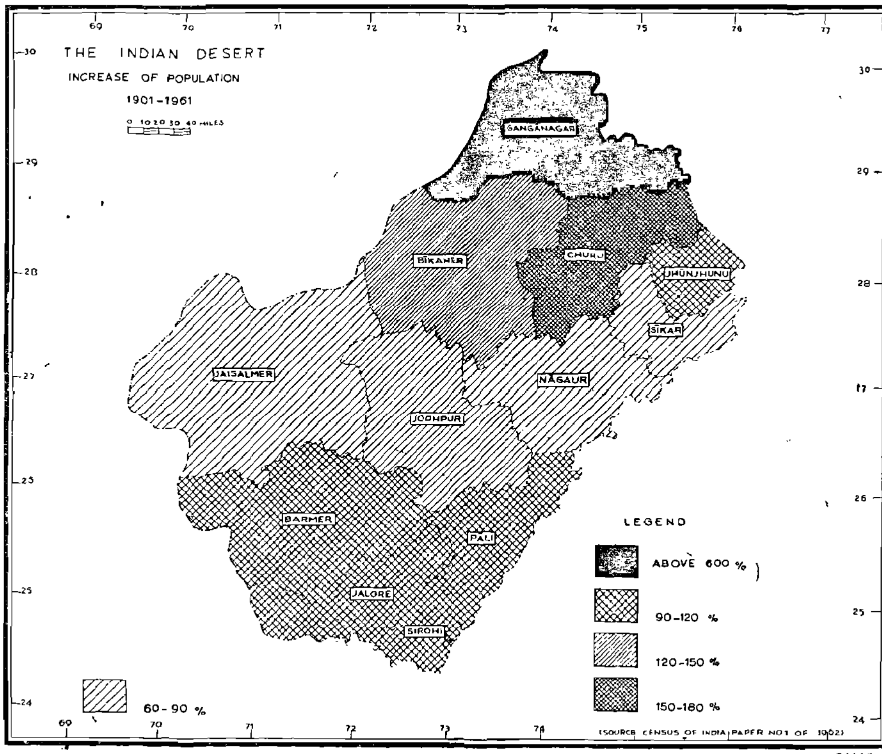
By Dr Aitkin's method a smoothed curve was obtained without the aid of logarithms by correcting a straight line interpolation. It was assumed that the smooth curve was exponential, passing through the first and last given points (i.e. the population at 1901 and at 1961), and an average deviation of the given values (for each census year) from this curve was constructed, being expressed as a mean of the first and last values. In evaluating the mean deviation it was decided to divide it by 6. The variabilities were then plotted on a map which gives a fairly clear idea of the changes of population for each district. As the administrative units and their boundaries changed between the years 1901-1961, the previous census counts were roughly adjusted for the present boundaries of the districts (Map 3).

If we compare the map showing the variation in the population of the Indian Desert (1901-1961, Map 4) and the map showing the indices of variability for the same period in different districts and examine their relationship with the help of the 1961 population density map we could make a few broad observations:

(1) The districtof Ganganagar (1961, Pop. 1, 037, 000 and density, 130 persons per sq. mile) shows the highest net increase of population in the period 1901-1961 (c = 626). It has also the highest variability index (v = 14·4). A very high c supported by an equally high v indicates abnormal increase due to irrigation and colonization which actually



Map 3



Map 4

occurred in the canal colonies of this district. The present density of 130 persons per sq. mile is low as compared with the eastern districts of the Desert i.e. Jhunjhunu (315), Sikar (271) and Pali (168). This shows that large areas in this district which are away from the canals are still scantily populated.

(2) The districts of Nagaur, Sikar and Jaisalmer are regions of lowest net increase (c = 78·1, 89·1, 89·0 respectively) but the index of variability for the first two is fairly low (Nagaur, 4·7% and Sikar, 4·3%) while that for the last is notably high (v = 12·4%). Thus Sikar and Nagaur suffer from relative stagnation while Jaisalmer has been subject to recurrent crises. It is to be noted that Sikar lies within the belt of 15-16″ rainfall and highest well-irrigated area (next to Pali) while the Jaisalmer district depends entirely on rainfall (7·05″).

(3) In the districts of Pali, Jhunjhunu, Jalore, Jodhpur and Barmer the value of c (or the net increase) is nearly the same (= 104·8, 110·2, 102·2, 106·3 and 106·0 respectively) but v is comparatively high in Jodhpur (V-7·7%) and (6·8%) and fairly low in Pali (v = 4·9%), indicating a variable increase in the former districts and steady natural increase in the latter.

(4) Bikaner and Churu both show a high net increase (c = 134·9 and 153·5 respectively) and v for both of these districts is very nearly the same (= 11%). This indicates checks and losses in both districts due to droughts, famines and periodic exodus.

The above analysis of population changes in the Indian Desert is neither complete nor conclusive. The units are too big for bringing out regional patterns by c and v relationships. Tehsils or even smaller units would have revealed the behaviour of population groups in the Desert more convincingly and in a more realistic manner.

SETTLEMENTS

As mentioned above, inspite of the scarcity of water the region under study has always been predominantly agricultural in outlook. 81 per cent of the total population is rural and only 19 per cent of the total lives in towns and cities. The rural area again has a medieval-type village system. Beset for centuries by the dangers of political instability e.g. organized banditry, confiscatory taxation, military looting and local tariffs, the whole population in general, and urban population in particular, has agglomerated for mutual protection in compact units. In rural areas, the culturable land round the settlements had been out into strips to equalize for the villagers, the advantages and disadvantages of the surrounding terrain. Some land, of course, was left for common pasture, and some as waste-land. The site is necessarily near the water supply but wherever the land is subject to occasional floods during the monsoon, the settlement is perched on the nearest level or high mound above the highest flood-level. In many settlements, the remains of the old forts still exist and the ruins of walls within which the local headman or chief resided, and within which the villagers collected together for safety against passing armies, freebooters or tax-collectors, can be easily traced. The *abadi* or village site is often congested, and when a village site is completely filled up by houses or where for social reasons an untouchable caste has to be segregated small hamlets are sometimes formed, which may be situated on the sides of main tracks at some distance from the *abadi*. Otherwise the same tiny self-sufficient-rural village persists even today and a compact settlement with its temple, tank and a struggling bunch of *acacias*, *tamarix* and *zizyphus* in the midst of yellowish sand is still the dominant feature of the landscape.

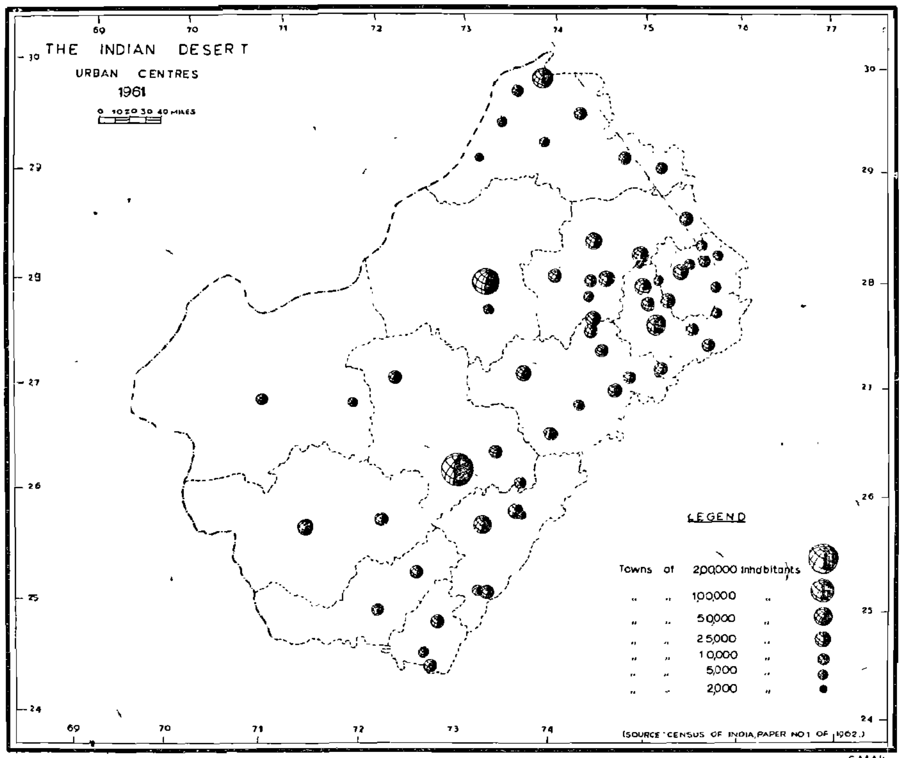
Towns are bigger villages, or to be more correct, bigger rural settlements. No satisfactory definitions of a village or town have been devised for these regions which may ensure a uniformity of interpretation. The designation of areas as urban or rural is so closely bound up with historical, political, cultural and administrative considerations, that the process of developing uniform definitions and procedure has become exceedingly difficult. The most convenient but rough method of classifying settlements as rural or urban is to label them according to their size irrespective of their livelihood pattern or functional structure. The method had so far been applied in all Indian census reports and all settlements having a population exceeding 5000 were treated as towns. In the 1951 census report a change was introduced. All centres of population where Municipalities, Town Boards, Cantonments or Notified Areas existed, were given the status of a town, irrespective of their size. A settlement which possessed this amenity or organization was presumed to have achieved a definite urban character. In the 1961 census towns were determined on the basis of a number of empirical tests: (a) a density of not less than 1000 per sq. mile (b) a population of 5,000; (c) three-fourth of the occupation of working population should be outside of agriculture; and (d) the place should have, according to the Superintendent of Census of the State, few pronounced urban characteristics, the definition of which, however, leaves room for vagueness. These tests eliminated a fair number of places which had passed for town in the past and led to the emergence of new places as towns in 1961. Towns with a population of 100,000 or more were treated as cities. The number of towns in the desert region recorded in the Census Report, 1961, is 66 (as against 87 in the 1951 Census) and the number of cities, two.

THE DISTRIBUTION OF TOWNS IN THE DESERT

A glance at the map (No. 5) will show that the towns of the desert are very unevenly distributed over the whole area. No definite distributional pattern is apparent in the first instance with the exception of the simple fact that the frequency of settlements decreases toward the west and north-west. On closer examination, however, certain facts are revealed which help in the recognition of some patterns related to the physiography, water bodies, lines of communication, particularly railways, mining and other geographical factors.

If we compare the relief map of the region with the urbanization features shown in this map, it becomes clear that relief alone cannot account for the degree of urbanization. Considering particular tracts in the hilly region of the east and south-east one finds significant differences advantageously, not because the slopes of the hills offer suitable vantage points for urban centres, but because such centres have taken root in the flat-bottomed valleys or basins in between the hills of the Aravalli system or in the northern piedmont belt and have thrived on the waters brought down their slopes during the rainy season. It is significant that the towns thus associated with the Aravallis increase in number towards the north-east, where latitude and longitudinal extension, and towards the south-east, where altitude raises the rainfall average to 18-20″. Although it does not mean more than its face value, it is a striking fact that out of 66 urban centres of the region, 75 per cent lie between the 1000 and 2000 feet contours although the area between these heights is hardly 20 per cent of the total area. Besides, outside the limit of the 1000 feet contour there are at least 6 towns including the city of Jodhpur which lie in the shadow of isolated hills which evidently serve as bastions against the sand-laden hot winds in summers and provide water for the adjoining tals or *jhils* and in the past suggested a suitable site for forts to protect the town below. All such towns are the oldest towns of the area and have been at one time or the other, the capitals of large kingdoms or headquarters of local chiefs. Barmer clings to a hill the height of which is 1388′, Jaisalmer lies by the side of the famous three-peaked hill — Trikuti, Sojat, Jalore and Siwana sleep in the shadow of hills, 1105′, 2409′ and 1500 ′ high respectively, while the largest city of the desert, Jodhpur is sheltered by hills on three sides, their peaks rising to 1000 to 1500 feet a.s.l. and 400-700 feet above the general level of the surrounding country.

The relation of urban settlements to water specially when it constitutes a seasonal or perennial stream or lake, is clearly brought out. In the eastern and south-eastern piedmont on the waterlines between the Aravallis and the main axis of the Luni are the outstanding cases. Here, for obvious reasons, the urban settlements in the sense



Map 5

defined above, tend to occur on the banks of the tributaries of the Luni. Pali lies on the left bank of the Mitri, Sadri on the right bank of the Mitri, a small stream which is lost in the sand before it could reach the Luni. Sadri is situated on the right bank of the Sukri, Pali on the right bank of the Bandi and Sojat on the left bank of another stream which is also named Sukri. Balotra is on the Luni itself and Bilara lies hardly 3 miles away from the confluence of the Raipur Luni and the Luni. Even the dry beds of the Ghaggar and Naiwal in the north appear to have influenced the establishment of old fort towns, e.g. Anupgarh, Suratgarh and Hanumangarh on the Ghaggar and Gajsingpur, Ganganagar and Singharia on the Naiwal. The latter group is however, associated now with perennial canals which carry the waters of the Sutlej to the northern fringe of the Desert. In general, about 16 per cent of the total number of settlements are on the natural or artificial water lines, seasonal or perennial, which are of importance at present or were so in the past.

The lakes or tanks, natural and artificial, affect the site and size of settlements according to the quality and quantity of water which they contain. Their relation is threefold. If they hold fresh water, the size of settlements is directly proportional to the amount of water available during the long dry season, and the area of their dry bed which can be utilized for the cultivation of cereals or vegetables. Salt-pans or Sars where salt deposits are thick enough to be of commercial value, have given rise to towns of moderate size. Devi Kund, five miles east and the artificial tank of Gajner 19 miles S.W. of the city of Bikaner, Mulraj Sagar and Amar Sagar of Jaisalmer, the Jaswant Sagar of Bilara, the Rani Talab and the Gulab Sagar of Jodhpur, the Ramdev Sagar of Pokran, the Bhap Talao of Barmer, the Hemawas Tank of Pali are some of the well-known natural or artificial lakes of the Desert. In fact, the whole of the desert region, except the piedmont zone is studded with big and small tanks and lakes serve as the sole or supplementary source of water for the nearest towns or cities.

Sars (Salt pans) have given rise to many an important centre in the Desert. Although at present the number of towns which derive their importance from salt (sodium Chloride, Sodium Sulphate and Saltpetre) is few, there are quite a few settlements which started their career as salt centres. Although their importance as producers of salt is eclipsed today by larger deposits elsewhere in the Desert, they still retain their characteristic name which invariably ends with *sar*. For instance the towns of Lunkaransar, Bhinasar, Napasar, Rajaldesar, and a number of smaller settlements such as Rewatsar, Pandusar, Bisrasar, Kesardesar, Bachasar, Randisar etc. suggest their association with dry pools or lakes.

Railway communications have been particularly effective in the development and growth of towns in the area. These towns appear to be fairly well urbanized, judging from the average standard of urbanization of the region and the frequency of railway tracks appears to correspond with changes in urbanization frequency. Out of the 66 towns and 2 cities of the area, 40 towns and 2 cities are served by railway i.e. 50 per cent of the urban centres are directly on the railways but conversely, they have in general followed urbanization. There are quite a few cases where railways in conjunction with other less important factors have raised new towns out of old straggling settlements e.g. Anupgarh, Hindumalkot, Gajsinghpur and Karanpur in the northern parts of the Desert. It may be added that points of railway convergence are nearly always marked by a town or a city and it may be said that railways are the cause of the rise of such settlements. This is true of a number of cases but it cannot be accepted as a general principle.

Natural routes important for centuries, significant passes, valleys, and paths may be correlated with the urbanization frequency in three instances only, namely, along the old Delhi-Multan, Delhi-Sind and Delhi-Gujrat routes except where the most difficult route crossed the rocky and desolate desert through Jaisalmer, the railway lines joined the then existing towns aligned along the old routes and thus very nearly adopted the same old pattern.

Mining nearly always affects the frequency of settlements. It leads to the agglomeration of settlements in some areas of the Desert where the deposits are workable and this particular occupation is profitable. Lignite beryle, sandstone and glass-sand add to the importance of Bikaner, gypsum to that of Lunkaransar, Suratgarh and Jaisalmer, Fuller's earth to Jodhpur and Bhinaml; it is, of course, a well-known fact that Makrana is the marble town of Rajasthan.

Regional differences in land utilization do explain the difference of urban frequency as studied here. The canal irrigation area of the north the well-irrigated tracts of the north-eastern corner of the desert (i.e. Sheikhawati), the piedmont zone of the south-east, the barani area in Jodhpur and Bikaner and the cases of the Desert in the west differ strikingly in urbanization but they are not of much use as a basis for an explanation of urbanization differences.

CONCLUSIONS

1. The Indian Desert, as defined earlier, represents an area of great variations, not only in climate but also in human occupation and concentration.

2. On the basis of natural environment land-use, urbanization, density and variability of population, the Indian Desert can be divided into 4 broad regions.

(a) The Canals Colonies of the north.
(b) The western piedmont zone of the Aravallis.
(c) The marginal belt between (a) and (b) above and (d) below.
(d) The arid desert.

3. The above study is incomplete inasmuch as it is based on districts as units of population and landuse. It only indicates an approach to the study of the human geography of the desert, which may be of practical value if intensive work is done on the basis of smaller units.

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MAN, LAND AND LIVESTOCK IN THE ARID ZONE[1]

by

A. B. Bose and S. P. Malhotra[2]

INTRODUCTION

The increasing pressure of population on resources is a problem of serious magnitude in developing countries impeding economic development and consequently efforts to raise the standard of living of the people. Several economists had earlier pointed out the consequences of uninhibited population growth and discussed the nature of relationship between resources and population (Mukherjee, 1938, 1946; Ghosh, 1946; Ganguli, 1938; Singh, 1947). The falling death rate due to improved medical facilities, means of communication and checks on natural factors have accentuated the gravity of the problem since the birth rate has remained disquietingly constant. Earlier studies in the Institute based on secondary data show that in the arid zone of Rajasthan too this problem is acute since the population increase here has been higher than in the semi-arid parts. Agriculture, which is the chief source of livelihood, has reached saturation point. Since the resources are extremely limited, the large increase in numbers has put a severe strain on the economy of the region (Bose, 1961).

Land use, demographic features and sources of livelihood were studied in the Central and Lower Luni basin, western Rajasthan, through a sample survey of 13 contiguous Community Development Blocks covering 1,188 villages spread over about 28,000 sq. km in eastern Barmer district, whole of Jalore district and Sheoganj *tehsil* in Sirohi district. Aridity is more pronounced in the north-western side of this region, the normal annual rainfall varying from about 270 mm in the north-west to about 400 mm in the south-east. There is, however, extreme variability in the distribution and quantity of rainfall. The Luni and its tributaries are ephemeral, the flow of water depending upon the intensity of rainfall in the catchment. Blown sand occurs throughout the region, but is more pronounced on the western part, hill slopes and close to major water courses which are Luni, Sukri, Jawai, Khari and Kishnotri. The vegetation is sparse varying from a dry deciduous to a low thorn forest. The region is, in general, inhospitable except for some favourable pockets and is characterized by extremes of temperature and hot dessicating winds in summer.

For the collection of data a two-stage sampling procedure was followed. At first stage a sample of one in fifteen villages was taken by the method of systematic sampling. In each sample village all the households were enumerated and a sample of twenty per cent households drawn by the method of simple random sampling. From the heads of sample households schedules were filled by field investigators. The period of enquiry was 1961-62. Secondary data pertaining to land use, area under crops and livestock were obtained from the *tehsil* office.

LAND UTILIZATION

The land utilization pattern in the different *tehsils* given in Table 1 shows that the cultivated and fallow lands together occupy more than four-fifths of the total land area. The data also indicate the utter inadequacy of the land classified as forests or as permanent pasture and grazing land. *Tehsils* of Barmer, Pachpadra and Sanchore do not have even one per cent of the area under irrigation. In the other *tehsils* the extent of irrigated area is about five per cent. The chief source of irrigation is wells. Thus the bulk of the cultivated land grows only *kharif* crops which are entirely dependent upon the vagaries of the rainy season.

DEMOGRAPHIC FEATURES

It is a paradox that even the arid regions have a high rate of population growth. The percentage variation in population between the years 1901 and 1961 is 102·8 per cent in the arid parts of Rajasthan as compared to 92·1 per cent in the semi-arid parts.

In the absence of statistics regarding births and deaths it is difficult to assess correctly the relative importance of the different factors influencing the growth of population. It seems, however, that the birth rate has been fairly constant while the falling death rate due to improved medical facilities has given the spurt to population growth. Migration has had a very limited influence on the growth of population in the arid zone because of the social inertia towards out-migration and the absence of economic factors favourable to inmigration.

1. Contribution from Central Arid Zone Research Institute, Jodhpur.
2. Sociologist cum Economist and Research Officer respectively.

TABLE 1: Land utilization (hectares) in different *Tehsils* (1960-61)

Uncultivable	*Pachpadra*	*Siwana*	*Barmer*	*Jalore*	*Ahore*	*Sanchore*	*Bhinmal*	*Sheoganj*
a) Forests	74·9 (0·02)	2,178·0 (1·06)	—	1,347·8 (0·59)	159·8 (0·09)	162·3 (0·05)	3,928·3 (1·14)	2,000·4 (2·23)
b) Hills	6,955·3 (2·00)	26,294·5 (12·85)	23,510·2 (2·06)	6,336·2 (2·81)	8,072·7 (4·33)	44·9 (0·01)	20,823·1 (6·05)	20,789·9 (23·22)
c) *Usar* and barren land	10,621·0 (3·06)	4,156·5 (2·03)	19,593·7 (1·72)	12,786·0 (5·69)	6,428·8 (3·45)	22,383·2 (7·41)	19,120·6 (5·55)	5,874·0 (6·56)
d) Land put to non-agri. use	14,253·0 (4·12)	9,553·0 (4·67)	20,756·8 (1·82)	7,196·5 (3·20)	6,581·4 (3·53)	5,957·8 (1·97)	13,916·7 (4·04)	3,331·8 (3·72)
e) Permanent pasture and other grazing land	9,535·6 (2·75)	8,202·2 (4·01)	38,330·6 (3·37)	10,729·4 (4·77)	7,648·2 (4·10)	14,476·8 (4·79)	16,650·8 (4·55)	6,008·4 (6·71)
Total	41,439·8 (11·97)	50,384·2 (24·63)	102,191·3 (8·99)	38,375·9 (17·07)	28,890·9 (15·52)	43,025·0 (14·26)	73,439·5 (21·35)	38,004·5 (42·45)
II *Cultivable Fallow and Banjar Lands*								
a) Fallow	11,169·2 (32·23)	49,989·2 (24·44)	336,620·1 (29·63)	52,688·5 (23·45)	52,703·5 (28·31)	70,586·7 (23·40)	58,793·4 (17·09)	15,952·7 (17·82)
b) *Banjar*	21,475·2 (6·25)	11,198·1 (5·47)	31,609·4 (2·78)	2,532·9 (1·12)	3,161·0 (1·70)	23,679·1 (7·85)	5,517·8 (1·60)	4,499·3 (5·02)
c) Others	— (—)	5·6 (neg.)	1·6 (neg.)	— (—)	— (—)	3·8 (neg.)	31·4 (0·01)	— (—)
Total	133,172·4 (38·48)	61,192·9 (29·92)	368,231·1 (32·41)	55,221·4 (24·57)	55,864·5 (30·01)	94,269·6 (31·25)	64,342·6 (18·70)	20,452·0 (22·84)
III *Cultivated*								
a) Irrigated	2,717·5 (0·79)	5,205·1 (2·54)	1,462·5 (0·13)	12,457·4 (5·54)	12,519·4 (6·73)	18,18·2 (0·60)	16,713·1 (4·85)	7,586·6 (8·50)
b) Unirrigated	168,929·7 (48·81)	88,620·9 (43·33)	664,837·6 (58·51)	120,858·7 (53·78)	90,183·5 (48·45)	164,138·2 (54·40)	195,464·1 (56·83)	24,745·3 (17·60)
c) Total cropped area	171,647·2 (49·60)	93,826·0 (45·88)	666,299·1 (58·64)	133,316·1 (59·33)	102,702·8 (55·18)	165,956·5 (55·01)	212,177·3 (61·68)	32,332·0 (36·11)
d) Double cropped area	204·4 (0·06)	902·4 (0·44)	593·3 (0·05)	2,225·8 (0·99)	1,339·1 (0·69)	1,571·4 (0·52)	6,016·9 (1·74)	1,258·6 (1·41)
e) Net area sown	171,442·8 (49·54)	92,923·6 (45·43)	665,706·8 (58·59)	131,090·3 (58·34)	101,363·7 (54·46)	164,385·1 (54·48)	206,160·4 (59·94)	31,073·4 (34·70)
Total	171,442·8 (49·54)	92,923·6 (45·43)	665,706· (58·59)	131,090·38 (58·34)	101,363·7 (54·46)	164,385·1 (54·48)	206,160·4 (59·94)	31,073·4 (34·70)
Grand Total	346,055·1	204,500·8	1136,1 29·2	224,687·7	186,119·1	301,679·6	343,942·6	89,529·9

*The figures in brackets indicate percentage.

The future rate of population growth is likely to be high. The socio-economic survey data of the 13 Community Development Blocks indicate that the age and sex pyramid of the population is broadbased (Table 2). The percentage distribution of children (0-14 years), younger persons (15-34 years), middle aged persons (35-54 years) and old persons (55 years and above) is 45·0, 31·9, 16·6 and 6·5 respectively. Assuming the working age in rural areas to be 15-54 years, the percentage of population in the working age group is 48·5. There are 844 females per 1,000 males and 392 females in the reproductive period (15-44 years) for every 1,000 females. More than nine-tenths of the women in the reproductive period are married. Also, there are more women in the earlier part of the reproductive period when the incidence of maternity is high.

SOURCES OF LIVELIHOOD

General: Out of an average of 5·94 members per household, 3·36 are earners (2·01 males and 1·35 females). In other words, 43·5 per cent of the population is economically inactive. This high percentage of dependents may be attributed to the large number of children in the population pyramid. The distribution of number of earners per household is related to its size, the coefficient of correlation between the two being + 0·544. This is statistically significant.

TABL 2: Age sex and marital status

Age (years)	Males				Females				Total			
	Un-married	*Married*	*Widowed*	*Total*	*Un-married*	*Married*	*Widowed*	*Total*	*Un-married*	*Married*	*Widowed*	*Total*
0-4	1103 (99·5)	5 (0·5)	—	1108 16·2 (100·0)	1072 (99·4)	6 (0·6)	—	1078 18·7 (100·0)	2175 (99·5)	11 (0·5)	—	2186 17·4 (100·0)
5-14	1796 (96·2)	71 (3·8)	—	1867 27·3 (100·0)	1463 (90·9)	146 (9·0)	1 (0·1)	1610 27·9 (100·0)	3259 (93·7)	217 (6·2)	1 (0·1)	3477 27·6 (100·0)
15-24	686 (56·7)	512 (42·3)	12 (1·0)	1210 17·7 (100·0)	64 (7·1)	839 (92·7)	2 (0·2)	905 15·7 (100·0)	750 (35·5)	1351 (63.9)	14 (0.6)	2115 16·8 (100·0)
25-34	97 (9·1)	941 (88·1)	30 (2·8)	1068 15·6 (100·0)	—	813 (97·8)	18 (2·2)	831 14·4 (100·0)	97 (5·1)	1754 (92·4)	48 (2·5)	1899 15·1 (100·0)
35-44	12 (2·1)	537 (93·5)	25 (4·4)	574 8·4 (100·0)	—	481 (91·6)	44 (8·4)	525 9·1 (100·0)	12 (1·1)	1018 (92·6)	69 (6·3)	1099 8·7 (100·0)
45-54	6 (1·1)	488 (87·8)	62 (11·1)	556 8·2 (100·0)	—	318 (71·9)	124 (28·1)	442 7·7 (100·0)	6 (0·6)	806 (80·8)	186 (18·6)	998 7·9 (100·0)
55-64	4 (1·3)	226 (73·6)	77 (25·1)	307 4·5 (100·0)	—	101 (38·5)	161 (61·5)	262 4·6 (100·0)	4 (0·7	327 (57·5)	238 (41·8)	569 4·5 (100·0)
65 & above	—	82 (58·6)	58 (41·4)	140 2·1 (100·0)	—	11 (9·8)	101 (90·2)	112 1·9 (100·0)	—	93 (36·9)	159 (63·1)	252 2·0 (100·0)
Total	3704 (54·2)	2862 (41·9)	264 (3·9)	6830 100·0 (100·0)	2599 (45·1)	2715 (47·1)	451 (7·8)	5765 100·0 (100·0)	6303 (50·0)	5577 (44·3)	715 (5·7)	12595 100·0 (100·0)

In spite of the erratic and unevenly distributed rainfall, cultivation is the mainstay of the village population. Other occupations followed broadly conform to the caste composition. There are certain occupations like cultivation and agricultural and other forms of casual labour which could be followed, without restriction, by any caste. But, there are others which are traditional to certain castes. The right to follow these occupations is recognized in the village and it is highly unusual for a household to follow an occupation which is traditional to another caste.

TABLE 3: Main occupation of earners

Occupation	*Percentage*
Cultivation	87·3
Sheep and goat rearing	4·5
Other	8·2
	100·0

Almost three-tenths of the earners also practise subsidiary occupations. These are usually the traditional caste occupations and agricultural and casual labour.

Land holdings: With the abolition of *Jagiri*, the land is now held by the cultivators directly from the government on payment of land revenue, the rates of which vary according to the type of land, namely, *barani* (unirrigated), *sewaj* (land where rain water accumulates and is cultivated when the water dries up), *chahi* (land irrigated by wells) or *nahari* (land irrigated by canals).

The distribution of agricultural holdings by size shows the presence of fairly large holdings, the average size of an agricultural holding with a cultivator being 14·04 hectares. 31·9 per cent of the cultivators have irrigated holdings, the average area of which is 0·87 hectares. The coefficient of correlation between size of agricultural holding and number of fragments per holding is +0·326 which is statistically significant indicating that the number of fragments per holding increases with the size of holding. Only 9·4 per cent of the households do not have agricultural holdings. Subletting of holdings is uncommon both because of the absence of any large holdings, and the legislation relating to the ownership and actual tilling of land. Absentee landlordism is negligible.

Subsistence farming is practised in the region. The pattern of cropping as evident from Tables 5, 6 and 7 giving the area under different crops shows that *bajra* (*Pennisetum typhoides*) is the most important *kharif* crop followed by *gawar* (*Cyamopsis tetragonoloba*) which is a fodder crop. Every farmer grows both these crops to meet his needs for food and fodder. The percentage area under cereals

TABLE 4: Size of agricultural holding and number of fragments per holding

Size (hectares)	1-3	4-6	7-9	10-12	13-15	16 & above	No.	Total %
6·5	513	114	33	12	4	5	681	36·4
6·5-12·9	279	125	42	14	6	3	469	24·7
12·4-19·4	163	85	34	10	7	2	301	16·0
19·4-25·9	89	66	15	4	5	2	181	9·6
25·9-32·4	46	33	9	3	—	—	91	4·8
32·4-38·8	20	16	9	4	1	1	51	2·7
38·8-45·3	12	16	7	1	3	—	39	2·1
45·3-51·8	8	7	3	3	—	—	21	1·0
51·8-58·3	9	2	—	1	3	—	15	0·8
58·3 and above	10	14	3	2	2	5	36	1·9
Total	1,149 (60·9)	478 (25·4)	155 (8·2)	54 (2·9)	31 (1·6)	18 (1·0)	1,885 (100·0)	100·0

and pulses varies from 47·5 per cent in Ahore to 83·9 per cent in Barmer while the percentage area under *gawar* varies from 11·8 per cent in Pachpadra to 38·8 per cent in Sanchore. Ahore and Sheoganj *tehsils* have approximately one-fourth of the area under *til*, in the other *tehsils*, the percentage area is about 5 per cent or less. In *rabi*, cereals and pulses cover nine-tenths of the area. Oil seeds, spices, vegetables and fodder crops are grown in very limited areas. In *zaid*, fodder crops predominate. Thus, cereals and fodder crops cover the largest area.

Agricultural practices: Traditional agricultural practices are followed in the region surveyed.

Kharif: The fields are prepared for the *kharif* crops in the months of May and June by clearing the fields of shrubs and other weeds; they are ploughed with the start of the rains in July. In the case of *bajra* (*Pennisetum typhoides*), *moth* (*Phaseolus aconitifolius*), *moong* (*Phaseolus radiatus*) and *til* (*Sesamum indicum*), the land is ploughed only once* while in the case of *gawar* (*Cyamopsis tetragonoloba*) it is ploughed thrice. Among the *kharif* crops *til* is sown broadcast while *bajra, moth, moong gawar* and *jawar* (*Sorghum vulgare*) are sown in lines. Usually *bajra, moth, moong* and *til* are sown mixed in the ratio 20:1:1:1. After about a month of sowing, weeding and hoeing operations are carried out in the fields. Towards the end of September and early October the crops are harvested. In the case of *bajra* the earheads are first picked and the stalks are cut latter for use as fodder leaving about six inches high stubble. All the agricultural operations are labour intensive practised with traditional agricultural implements. Fertilizers or farmyard manure are not used by the cultivators on account of the widespread belief that the crops will be burnt up if there are no rains. Cattle are allowed to graze on the *bajra* stubble after the harvesting is over so that some amount of manuring is done naturally. The rotations actually followed vary from village to village depending upon the capability of the land and the needs of the cultivator. Usually *gawar* is grown in the first year, followed by a mixed crop of *bajra, moth, moong* and *til* for about four years, with *bajra* predominating. Then the land is left fallow for about three years.

Rabi: In the case of *rabi* (winter crops) the fields are prepared in the month of September when farmyard manure is applied. Payments are even made to owners of sheep and goats for penning their flocks on lands which have facilities of well irrigation. The lands are then ploughed about four to five times with the traditional plough and seeds sown by broad-cast. As in the case of *kharif* crops, the seeds used are either from the previous year's produce or are obtained from the *mahajan* on *sawai** basis. The latter practice is more common. Wheat and barley are also sown mixed in almost equal proportions. Most of the irrigated lands are served by wells which are operated jointly by several cultivators. This system, which is known as *bawli*, cuts across caste and kinship boundaries. The crops are weeded usually once. For watering the crops and for watching them, labour have often to be engaged. Harvesting is done in March-April. In the case of *rabi* crops, also, all the operations are labour intensive and traditional agricultural implements are used.

Zaid: *Zaid* are spring crops grown on lands having proper irrigation facilities. They are sown usually in mid or late April and harvested after 6 to 8 weeks.

Agriculture produce: In normal** years, the average yield per hectare usually falls within the range

*More than one ploughing is done if the land was left fallow for several years.

*Returning 1·25 kg of grain of the harvest for every kg taken.

**There is a saying in the arid parts of Rajasthan that "in a hundred years there would be 7 scarcity years, 27 good years, 63 half-ripe years and 3 such terrible famines that the mother will not meet their sons".

TABLE 5: Area (hectares) under different *kharif* crops (1960-61)

Crops	Pachpadra		Siwana		Barmer		Jalore		Ahore		Sanchore		Bhinmal		Sheoganj	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Cereals *Pulses*																
1. *Bajra*	108,678·0	64·3	52,789·7	59·8	538,769·4	81·0	65,914·0	53·8	40,313·6	45·5	98,558·8	60·0	108,932·9	55·6	7,752·6	32·2
2. *Bajra & moth*	18,033·0	10·7	12,162·8	13·7	17,734·1	2·7	1,844·1	1·5	4·8	(neg.)	(neg.)	(neg.)	2,018·6	1·0	613·9	2·5
3. *Moth*	5,451·0	3·2	317·3	0·4	653·2	0·2	70·8	(neg.)	47·3	(neg.)	315·6	0·2	144·9	0·1	273·1	1·1
4. Maize	2·8	(neg.)	23·7	(neg.)	nil	—	615·1	0·5	173·2	0·2	nil	—	94·3	(neg.)	168·7	0·7
5. *Jowar*	6,103·9	3·6	1,342·3	1·6	25·9	(neg.)	12·5	(neg.)	696·0	0·8	607·4	0·4	3,547·5	1·8	27·1	0·1
6. Others	2,264·0	1·3	658·6	0·7	106·0	(neg.)	1,536·2	1·3	849·0	0·9	656·4	0·4	10,527·1	5·4	6,100·2	25·4
Oil Seeds																
1. *Til*	6,640·0	3·9	6,662·3	7·5	227·4	(neg.)	5,574·1	4·5	23,770·8	26·8	169·1	0·1	10,027·7	5·1	4,227·7	17·6
2. Other oil seeds	2·0	(neg.)	88·2	0·1	4·0	(neg.)	129·5	(neg.)	55·8	(neg.)	60·7	(neg.)	777·0	0·4	24·7	0·1
Fodder Crops																
1. *Gawar*	19,894·0	11·8	13,830·9	15·7	106,896·2	16·0	43,024·6	35·1	20,856·3	23·5	63,648·6	38·8	57,938·5	29·6	3,708·9	15·4
2. Other fodder crops	1,881·0	1·1	123·8	0·1	389·5	0·1	264·2	0·2	1,252·1	1·5	77·7	0·1	1,172·4	0·6	758·8	3·1
Species	11·0	(neg.)	54·4	0·1	7·1	(neg.)	773·8	0·6	159·4	0·2	21·0	(neg.)	418·0	0·2	126·7	0·6
Others	12·0	(neg.)	201·9	0·2	21·9	(neg.)	2,662·9	2·2	448·2	0·6	7·7	(neg.)	233·9	0·2	296·3	1·2

TABLE 6: Area (hectares) under different *Rabi* crops (1960-61)

Crops	Pachpadra		Siwana		Barmer		Jalore		Ahore		Sanchore		Bhinmal		Sheoganj	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Cereals and Pulses																
Wheat	2,367·0	86·7	4,259·3	87·5	1,244·8	95·4	7,385·1	85·3	8,615·4	64·8	1,317·6	83·0	10,954·4	85·2	3,537·4	47·4
Jav	86·2	3·2	257·0	5·3	5·6	0·4	96·7	1·1	1,234·7	9·3	178·9	11·3	13·7	0·1	1,687·5	22·6
Gram	48·2	1·8	—	—	—	—	21·3	0·3	1,726·0	13·0	—	—	116·1	0·9	250·9	3·4
Others	22·1	1·1	—	—	—	—	370·3	4·3	1,018·6	7·6	0·8	(neg.)	1·2	(neg.)	1,127·4	15·1
Oil Seeds																
Sarson	2·4	0·1	15·8	0·3	0·4	(neg.)	197·5	2·3	202·7	1·5	3·2	0·2	219·3	1·7	296·6	4·0
Others	16·2	0·6	1·6	0·1	0·4	(neg.)	0·1	0·1	4·0	(neg.)	0·4	(neg.)	8·5	0·1	13·3	0·2
Spices etc.																
Jeera	76·5	2·8	145·7	3·0	32·4	2·3	138·4	1·6	93·1	0·7	23·1	1·5	1,167·1	9·1	34·8	0·5
Others	28·3	1·1	4·8	0·1	0·5	(neg.)	55·0	0·6	12·5	0·1	8·1	0·5	40·5	0·3	94·7	1·3
Vegetables & fruits	32·4	1·1	136·8	2·8	28·9	1·7	159·0	1·8	50·2	0·4	46·9	3·0	202·3	1·6	25·9	0·4
Fodder crops	39·3	1·4	46·5	0·9	3·2	0·2	226·6	2·6	333·0	2·5	8·1	0·5	110·5	0·9	367·4	4·9
Others	3·2	0·1	—	—	—	—	0·4	(neg.)	10·9	0·1	—	—	16·2	0·1	19·0	0·2

TABLE 7: Area (hectares) under different crops (Zaid Rabi) 1960-61

Crops	*Pachpadra*	*Siwana*	*Barmer*	*Jalore*	*Ahore*	*Sanchore*	*Bhinmal*	*Sheoganj*
Human consumtpion (*kharbuja*, etc.)	12·8	12·2	0·2	402·1	11·1	neg.	155·7	56·6
Fodder crops	11·3	228·0	72·0	449·7	292·8	240·2	1152·3	704·1
Others	—	11·9	1·2	43·1	6·8	0·1	102·1	37·2

TABLE 8: Principal crops of the region and their yeild

Season	*Crop*	*Range of yield kg/ha*
Kharif	*Bajra*	115-230
	Moth	138-184
	Moong	138-184
	Til	92-184
Rabi	Wheat	644-828
	Barley	552-736

indicated. The yield are thus very low and have remained almost constant on account of traditional farming practices followed by farmers and virtual non-acceptance of improved agricultural methods.

Disposal of agricultural produce: As soon as the harvesting is over, payments in kind are made to the occupational castes who have assisted in cultivation or in socio-religious ceremonies. Village functionaries like the *Gaon Bhambi*, village grazier and the village *Chowkidar* also receive some grain at the time of harvest. The total amount so distributed usually amounts to about 55 kg of grain (Rs. 25/- app.) in case only *kharif* crop is grown and 110 kg of grain (Rs. 50/- app.) in case the *rabi* crop is also cultivated. The village *mahajan* claims a part of the produce as repayment of debt of the cultivator or in settlement of the purchases effected by the cultivator during the year. The average sale value per household of agricultural produce sold during the preceding year was Rs. 118/-. 44·3 per cent households did not sell any agricultural produce.

ANIMAL HUSBANDRY

Livestock distribution: Next to land, livestock constitutes the most important asset of the cultivator. Table 9 gives the livestock population in different *tehsils* in 1960-61. In all the *tehsils* goat and sheep together constitute about two-thirds of the total number of livestock. Of the total adult bovine population, about half comprise of draught cattle which shows that livestock here are subsidiary to agriculture. Almost one-third of the adult cows and one-fourth of the adult buffaloes are periodically dry. The percentage of such livestock is higher in the lesser rainfall areas.

The figures in Table 10 give the extent of ownership of different types of livestock by households in the region surveyed. The data show that bullocks and cows are kept by the largest percentage of households. The former are necessary because agrarian economy is still based on the use of draught cattle while cows prove useful for their milk and for raising young stock. Camels are sometimes used as a draught animal. Its chief importance is, however, as a pack animal or as a means of communication. The raising of goats and sheep in large numbers is the traditional occupation of certain castes like *Raikas*, *Jats* and *Rajputs*. On an average a household has 1·32 bullocks, 2·28 cows, 1·48 cow young stock, 0·62 buffaloes, 0·38 buffalo young stock, 6·48 sheep, 6·50 goats and 0·49 camels.

Breeding: For the breeding of livestock most villages have their own arrangements. A bull of local breed is selected from within the village, but here too efforts to improve breed are impeded by the large number of scrub bulls which roam about the village. In some villages pedigree bulls have been provided by the *Panchayat Samitis* but the number is too small. Besides, no definite feeding arrangements exist in the villages where the pedigree bulls have been provided. The services of a bull are not utilized in a particular village for more than four years to prevent inbreeding with its offspring. In the case of well-fed cows calving takes place at the age of about four years while in the case of well-fed buffaloes it takes place at about five years' age. Under-fed cows and buffaloes calve about a year later. Similarly, sheep owners keep rams for breeding purposes. These are, however, neither selected on wool performance nor on breed confirmation basis.

Castration: Many households consider it irreligious to castrate their male stock. This attitude has both a caste and a territorial basis. They have, however, no objection to getting their uncastrated stock exchanged with the castrated ones either in

TABLE 9: Livestock population in different tehsils (1960-61)

Livestock	Pachpadra No.	Pachpadra %	Siwana No.	Siwana %	Barmer No.	Barmer %	Jalore No.	Jalore %	Ahore No.	Ahore %	Sanchore No.	Sanchore %	Bhinmal No.	Bhinmal %	Sheoganj No.	Sheoganj %
Cattle	91,749	31·9	58,305	25·0	231,443	22·6	78,448	23·5	72,924	23·6	132,886	32·9	89,495	36·0	40,409	27·1
Buffaloes	8,052	2·8	8,773	3·8	6,741	0·6	17,940	5·4	15,335	5·0	31,892	7·9	17,589	7·1	9,708	6·5
Sheep	94,692	32·9	76,342	32·7	273,568	26·7	128,288	38·4	139,201	45·0	133,003	32·9	84,101	33·9	42,279	28·4
Goats	84,999	29·6	84,876	36·2	463,077	45·2	103,801	31·1	78,076	25·2	97,481	24·2	48,515	19·5	54,324	36·5
Camels	6,132	2·1	4,034	1·7	39,610	3·9	3,165	0·9	1,888	0·6	5,070	1·3	5,396	2·2	1,130	0·8
Donkeys & mules	1,609	0·6	1,009	0·4	8,978	0·9	1,920	0·6	1,587	0·6	2,385	0·6	2,020	0·8	839	0·6
Others	257	0·1	170	0·1	1,045	0·1	450	0·1	333	0·1	939	0·2	1,234	0·5	132	0·0
Total	2,87,490	100·0	2,33,509	100·0	10,24,462	100·0	3,34,012	100·0	3,09,344	100·0	4,03,656	100·0	2,48,347	100·0	1,48,821	100·0

the cattle fairs or from *Sansi* or *Sattia* nomads who visit their village.

Animal feed: The feed given to livestock depends upon the utility of the animal, the economic status of the owner and the available supplies. Cows are given *cheepta* (green *jawar*), *pala* (dried *Zizyphus numularia* leaves), *doka* (*bajra* stalks) and grass as roughage and *gawar*, *bajra*, wheat, cotton seeds, and *til* as concentrates. Promising cow calves, both male and female, are allowed to take about a quarter kg of concentrates besides suckling their mothers. Male buffalo calves are of little use as draught animals. They are usually under-fed and ill-cared with the result that they die very young or are sold off at a nominal price. Bullocks are given *cheepta*, *pala*, *doka*, *grass* and leaves of *moth* as roughage. The concentrates given are *bajra*, *gawar*, oil cakes, cotton seeds, *til* oil, *haldi* and *ghee*. Cultivators of irrigated holdings give *bhusa*, etc. to their livestock.

The chief sources of animal feed are the grazing, on the common lands, cultivators own land and his crop residues. Shortage of village grazing land is a pressing problem. The density is not, however, constant and shows wide fluctuation from year to year depending upon the livestock mortality. There seems to be heavier pressure in the higher rainfall areas with facilities of irrigation than in the less favourable tracts.

Watering facilities: Livestock drink water from the same sources as human beings. So long as water is available in *nadi* (tank) this is utilized. When the water dries up (usually by the middle of the winter season) well water is provided to the stock. Payments have, however, to be made to the men working at the well. Separate rates are levied for large and small animals.

Sale of livestock and livestock produce: The nature and type of livestock kept is in most cases determined by the needs of cultivation. Except in the case of certain specific castes like *Raikas* whose traditional occupation is the raising of sheep and goats, most of the households keep livestock just enough to meet their needs. The sale of livestock, particularly cattle and camels, is made usually at the cattle fairs. Sometimes the *mahajan* also accepts these animals in settlement of the debt of the cultivator. The male stock of sheep and goats are sold to the visiting traders who go about collecting them for slaughter in the cities. The average sale value of livestock per household in the preceding year was Rs. 45/-.

On account of the poor quality of livestock, produce is meagre and usually goes to meet the requirements of the household. Most of the livestock produce sold comprises of wool and *ghee*. These are usually sold to village *mahajan*. The sale of milk is considered degrading. Families living in villages near towns have, however, shaken off age-old barriers in this matter. It is interesting to note that milk is sold only by the upper castes, and no milk is pur-

TABLE: 10 Ownership of livestock

No. per household	*Bullocks* %	*Cows* %	*Cow young*	*Buffaloes* %	*Buffaloe young*	*Sheep* %	*Goats* %	*Camels* %
Nil	33·4	28·1	42·5	71·3	81·4	81·7	71·0	79·4
1-4	63·5	61·3	52·4	27·9	18·3	3·9	9·5	19·8
5-9	2·8	7·4	4·4	0·6	0·2	3·1	4·7	0·4
10-14	0·2	1·9	0·4	0·1	0·1	2·4	3·6	0·2
15-19	0·1	0·6	0·1	—	—	1·2	2·6	0·1
20-24	—	0·2	0·1	—	—	1·0	2·0	—
25-49	—	0·4	0·1	0·1	—	2·9	4·0	0·1
50-74	—	0·1	—	—	—	1·2	1·1	—
75-99	—	—	—	—	—	0·8	0·9	—
100-149	—	—	—	—	—	1·0	0·4	—
150-199	—	—	—	—	—	0·4	0·1	—
200 and above	—	—	—	—	—	0·4	0·1	—
	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0

chased from inferior castes. The average sale value per household of livestock produce sold in the perceding year was Rs. 39/-.

OTHER SOURCES OF LIVELIHOOD

The other sources of livelihood are agricultural and caste occupations like carpentary, blacksmithy, oil pressing, tailoring, pottery making, tanning, leather work, drumming, dyeing, shopkeeping, money lending and goldsmithy. The later are the monopolies of the castes concerned and are governed by conventions as regards the nature and type of services rendered and dues received. They are usually followed as subsidiary occupations and generally cater to the needs of the village. The annual earnings of a household from most of these rarely exceed Rs. 15.

INDEBTEDNESS

Six-tenths of the rural households are indebted. The average indebtedness per household is Rs. 533. Most of the loans are taken for socio-religious ceremonies where obligations to the community over-ride prudence and force the cultivator into the clutches of the money-lender. The *Mahajan* is the chief source of credit. Cooperative societies have been functioning in some villages but have not been able to eliminate the money lender.

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DISCUSSION

K. S. Sankhala : What is present contribution of agriculture to the income of inhabitants as compared to contribution of animal husbandry in Western Rajasthan ?

A. B. Bose : Over 80 per cent of the population is dependent upon agriculture. The contribution of animal husbandry towards income of the people of Western Rajasthan is relatively much less than from agriculture.

ECOLOGY AND THE BIRHOR[1]

by
DR ŚACHCHIDANANDA[2]

I

WHEN Ernst Haeckel coined the term ecology in 1870, his purpose was to formulate a logical scheme for the zoological sciences. Slowly the term became established as a word and as a science though there is no universal agreement about its usage or meaning. This is more particularly true in the case of Human Ecology which stems from five divergent sources. Human Ecology stemming from medicine stresses environmental relations of disease. It also draws from geography, sociology and anothropology. Sometimes the terms is used as a tag to indicate that a particular study has broad relevance to problems of human conduct.

The importance of ecology can be studied even with reference to the anthropoid apes. The omancipation from tree life offered wider scope for the latent intelligence of the anthropoid apes. By widening their diet and becoming tool makers, the hominidea vastly increased their adaptability. Instead of eating almost continuously like their fruit and plant eating anccestors the earliest men must have spent most of their day-time in hunting. This activity increased inter-dependence and led to the formation of large social groups. New skills and aptitudes were developed. There is interrelation between development of intellect and changing environment. Close interrelation is also found between the density of population, modes of subsistence and technological equipment.

Evans-Pritchard has clearly brought out the implications of the ecological factor on the Nuer of Sudan. The Nuer have a mixed pastoral-horticultural economy. The environmental bias coincides with a bias of their interest. They cannot live at one place throughout the year. Floods drive them and their cattle to seek protection on higher ground. Absence of water and pasture on higher ground compels them to move during draught. Their ecology has made them transhumant. As long as they live in the village, they engage in horticulture. When they move to higher ground, they live in camps and figure as pastoralists. The variation in food supply and its sufficiency for life at all seasons is determined by the annual cycle of ecological changes. Owing to the conformation of Nuer villages, there is a rough correlation between the size of population and the area of cultiivable land, for where suitable land is limited so is the space for building. Scarcity of food at times and the narrow margin which divided sufficiency from famine cause a high degree of interdependedce among members of the smaller local groups which may be said to have a common stock of food. Low technology, meagre food supply and scanty trade has some effect upon social relations and their character. Social ties are narrowed.) People of a settlement are drawn closer. Technology may be viewed as an ecological process, an adaptation of human behaviour to natural circumstances. Some qualities of Nuer character, such as courage, generosity, patience, pride, loyalty, stubbornness and independence have been traced by Evans-Pritchard to their ecology.

II

The way in which Birhor life is changing illustrates the close interdependence botween ecology and society and culture. Julian Steward has viewed the concept of cultural ecology as a method for recognizing the ways in which culture change is induced by adaptation to environment. Cultural ecology implies a creative process which aims at maintaining equilibrium at different levels in the development of culture. Cultural development, therefore, must be conceptualized not only as a matter of increasing complexity but also as one of emergence of successive levels of socio-cultural intergration. In the process of culture change, society permits a certain latitude as regards behaviour patterns. People choose one of the two alternative patterns according to convenience.

The Birhor are one of the smaller but at the same time much studied Mundari tribes of Chotanagpur. In 1961 they numbered about 2,500. They are mainly found in the districts of Ranchi, Hazaribagh and Singhbhum. They are divided into two sections — Uthlu and Jaghi. The line of distinction between them is not rigid. Uthlu Birhors are so called as they are habitually on the move while the Jaghi are those who have found a fixed place or *Jagah* for themselves. As soon as an Uthlu Birhor settles down permanently he begins to regard himself as Jaghi. The two sections are not endogamous and marriage takes place between

1. Contribution from Bihar Tribal Research Institute, Ranchi.
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persons belonging to two sections. Even the Jaghi Birhor are not firmly rooted to the soil as other tribesmen who are their neighbours. The slightest ill — treatment or even apprehension of trouble may make them leave their settlement. The agricultural techniques of the Jaghi Birhors are comparatively more primitive than those of the Munda and the Oraon. They, however, use the plough.

Of the two sections, the Uthlu are more numerous. Their socio-economic set-up is extremely simple. The shifting settlements are known as Tanda. Each settlement has five to eight nuclear families comprising a minimal lineage. Besides these agnates, there might be one or two families who are affines. The Tanda is a unit of food quest and for social and religious activities. It is shifted when the resources of the neighbouring forest are nearing exhustion or if the settlement is discovered to be inauspicious. Though the Tanda can be regarded as an isolate, it has to depend on its other counterparts for marital alliances, social disputes which cannot be solved in the Tanda itself and for communal hunts. The inter-tanda co-operation does not lead to the formation of permanent groups with fixed membership and leadership. The level of integration does not proceed beyond the Tanda.

The Birhor live in conical leaf-huts which they can put up in a day. The huts are so well made that they are almost air tight and waterproof. So strong is the insistence on waterproofing that a person whose hut is known to leak is promptly excommunicated. They have very few earthly belongings which they carry in a single basket or in a balance-like contrivance resting on one shoulder. They do not keep beasts of burden like other nomads. They change their place of abode with the change of season and convenience sometimes even four times a year. A survey of migration regarding the Birhor of Bishunpur Block revealed that the Chatakpur Tanda covered 29 miles within three years nine months. Sirka Tanda covered 67 miles within ten years seven months. In Narma Tanda the two groups migrated at different times and visited different places and then came to a common camp. The first group covered 26 miles within five years and encamped at five places. The second group covered 20 miles within 9 years and encamped at four places.

The Birhor are famous for hunting monkeys. They eat the flesh with great relish and use the hide for making long drums. Besides this they also hunt rabbits, deer, porcupine, squirrels and wild hen. They collect wild roots, tubers and fruit for food and honey and bees wax for sale. They also go in for chop fibres (Bauhenia Scandens) with which they make ropes. They make crude wooden vessels like Kathauts, mortars, drum cases etc. Monkey skins, honey, bee's wax, ropes and wooden vessels are sold by them in the weekly markets. With the money thus earned, they buy their food stuffs. In exploiting their forest resources, each Birhor Tanda restricts itself by common understanding to a limited area. The knowledge of each others forest zone is so perfect that a Birhor of one Tanda does not poack upon the resources of another.

Most of the Birhor lead a precarious existence. They are almost always on the brink of starvation. The right to hunt in the reserved forests has been severely restricted. The right to cut timber for making wooden vessels is also no longer there. In regard to collection of chop fibres some concession have recently been made. Restrictions on hunting have deprived them of an important source of food supply. They nostalgically recall the days when they could freely hunt monkeys whose meat they relish above anything else. In certain areas, the making of wooden vessels has come to a stop. In Jaldega, the Birhors do not make ropes as they cannot compete with flax ropes.

III

In 1956, the Government made an attempt to settle the Uthlu Birhor living in or near the Bishunpur Block. A colony with fifteen houses was built for them at Jehengutua. Each family was given a pair of bullocks, a plough some other agricultural implements, seeds, a cow, poultry and goats. Provision was also made for an elementary school, a community hall, a well and supply of medicines at the Jehengutua colony. 72·45 acres of land was also placed at their disposal for cultivation.

In 1957 another colony was established at Beti, four miles from Banari for thirty families. They were given the same quantum of aid to turn them into agriculturists. 165 acres of land was made available to them for cultivation. Similarly in 1959 a colony consisting of twelve houses was set up at Jaldega about five miles from Palkot in the Ranchi District. A fourth colony came up about the same time in Katia twelve miles from Banari. It may be noted that in all the colonies, the type pattern of aid was the same but the response or the success achieved in each case was different.

The Jehengutua colony came into being under the leadership of Manjira Birhor a man of rare ability and foresight. He gathered together the Birhors of Narma, Serka and Chatakpur Tanda and prevailed upon them to settle there. " He was attracted by prospects of settled life and agriculture. He never thought of replacing his culture, his goal was to add useful elements therein." He did not like the idea of introducing the rope making machine. The leaf huts that surrounded the colony initially disappeared by 1958. The traditional occupation of some of the Birhors was already affected. At the beginning there were some difficulties with regard to lands the right over some of which was disputed by the neighbouring tribes. This earned them the hostility of their neighbours. Except their kitchen gardens other fields needed much labour to which they were not used. With the passage of time the hostility of neighbours has worn off. As the jungle resources are becoming scarce there is greater dependence on agriculture. But a recent survey by the present author revealed that agriculture does not contribute more than one third to their livelihood. The maize, paddy, pulses and oil seeds and the few vegetables they grow scarcely support them for long. Their main stay is the making of ropes which they sell in the weekly market and also be going round in the neighbouring villages. This source gives each family roughly an income of ten rupees per week. Two of the Birhor youngmen have received training as weavers for a year and have set up looms in their houses but they have no money to buy yarn. Two houses are vacant. Their occupants have reverted to wandering life as they were not interested in agriculture. One of them earns his livelihood by working as a spirit doctor or ojha.

The families living at present in Jehengutua are determined not to leave the colony and are slowly reclaiming the lands given to them for agricultural purposes. They are interested in education. About 26 children attend the Balbari run by the tribal Gram Sevika there. A large number of boys and girls attend the local lower primary school. Some Birhor boys from this colony are in the High School at Bishunpur. One of the Birhor youngmen went to Ranchi and worked as a khalasi on a truck, but he came back after three months as he was home-sick. Another worked as a watchman in a garden in North Bengal for many years. Some youngmen want to go out into the wide world and seek new avenues of employment. The Birhors are demanding that land should be alloted to each family so that they may take greater care and more pains for making agriculture a success.

Formerly the level of socio-cultural integration was the minimal lineage in the Tanda. In the colony there are families belonging to different clans who came from different tandas. Competition and rivalry developed between groups hailing from different places in the exploitation of forest resources and witchcraft accusations against families belonging to alien clans and Tanda were made. Sinha has noted a case in which a family had to leave the colony on that account. Such conflicts have not since raised their head. Sukhram, son of Manjira, the founder of the colony is the headman of the village panchayat. Different persons hold the offices of Baiga, Pujar and Ojha. Sukhram is the spokesman of the Birhors of this colony. He is respected and enjoys the confidence of the villagers. Thus a higher and comparatively more complex level of socio-cultural integration has emerged in Jehengutua.

Government efforts at resettlement did not meet with equal success in the other colonies. There were thirty houses in Beti out of which only 17 are inhabited now. One reason is that 73 per cent of the lands allotted for Birhors of this colony are at present covered by jungle. Out of the sixty bullocks given for cultivation only twelve are living at present. The majority of them died in an epidemic a few years back leaving their owners destitute. The families settled there all came from Gungutoli near Banari They belong to four different clans and the level of integration is comparatively low. The settlers were troubled by two persons, a Gond and a Birhor who were in the habit of eloping with some-one else's wife. The Gond is now dead but Chhatrapal Birhor is still persisting in his antisocial behaviour. The agencies of social control in the colony have not been able to bring him to book. The market for the sale of ropes is also about sixteen miles from Beti. Due to all these factors thirteen families have reverted to Uthlu status.

Katia colony situated deep in the interior of the forest is more than twenty miles removed from the market. The lands are in the same condition as in Beti. None of the houses is inhabited now.

In the Jaldega colony twelve families of Uthlu Birhor were settled. All the families are related and came from the same settlement. They belong to six different clans. The market is only five miles away and it is not difficult for them to sell the wooden vessels, ropes and skins. All the families are serious about agriculture. Their houses are made with bricks and plaster with tiled roofs and cemented floors. They do not resent their new surroundings nor do they complain about the cold as the Birhors of Jehengutua did at an early stage. About 53 acres of land have been given to them. They have already reclaimed a large part of it and grow maize, paddy, Gondli, Marua, Sweet potatoes and pea-nuts. Fruit trees like plantain, papaya and guava are also popular. They are willing to learn other crafts such as weaving and carpentary if an opportunity is given to them. Of all the colonies the Birhors of Jaldega were found to be the most prosperous.

It is clear that most of Birhors in the colonies have realized that they cannot survive with their traditional occupation. Opportunities and facilities of wandering life are closing in from all sides. As against this they are becoming used to the advantages of settled life. A decade before for the Birhors of Bishunpur and Palkot, like their wandering brethren in Hazaribagh, " this self-imposed poverty, this refusal to respond to the call of Mother Earth, to agriculture and the fruits thereof, the security and the comforts of a fixed home, shelter from weather and hunger are things for which they were not prepared to surrender their freedom. Freedom to roam the wilds, freedom from the nightmare of domination, freedom from the thralls of domestic life are things which they seem to prize above all else " (Sen). This delineation of Birhor character does not now hold good for most of the Birhor of Bishunpur and Palkot. Their poverty was not self-imposed, it was forced by their environment. The refusal to respond to the call of Mother Earth was not instinctive but caused by want of land and knowledge of agricultural techniques. Experience has shown that like other people they do like the security and comforts of settled life. They do prize freedom, detest domination and interference by others in their affairs but they now like to develop fruitful contacts with the wide world outside their own circle of kin, contacts which might bring them new techniques, opportunities and facilities so that they can mitigate their poverty. Wide contacts have created fresh needs. Their level of aspiration is rising. There is demand for more educational facilities and training for new occupations. The feeling for private property in house and land has arisen. This is reflected in the demand for family-wise allotment of land. A higher level of socio-cultural integration is being reached. Formerly the Tanda hardly formed any extension. Now extensions are being forged with new clans, new tribes, non-tribals, the Community Development Block, etc.

Culture is adaptation to an environment. But this adaptation is never perfect. In the case of the Birhor the ecology is changing. So is their culture. Old habits, however, die hard, new ways take time to strike root. The hangovers from the past may continue for sometime. The direction of social change has been set by the new environment and with the passage of time the process will work itself out.

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ECOLOGY OF HUMAN FACTORS

A RESEARCH PROGRAMME IN AGRICULTURAL ECONOMICS FOR ARID LANDS

by

J. P. HRABOVSZKY[1]

AGRICULTURAL Economics is an applied science. Even when working with highly abstract models on theoretical solutions, at the back of the agricultural economic researcher's mind is always the question: How will the results of my efforts directly or indirectly create a better allocation of resources in agricultural production, and thereby serve the welfare of the nation or humanity.

In relation to these efforts, in a rough fashion, one could talk about three major research areas within the field of agricultural economics. The first one relates to the economic interpretation of the findings of the physical-biological scientists. The second area may be called an integration of results both from the physical-biological sciences and from the social sciences by relating the physical production possibilities to the social-psychological framework of society through the analysis of economic behaviour, which is influenced by both. In the third area agricultural economists work mainly with phenomenon that is largely economic. These are the areas of price and demand-supply analysis, though even here the basic relationships are underpinned by human behaviour and the limitations of the physical world.

The activities described in the above areas do not permit the agricultural economist to experiment. He has to interpret the results of experiment carried out by others, or analyse real life situations to see whether theoretical concepts are able to explain them or to predict them. It is because of working with real life situations that the agricultural economist is forced to consider many aspects of a given problem simultaneously on account of the interdependence and concurrence of the factors bearing on the phenomenon under research. It is in the light of all the important influencing factors, relevant to the optimal allocation of resources, that he looks at problems of agricultural production and tries to formulate plans which will take into consideration both the physical possibility and the economic and social desirability of the proposed solution, judging it both from the point of view of the individual and from that of society. In the following part an effort is made to show how well this threefold division of agricultural economic research fits into the research programme of the Central Arid Zone Research Institute.

As it was pointed out earlier, agricultural economics is an applied science, therefore, many of the thoughts expressed in this paper on the co-operation between agricultural economists and other scientists at the Institute relate mainly to that portion of the research activities which fall under the applied sciences when dividing their activities into applied and basic scientific research.

Considering the first area of research, that of cooperating with other sections of the institute, the agricultural economist has the important role of constantly raising two questions in relation to the applied research done. The first of these is: Is this research effort aimed in the direction of providing an answer to the problems of agriculture in the Arid Zone? The second one is: What is the economic meaning of these findings of research in the solution of these problems? To be able to pose these questions meaningfully, the agricultural economist himself has to be familiar with the problems, as perceived both by the cultivators themselves or by those who are in charge of guiding the performance and development of the agriculture of the Arid Zone. The general surveys carried out by the Human Factor Studies Section provide opportunities for assessing these problems and to derive from them ideas on the kind of new knowledge required for their solution.

The second question would help to keep the solutions found to be economically feasible, or at the best, optimal ones. It is one of the favourable signs that many of the studies in the applied sciences of the various sections in *CAZRI* do contain a short economic analysis. However, the fitting of these individual findings into the total economic organization of the productive units can be done optimally through the skills of the agricultural economist.

The same way as the economist has to learn from the physical-biological scientists about the limitations in the production process, similarly, he has to rely on the sociologist and anthropologist to provide him with knowledge with regard to the effects of human organization on the economic performance and limitations of given groups and individuals. Basically, economics is a behavioral science specializing in the analysis of those human

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activities which are connected with mankind's use of scarce resources.

It is in this role of acting between the two groups of scientists that economists fulfil an important integrating function.

At CAZRI this area has been generally termed as "human ecological studies" with a focus on a desired equilibrium between man and nature. Nearly all of man's activities in water and land use come within the area of production and thus require an economic type of analysis for the maximum gain from their use. Fundamentally, it is a problem of assembling knowledge about the alternative modes and levels of use and seeing which one of these results in the maximum welfare for the people, both in monetary and non-monetary utilities. In the institutional setting of CAZRI these integrative activities appear to be the most important part of the agricultural economics research programme. The agricultural economist should be able to communicate with all the other scientists on whom he relies for a large part of his information and at the same time it is imperative for him to know what the problems of agriculture are to be able to evaluate the usefulness of the alternative solutions to them.

Up to this point the objectives of an agricultural economics research programme were discussed in a broad fashion. In the rest of this paper a number of more narrowly defined areas of research are delineated. The criteria for choice underlying these proposals are based on four major considerations. First and paramount of these is their importance in the relation to the problems of the agriculture of the zone. Secondly they are guided by consideration of the general objectives and by the tasks undertaken by the Institute. Thirdly, an attempt is made in them to build on the material already collected by the Human Factor Studies Section, and fourthly they are hoped to be within the realm of realistic possibilities, considering the personnel and material resources available. Those kinds or research studies where the economist acts mainly as an interpreter of the findings of other scientists, is not discussed here. The study areas proposed here represent research activities, where the economist is the originator and would rely mainly on findings in the field collected by their section, with support from the other scientists on questions of technical know-how.

For purposes of presentation a three way classification of the proposals is offered here, recognizing that the distinctions between them are not sharp. The three groups are: studies in the economics of the farm; studies which are related partly to the individual farm, but have important institutional aspects; and studies where the institutional aspects are dominant.

Studies in the first group could be called farm management-production economic studies. One of the basic studies to be done in this area is to carry out a Farm Account Survey, possibly over three or five years. The aim for this study would be to collect data which would enable the assembling of a set of input-output coefficients according to various enterprises carried out in the zone. This is highly desirable for the purpose of facilitating production planning activities both on the individual farm or at the larger unit level. In the short run smaller studies could be carried out on individual problems which have been identified in the general surveys already completed. Such studies could be done by the use of budgetary analysis of individual enterprises and their comparisons. An important area to explore would be the process of mechanization and its effects on the organization of the farm production, and net returns. Special emphasis could be given here to possibilities of work done by hiring services or by cooperative use. Both in the dry and the irrigated areas studies could be carried out on the cropping pattern and rotation of crops on the farms, with the goal of learning about the factors which influence the decision creating these patterns and to analyse the differential results of them.

Those studies where consideration of both the individual farm and institutions are important, could be undertaken in two essential areas. One of these is in the area of risk and uncertainty and the measures taken by individual farmers, or groups, to meet them. In here the aspect of the problem of primary interest is to analyse what measures or institutions have served this purpose in the past, what is likely to happen to them under the changing conditions of our times, and what measures or institutions could serve to replace them under the new conditions. Uncertainty, mainly weather uncertainty is the focal element in the agricultural production process of the Arid Zone, thus, the measurement and analysis of uncertainty and the devising of appropriate counter-measures should constitute a principal item in the research programme of the Section.

Studies in the economics of soil conservation are the other area where the individual farm and the general welfare analysis are equally relevant. Often the perceived interests of the individual and that of the nation are contradictory in the carrying out of soil conservation measures. In the evaluation of alternative soil conservation proposals, economic analysis does yield guidelines which are extremely useful for policy making purposes. This problem area gains additional importance from the fact that a large part of the total efforts of the Institute fall into this problem field.

Among studies with a predominantly institutional aspect, a study on use and ownership rights to water and land resources, both customary and legal, should be mentioned first. Because a large part of the government's future role in the utilization of natural resources of the zone will be of a regulatory nature, it is extremely necessary to study the present situation, so as to be able to build on the present system towards an optimal use pattern, involving the least disturbance of the traditional rights to use and of ownership.

The Institutional setting; of the creation of new resources by the government, offers interesting and important research possibilities. The creation of new water sources, transportation links, and other public services lend themselves well for economic evaluation and provide information on this type of investment which represents a large portion of total developmental efforts.

In addition to the studies on the problem of settlement of nomadic and semi-nomadic groups, already in progress, further studies could be made in this direction utilizing the experience gained from other settlement schemes and emphasizing the economic aspects of the problem as it exists and of the proposed solution.

With an irreversible trend towards increasing monetization of agricultural production, the problems of marketing and credit will require attention. Alternative marketing channels could be analysed and the performance of the present credit system explored with special emphasis on the possibilities of creating a new effective credit system more favourable to the development of production.

Studies on the existing traditional forms of cooperative use and ownership of resources could be carried out, with the hope of learning from them about the factors contributing to their success and to utilize this knowledge in the formation of new types of cooperative efforts.

Finally, studies related to the two dominant factors, causing dynamic changes in Rajasthan agriculture ought to be done. I refer here to the expansion in population and to new technology of production. Studies in the relationship between population, water and land resources and the standards of living for specified areas could be initiated. With respect to new technology, its physical economic effects on production ought to be studied in the framework of the studies mentioned under those in farm-management and production economics. From the institutional point of view the interest here would be in analysis of the process of adoption, the factors which influence it and the problems involved in speeding up the process. The section has already started work in this direction and the studies to be made would represent a continuation of that work.

In summary it can be said that two major topics were treated in the first part of this paper. To begin with three major research areas were postulated as the broad objectives of agricultural economic research. This was followed by discussion on the suitability of these areas of research to be incorporated in the work of CAZRI. In the institutional setting of CAZRI, it appears that of these, two areas, namely, the area of interpretation of the findings of the physical-biological scientists into economic terms and the area of integration of the knowledge gained from research in various fields in an effort to solve some of the problems of the Arid Zone constitute the most important areas of research as visualized at the Institute.

In the second part of the paper thoughts on some specific studies were presented. Among these, the following are perceived as the central ones: (1) the study on input-output coefficients, (2) the study on uncertainty, and (3) the one on the institutional aspects of water and land use rights.

The role of the agricultural economist in working within an Institute like CAZRI has been succinctly summarized by Logan*, when he said:

> "One finishes the reading of this symposium with mixed feelings. The accomplishments of scientists in the laboratory and in the field in detecting, describing, and analysing the most minute conclusion that man can and will conquer nature in any of its aspects. Yet again and again throughout the work, a note of warning is sounded: that the deserts are enlarging, that 'desertification' is on the march, that man himself is the chief cause. There is, of course, no paradox here. It is simply a matter for the political economist to handle. The scientist in the field or in the laboratory is thoroughly capable of directing the battle against the deserts, whether or not the world pays heed to him is another matter."

*R. F. LOGAN, in Institute of Biology: *Biology of the desert*. The proceeding of a symposium on the biology of hot and cold deserts. London 1954 p. 224.

LOCUST ECOLOGY, CONTROL, ETC.

LOCUST ECOLOGY AND CONTROL[1]

by

D. R. BHATIA[2]

THREE species of locusts, viz., the Bombay (*Patanga succincta*), the migratory (*Locusta migratoria*) and the desert (*Schistocerca gregaria*) occur in India. Studies on their biology, ecology and control are in progress at the Field Station for Investigations on Locusts, Bikaner. The Bombay locust normally breeds in the open areas of the Western Ghats. Its plagues occurred during 1835-45, 1864-66 and 1901-08, resulting in heavy damage to crops. Its swarms have not been reported since 1908 though scattered individuals are found in Rajasthan-Gujerat, mainly among a sedge (*Cyperus tuberosus*) in Barmer district, population being up to 24,600 psk. Once about half a dozen hoppers were also located. During 1960, concentrated breeding occurred in Madhya Pradesh, necessitating control. The locusts occurring in Rajasthan may have originated from some such area. Significant number of adults and hoppers have also been found in Kadmat (11°15′ N 73°00′E) and Agathy (10°51′N 72°28′E) islands since 1960. They inflicted damage to coconut trees and control measures had to be adopted. The migratory locust swarms were found in Madras State during 1878 and at Bangalore in 1954, resulting from breeding in Ramanathapuram district of Madras. Concentrated breeding occurred in Rajasthan-Gujerat during 1937, 1956 and 1958 but no swarm developed due to timely control.

The following account relates to the desert locust, the main species affecting India:

DISTRIBUTION

The invasion area extends from West Africa to Assam affecting 60 countries over about 30 million sq. kms. In India, swarms generally invade entire north-western region, penetrating the hilly tracts in the north but sometimes reach Assam in the east and Kerala in the south. Breeding, however, occurs up to Barabanki (U.P.) in the east and Dhar (M.P.) in the south.

MIGRATIONS

Broadly speaking there are two rainfall regions, viz., winter-spring and summer. As locust breeding is dependent upon rainfall, those developing in one region migrate to the other on close of rainy season, e.g., swarms developing in Iran and Baluchistan (Pakistan) invade India in summer whereas those arising in Indo-Pakistan region migrate westwards in autumn. Isolated locusts also undertake flights, resulting in seasonal changes in their geographical distribution, paralleling those of swarms. Isolated locusts generally fly at night and swarms during day. How such distant migrations are brought about? Locusts normally fly down-wind. There are areas of convergence, across the boundaries of which surface winds show a net excess of the inflowing air over outflow and within which the overall vertical motion of the air is one of ascent and there are areas of divergence across the boundaries of which outflow exceeds inflow and within which overall vertical motion of the air is one of descent. Convergence is essential factor in production of widespread heavy rainfall while divergence, is associated with dry weather. Thus down-wind locust movements result in their displacement away from zones of divergence, rain and swarms being brought and deposited in zones of convergence.

THEORY OF LOCUST PHASES

Hoppers kept crowded exhibit black colour pattern, resultant adults being pink whereas those kept singly assume colour of the vegetation they live upon, the resultant adults being grey. Some structural and behavioural differences also develop, e.g., those crowded move together and those in isolation remain singly, elytra/femur ratios of the former being above 2·15 and of the latter below 2·06. Locusts kept crowded are of phase *gregaria*, isolated of *solitaria* and those in between *transiens*. In nature due to natural enemies and unfavourable climatic conditions (e.g., deficit rainfall, swarms reaching heavy rainfall areas, getting drowned into sea) the locusts perish without producing progeny, resulting in termination of plague (cycle). During the swarm-free interval (recession period) only isolated locuts are left which produce *solitaria* progeny. On return of favourable conditions there is mass multiplication and aggregations into favourable ecological pockets (e.g., localized rainfall, vegetation) and the locusts transform into phase *gregaria*, leading to swarm formation and initiation of fresh plague. Low density (one hopper per sq. metre) desert locust populations found in

1. Contribution from Field Station for Investigations on Locusts, Bikaner.
2. Locust Entomologist.

association with high populations of grasshoppers having similar habits (*Oedaleus senegalensis*) also exhibit black colour pattern leading to their gregarization.

LIFE HISTORY

Each female lays about 500 eggs in batches of 40-120 in moist soil 8-15 cm deep, laying period extending over 4-6 weeks. Under Rajasthan conditions during July-September, eggs hatch in about a fortnight and larvae emerge to soil surface. They aggregate and form bands which move about and feed on vegetation. They moult (cast off skin) 5 times during a period of about 4 weeks and fledge into winged adults, which gather together and leave the breeding grounds as swarm. In turn they mature in about 3-4 weeks and oviposit. Within certain limits the incubation, larval and maturation periods are inversely proportional to temperature. Being migratory, they are able to breed in some part or the other of the desert belt throughout the year and may produce four broods.

BEHAVIOUR

Study of locust behaviour is essential for its efficient and economical control. At night, hoppers roost, preferably on bushes. At sunrise, they orientate towards sunny side of vegetation and thereafter descend to ground and form morning ground groups, basking in the sun generally with their bodies at right angle to the sun's rays. Thereafter, various groups merge to form a band which normally marches throughout the day except when feeding or moulting. However, at high soil temperatures (say 45°C) the hoppers group on the shady sides of bushes or ascend vegetation for midday roosting but resume marching when it is cooler. The marching may also be interrupted due to rainfall, strong winds or predation by birds. As evening approaches, hoppers form dense groups and after sunset ascend vegetation for night roosting. Occasionally marching occurs during night.

During night, swarms roost on trees or tall bushes. At sunrise, they move to sunny sides and thereafter descend to ground. They first commence flying haphazardly but subsequently various groups merge and the swarm as a whole leaves the roosting site. Swarms can fly eight to ten thousand feet high but normally they do so up to about two thousand, sometimes only at a few feet above the ground surface. Swarms are mostly rolling, i.e., some locusts settle down but rejoin the main swarm and perfect cohesion is maintained inspite of air turbulances. In evenings they fly low, get dense, hover around and settle for the night roosting. Sometimes flights may occur at night.

Initially swarms settle down anywhere, but subsequently females select for egg-laying, sandy heeps around bushes, bare portions of sandy soil, bare parts in cropped areas, etc. They show preference for sandy soils but may lay in clay to fine gravel.

The desert locust is polyphagous, eating most type of vegetation and even committing cannibalism. The main plants discarded are *Azadirachta indica* and *Calotropis procera*. Generally succulent leaves are preferred though it exercises food preference. Type and quality of food affects larval duration and sexual maturity. Locusts feed throughout the day and till late at night, the peak periods being mid-morning and evening in summer and 1000 to 1500 hrs. in winter. Each locust consumes its own weight of food daily. One square mile swarm contains 300 tons locusts and 300 sq. mile swarms are on record. Therefore, the damage caused is colossal, sometimes resulting in famines. Locusts, by consuming annuals in the desert, loosen the soil and thereby cause its erosion.

ECOLOGY

From the foregoing, it will be seen that the invasion area of the desert locust is very vast, long distant seasonal migrations occur, eggs can be laid in various types of soil and practically every vegetation is eaten. It is, therefore, difficult to define its normal ecological requirements. However, general aspect of its ecology is that its existence is closely dependent on rainfall as eggs are laid only in moist soil, hoppers cannot grow and adults cannot mature unless they eat fresh vegetation. The type of vegetation also affects their growth and maturity. Heavy rainfall is, however, detrimental. Broadly speaking, breeding occurs in areas receiving 125 mm to 1000 mm per annum. Eggs are generally laid in bare soil devoid of vegetation, sandy soil being preferred. Temperature is important factor in locust biology, there being no development below 18°C though even -8°C temperature can be withstood. The optimum temperature is, however, 30-35°C. During monsoon, conditions in the arid and semi-arid regions of Rajasthan-Gujerat, which conform to the above requirements, are ideal for locust development.

CONTROL

There are three approaches to control, viz., suppression of outbreaks, changing the special ecological conditions favouring gregarization and direct offensive.

SUPPRESSION OF OUTBREAKS

Under favourable conditions there is mass multiplication of solitary locusts which congregate and oviposit in favourable ecological pockets, resulting in crowding of hoppers and transformation to *gregaria*, leading to initial swarm formation. Such concentrations should be destroyed to suppress fresh outbreaks for which continuous watch over the entire desert area, during recession period is essential. In 1956, 1957 and 1964 such concentrations, which developed in India, were suppressed.

CHANGING THE SPECIAL ECOLOGICAL CONDITIONS

Changing the desert habitat, of about 15 million sq. km., where locusts breed, is not feasible. However, irrigation projects (like Rajasthan Canal) may have repercussions on locusts as they would change the desert habitat.

DIRECT OFFENSIVE

Previously, attempts to destroy locusts were initiated only when they invaded cultivation. Since 1942, coordinated efforts are being made for their destruction in the desert breeding areas of India. At present, FAO is the coordinating agency for the entire desert area, with the deliberations and activities of which the Government of India is associating actively.

It has been suggested that to save valuable crops and orchards *neem* kernel suspension be sprayed which serves as repellent to locusts. The old methods of digging eggs, ploughing egg-infested grounds, beating or burning settled swarms have been discarded. Hopper destruction by driving them into trenches has also been generally given up. Baiting, wherein poison mixed with wheat bran is spread over infested areas, has also been discarded since 1950.

Since 1949 several hydrocarbons (e.g. BHC, aldrin, dieldrin, heptachlor) or organophosphorous (e.g. methyl parathion) compounds are being used in locust destruction as dusts, oil solutions, emulsions or suspensions. Dusting is done by hand or power machines, failing which by cloth or gunny bags or spreading the insecticide in front of marching bands. For dusting, mainly BHC is used at about 20 lb./acre in strengths ranging from 1·5 to 10% (containing 0·2 to 1·3% gamma isomer) depending upon the locust stage. For spraying, mainly aldrin and dieldrin are used as they remain toxic till several days after spraying. 1 oz/acre dose is enough to give a complete kill. Spraying operations are handicapped due to water shortage in desert. This difficulty has been overcome after manufacture of exhaust nozzle sprayer which produces very fine insecticidal spray (droplet size about 70 microns) which, by wind-drift, contaminates vegetation on which locusts subsequently feed and die. This equipment is run by the exhaust gases of vehicle on which it is mounted and can disperse 5 oz insecticides per acre, covering 6 acres per minute. The drawback is that numerous vehicles are needed, procurement of which is difficult. Manufacture of portable drift-sprayers would solve this difficulty.

Another technique is of egg-bed spraying. Egg-laid grounds are sprayed with insecticides having toxicity lasting for several days. Hoppers on emergence die by contacting or eating the contaminated vegetation. Cultivation, after treatment, adversely affects the toxicity.

Aerial control, against egg-beds, hoppers and settled swarms, was started in India during 1951, using boom and nozzle spray attachment. The disadvantage is that it produces large drops (about 200 microns) which fall straight down, the coverage being low (about 1,000 hectares daily). It was, therefore, replaced by 'micronair' spray attachment during 1962, the main advantage being that its swath is about 1,000 metres (about 25 metres in case of boom and nozzle) the plane flying 15 metres high (daily coverage 150-200 sq. km.). The droplet size can be brought down to 50 microns and discharge rate is kept about 5 oz/acre.

The most important advantage in favour of aerial control is rapid reconnaissance and spraying of vast tracts. It is particularly advantageous in remote desert areas which are difficult to approach by ground and where manual labour is inadequate. It is the only method for destruction of flying swarms. However, bad weather and strong winds, non-availability of repair and maintenance facilities and suitable landing sites are important limitations in the Indian desert.

Natural enemies: Large number of birds (e.g. starlings, kites, crows) and cold blooded vertebrates (e.g. lizards) are well known predators of adults and hoppers. Some beetles also predate upon them. Grubs of one species (*Trox procerus*) predate upon eggs, sometimes causing 100% destruction. Sometimes, eggs get shrivelled due to fungal attack. In the laboratory stocks, bacterial and fungal diseases have caused heavy mortality. Efforts made, to disseminate cultures of viruses, bacteria and fungi in the hope of creating infections among locusts, have failed.

DISCUSSION

L. D. Ahuja: Can locusts killed by insecticides after drying be used as cattle feed? If so what is the effect of insecticides on animals? What is the effect of feeding cattle on grasses sprayed with insecticides?

D. R. Bhatia: The insecticides are sprayed at a dose of about 1 oz per acre. This is not likely to have any adverse effect on the cattle grazing on sprayed grasses. There has been no report of cattle death. The cumulative toxicity, however, requires investigation.

P. K. Sen-Sarma: What is the percentage dose used in case of aldrin and dieldrin? What is the period of residual toxicity of aldrin and dieldrin? What is the scope of introducing chemical attractants, specially sex attractants?

D. R. Bhatia: The stock solution of aldrin and dieldrin used are generally 10 & 20 per cent. The insecticide is applied at a dosage of about 1 oz (actual) per acre. The residual toxicity of aldrin lasts about three weeks and dieldrin about eight weeks. Investigations are needed to study the scope of introducing chemical attractants to control locust.

ASPECTS OF POPULATION DYNAMICS OF DESERT LOCUST[1]

by

M. L. ROONWAL[2]

INTRODUCTION

IT is well known that locusts undergo periodic population flux, the plague-years or years of high population alternating with periods of extremely low population. In the Desert Locust, *Schistocerca gregaria* (Forskal), in India, these periods vary greatly from cycle to cycle. On the basis of the records of cycles since 1860, the swarming periods vary from 5-10 years (average *c.* 7 years) and the non-swarming intervals from 1-8 years (average *c.* 4 years), the complete cycle lasting 7-14 years (average *c.* 11 years) (*vide* Roonwal, 1954).

It is also known (Roonwal, 1954, pp. 484-486) that the maximum land area of distribution of the species in the swarming periods is about 16,500,000 (or 16½ million) sq. miles, and is about 1·7 times the maximum area occupied during the non-swarming periods which is 9,500,000 (or 9½ million) sq. miles.

Furthermore, it has been known for long that individuals in the swarming periods (phase *gregaria* individuals) and those in the non-swarming periods (phase *solitaria* individuals) differ from each other in colour, size and proportion of body-parts (morphometry, etc.) as well as in physiology and behaviour.

From work in India, it was shown by Rao, Roonwal, Misra and others that characters such as the length of the elytron and hind-femur (E and F), the width of the head (C), etc., and the ratios E/F, F/C, etc., differ significantly in the two phases. The number of vertical eye-stripes also varies with the phase, being only 6 in ph. *gregaria* and 6-8 in ph. *solitaria* adults. Very rarely, 5-striped forms also occur.

Until recent years data from populations well in the middle of either the swarming of the solitary periods alone were available, and we had thus no information on what happens in the critical periods at the beginning or end of a cycle. Fortunately, such an opportunity was available in 1949 and again in 1955, the initial and end years respectively of the 1949-55 swarming cycle in India. In this contribution will be dealt with some aspects of the population dynamics of the Desert Locust, especially the morphometric characters and other related variations, in populations during critical periods of phase-transformation as elucidated from recent work.

PHASE TRANSFORMATION AT THE BEGINNING OF A CYCLE

Misra studied (1952) a collection of 192 individuals made by him in Kakko, Rajasthan, in July 1949, from a concentration with a population density of *c.* 18,780 per sq. mile. This concentration was the precursor of the full-scale swarming which started in 1950 (*vide* Roonwal and Misra, 1952, for data). Misra concluded regarding morphometry that the Kakko concentration was intermediate between phases *gregaria* and *solitaria* but was closer to the latter. Regarding eye-stripes, 94 per cent of the individuals had 6 stripes and 5·6 per cent 7 stripes. There was one 5 eye-striped individual, a fact of considerable importance whose significance is discussed below.

PHASE TRANSFORMATION AT THE END OF A CYCLE

Roonwal and Bhanotar (1966) have studied a large collection of 1,179 individuals made from Western India in 1955, the last year of the cycle. For study, the population was divided into 3 groups, thus:

Group I (January-April) — First generation: Overwintered swarms. Population high.
,, II (May-August) — Second generation: Also including incursions from outside. Population high.
,, III (September-December)—Solitary breeding: Population low.

Regarding morphometry, Groups I and II had phase *gregaria* characters, while Gr. III was close to *solitaria*. Regarding eye-stripe composition, the high proportion of 6-striped individuals in Gr. I (93%) and II (99%) indicates phase *gregaria* features; Gr. III (with only 66% 6-striped and 44% 7-striped individuals) was close to ph. *solitaria*. In Gr. II, two 5-striped individuals occurred, and their significance is discussed below.

1. Contribution from Zoological Survey of India, Calcutta-12.
2. *Present address*: Vice-Chancellor, Jodhpur University, Jodhpur.

SIGNIFICANCE OF 5-EYE-STRIPED INDIVIDUALS

The most commonly occurring individuals are with 6 and 7 eye-stripes (exclusively 6-striped in the swarming phase and both types in the solitary phase). Forms with 8 stripes occur infrequently, and always in extreme *solitaria* conditions. The occurrence of 5-striped forms has been reported only in three cases as follows: (i) In two laboratory mass-breedings (in one case with 800 hoppers in a small cage), about 60 and "over a dozen" 5-striped individuals of both sexes, including fully-winged as well as bractrypterous adults, were produced in Baluchistan and Sind (Mukerji and Batra, 1938). (ii) A single male found in the Kakoo (Rajasthan) concentration of 1949, the initial year of the 1949-55 cycle (Misra, 1952). (iii) Two females in the Group II (May-August) population in Rajasthan in 1955, the end-year of the 1949-55 cycle (Roonwal and Bhanotar, 1966).

It would now appear (Roonwal, 1963*a*, p. 22) that the rare occurrence of the 5-eye-striped forms is in some way correlated with the unstable or critical period of phase-transformation, when the equilibrium is most shaken and conditions are rather crowded but not fully *gregaria* and are either on the way to full swarming (*congregans* type) or, *vice versa*, on the way to *solitaria* phase (*dissocians* type).

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DISCUSSION

K. Goesswald: May I congratulate Dr. Roonwal for the excellent paper he has presented to the Symposium. The experiments on population dynamics are of great importance not only for applied entomology but also for applied biology.

L. D. Ahuja: What are the causes for locusts changing colour from pink to yellow? Can the change in maturity and colour be suppressed by any means? Do the locusts change their sex as seen in poultry?

M. L. Roonwal: Sexual maturity causes the change from pink to yellow and is probably controlled by endocrine glands. As far as known, locust do not change their sex.

D. R. Bhatia: In rare cases, 7-stripped individuals were found to be in gregarious form. How can this be explained?

M. L. Roonwal: This may be due to some pockets where scattering had occurred, leading to solitary-type conditions.

RODENT ECOLOGY, PHYSIOLOGY, CONTROL

SKELETAL MODIFICATIONS IN GERBILS IN RELATION TO THEIR ECOLOGY[1]

by

V. C. AGRAWAL[2]

INTRODUCTION

DESERTS are characterized by barren land, scarcity of vegetation and water, and extremes of climate. A combination of all these factors have exercised varying degrees of stress on the vital processes of desert life. Both plants and animals have developed, in the course of their evolution, adaptive mechanisms to withstand the drastic conditions of the desert environment, which may broadly be classified as ecological, morphological, physiological and genetic. Rodents like the gerbils, *Tatera*, *Meriones* and *Gerbillus* (Gerbillinae, Muridae) and the jerboas, *Allactaga* and *Jaculus* (Dipodidae) are good examples of desert species which have developed more or less all these mechanisms in varying degrees. Here an attempt has been made to correlate the morphological structures, especially the limbs and skull, of the gerbils with the desert condition and compare them with the jerboas to estimate the extent of adaptation.

Definitions of skull measurements: (i) *Occipitonasal length* (O.N.L.): From the anterior tip of nasal to the hindmost point of the occipital surface in the mid-line. (ii) *Tympanic bulla length*: Maximum length of the inflated portion of the bulla, excluding the mastoid portion. For other measurements see Roonwal and Agrawal (1966).

Acknowledgement: I am grateful to Dr. M. L. Roonwal, Director, Zoological Survey of India, for his valuable suggestions in writing this paper.

EFFECT OF DESERT CONDITIONS ON RODENTS

To overcome the difficulty of extremes of temperature, scarcity of food, and for protection from enemies in the open land, the gerbils have acquired the burrowing habit, the leaping habit, the sandy-brown coat-colour and acute power of vision and sound perception. The latter two requirements have resulted in the development of large eyes and tympanic bullae.

Changes in limbs: Gerbils are fossorial in habit and mainly use their forelimbs alternately for scraping and loosening the earth and the hindlimbs for throwing the earth behind and outside the burrow. The head does not play any appreciable part in digging except occasionally for pushing the soil outside (Agrawal, 1967*a*).

Equipped with a pair of hands, each having five well developed fingers (the thumb being the smallest) ending in sharp claws, these rodents dig fast and deep into the desert soil and the soil so dug is brushed away by its long hindlimbs which are studded with brush-like hairs underneath the sole as in species of *Meriones* and in *Gerbillus gleadowi*.

The gerbils are quick runners and in doing so they move in a series of leaps. During leaping, the hindlimbs are used as organs of propulsion and the forelimbs for alighting. The counterpoise is maintained by the long hairy tail (mean 155% of head and body length in *Gerbillus d. indus* and 160% in *G. nanus* and *G. gleadowi*) which acts as an organ of balance during leaps.

In order to take long leap the hindlimbs, particularly the foot portion, has become longer (mean 24% of head and body length in *Tatera indica* and *Meriones hurrianae*, 28% in *Gerbillus d. indus*, 33% in *G. nanus* and *G. gleadowi* and over 50% in *Allactaga elator*) as compared to the non-leapers like *Rattus rattus arboreus*, *Bandicota bengalensis*, etc. (under 22% of head and body length). In the anatomy of the hindlimbs the gerbils are more alike to *Rattus* than to the desert-adapted jerboa (*Jaculus*). The tibia is the longest bone of the hindlimb, and is strengthened by the fusion of fibula at the lower

TABLE 1: Measurements (in cm) of hindlimb-bones in some desert Rodents.

Name of species	*Length of tibia*	*Length of fused portion of tibia and fibula*	*Length of fused portion of tibia and fibula/Total length of tibia*
Gerbillvs gleadowi	2·60	1·30	0·50
Meriones hurrianae	2·60	1·20	0·46
Tatera indica	3·70	1·55	0·41
Rattus rattus	3·25	1·20	0·37
Funambulus pennanti	3·60	0·75	0·21

1. Contribution from Desert and Gangetic Plains Regional Station, Zoological Survey of India, Jodhpur.
2. Officer in charge.

two-fifth portion of it, as compared to the arboreal form like *Funambulus* and the ground-dwelling forms like *Rattus rattus*, where this fusion occurs to a lesser degree (Table 1). This strengthening of the lower portion of the hindlimb aids in leaping and in swift running. There is neither any reduction in the number of digits of the hindlimbs (except that the hallux is much smaller) nor any fusion of the metatarsal bones, as is found in jerboas (Dipodinae) where the number of toes are reduced to three and the three central matatarsal bones are fused to form a cannon bone (Ellerman, 1961), an adaptation to cursorial habit.

Changes in skull: In the desert rodents, since the head does not play any appreciable part in digging, the fossorial habit has the least effect on the form and structure of the skull as compared to the fossorial forms of non-desert regions like the

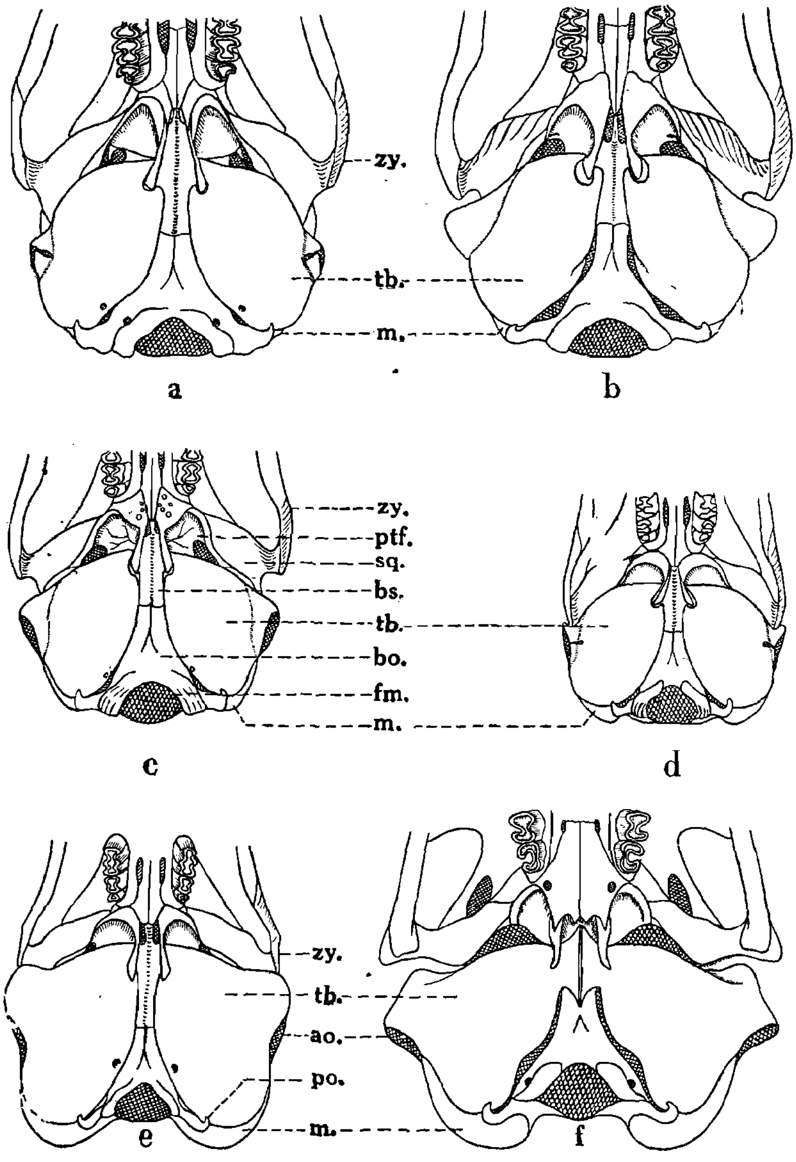

Fig. 1. Ventral view of the posterior portion of skull of desert rodents, showing the enlargement of tympanic bulla.

(a) *Tatera indica indica* (Muridae: Gerbillinae)
(b) *Meriones persicus* (Muridae: Gerbillinae)
(c) *Meriones hurrianae* (Muridae: Gerbillinae)
(d) *Gerbillus gleadowi* (Muridae: Gerbillinae)
(e) *Meriones swinhoe* (Muridae: Gerbillinae)
(f) *Jaculus jaculus* (Dipodidae: Dipodinae)

ao., auditory orifice; *bo.*, basioccipital; *bs.*, basisphenoid; *tb.*, tympanic bulla; *fm.*, *foramen* magnum; *m.*, Mastoid; *ptf.*, pterygoid fossa; *po.*, paroccipital process; *sq.*, squamosal; *zy.*, zygomatic arch.

bamboo rats (*Cannomys* and *Rhizomys*) and the voles (*Ellobius*) (Agrawal, 1967*b*).

In the gerbils the skull is mainly effected by the enlargement of eyes and the auditory organs. The tympanic bullae (over 24% of O.N.L.) (Table 2) and the mastoids have become unusually large and inflated (Fig. 1) as compared to the non-desert adapted forms like *Rattus*, *Bandicota* (Murinae), *Cricetulus* (Cricetinae), etc., where the bullae are less than 24% of O.N.L. The inflated bulla probably acts as resonator of sound vibrations and thus helps in the better detection of sound. This inflation seems to be correlated with desert condition. In *Tatera indica* (Gerbillinae), which is distributed throughout India (except Assam), Ceylon, West Pakistan and Iran, there is a continuous decrease in the size of the bullae from Baluchistan (the desert region) eastwards and southwards (the non-desert regions) (Fig. 2). The same is true of *Gerbillus*. In *G. nanus* (Baluchistan) the bullae are slightly larger (32·8% of O.N.L.) than in *G. d. indus* (Sind) (31·6%).

Among gerbils the bullae (Table 2) are smallest in *Tatera indica*, slightly more developed in *Meriones persicus*, *M. hurrianae* and in species of *Gerbillus* and reach their maximum size in *Meriones erythrourus* and *M. swinhoe*. In the last two species the bullae and the external auditory meatus are so large and inflated that anteriorly they touch the zygomatic process of squamosals (Fig. 1) and laterally they are extended more than the zygomatic arches, thus resulting in the maximum width of skull.

The mastoid is also inflated into an enormous structure. The inflation of the mastoid is less marked in *Tatera*, *Meriones hurrianae* and *M. persicus*,

TABLE 2: Variations in size of Tympanic bulla in Subfamily Gerbillinae (family Muridae) and the family Dipodidae.

Abbreviation: *O.N.L., occipitonasal length*

Name of species	*Distribution*	*Length of tymp. bulla as % of O.N.L.-(Mean within bracket)*
I. MURIDAE: GERBILLINAE		
1. *Tatera indica cuvieri*	India (Andhra Pradesh & Madras)	23·3-25·2% (24·3%)
2. *Tatera indica hardwicke*	India (Mysore)	23·0-25·0% (24·3%)
3. *Tatera indica ceylonica*	Ceylon	23·0-25·3% (24·0%)
4. *Tatera indica indica*	Iran, W. Pakistan, India (Rajasthan, Gujarat, U.P., Punjab, M.P. & Bihar)	24·6-28·6% (26·3%)
5. *Gerbillus gleadowi*	Rajasthan, Gujarat & Sind	29·9-30·9% (30·4%)
6. *Gerbillus d. indus*	Sind	— (31·6%)
7. *Gerbillus nanus*	Baluchistan	32·8-32·9% (32·9%)
8. *Meriones persicus*	Iran, Baluchistan	27·3-30·5% (28·9%)
9. *Meriones hurrianae*	W. Pakistan, Rajasthan & Gujarat	27·6-31·1% (29·3%)
10. *Meriones erythrourus*	Baluchistan	— (37·5%)
11. *Meriones swinhoe*	Waziristan	— (38·1%)
II. DIPODIDAE		
12. *Jaculus jaculus*	Egypt	31·2-31·9% (31·5%)

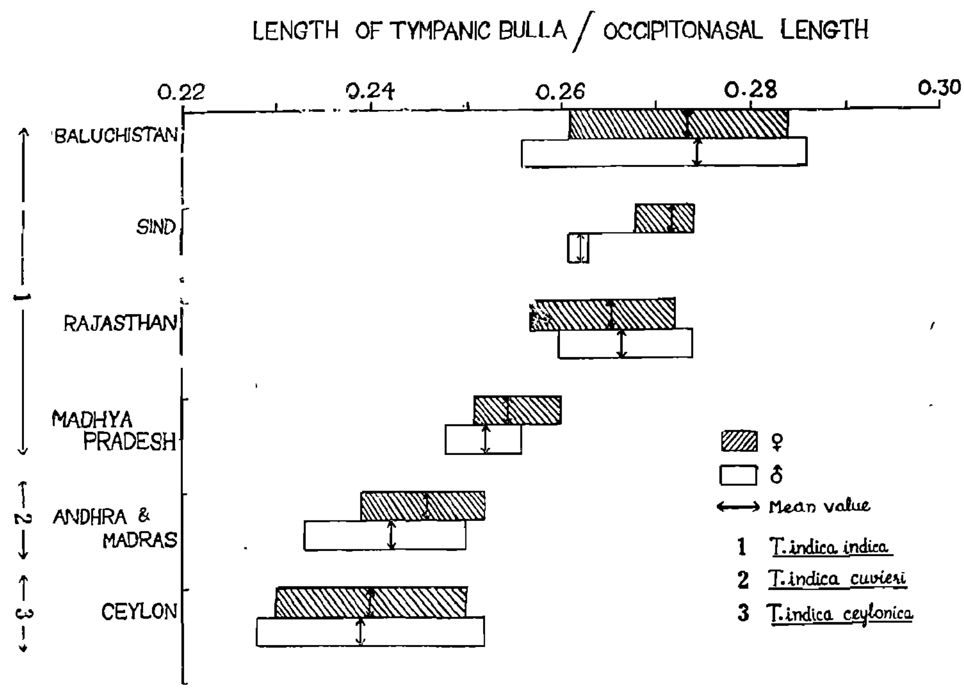

Fig. 2. Variation in size of tympanic bulla in sub-species of *Tatera indica* Hardwicke (Muridae, Gerbillinae) from Baluchistan (desert region) eastward and southward (non-desert region).

slightly more in *Gerbillus* (projecting posteriorly only up to occiput), and reaches its maximum in *Meriones erythrourus*, *M. swinhoe* and *Jaculus jaculus* where they are inflated into an enormous rounded chamber which extends posteriorly beyond the occiput (Fig. 3) and bulges out laterally through the supratympanic fenestra of squamosal.

The changes in the tympanic bullae and mastoids produce changes in the surrounding bones. The large size of the bulla has resulted in the narrowing of the basi-occipital and the basisphenoid (Fig. 1). The approximation of it anteriorly causes the reduction of the pterygoid fossa. Laterally, the squamosals are pressed, reduced and shifted dorsally, thereby causing slight reduction of parietals and the interparietal. The extent of reduction or narrowing of the bones depends upon the extent of enlargement of the tympanic bullae and the mastoids — it is least in *Tatera* and at its maximum in *Meriones swinhoe* and *M. erythrourus*.

The enlarged eyes, in gerbils, get themselves accommodated in the orbito-temporal fossa due to the poor development of temporalis muscles. Furthermore, in *Meriones hurrianae*, where the

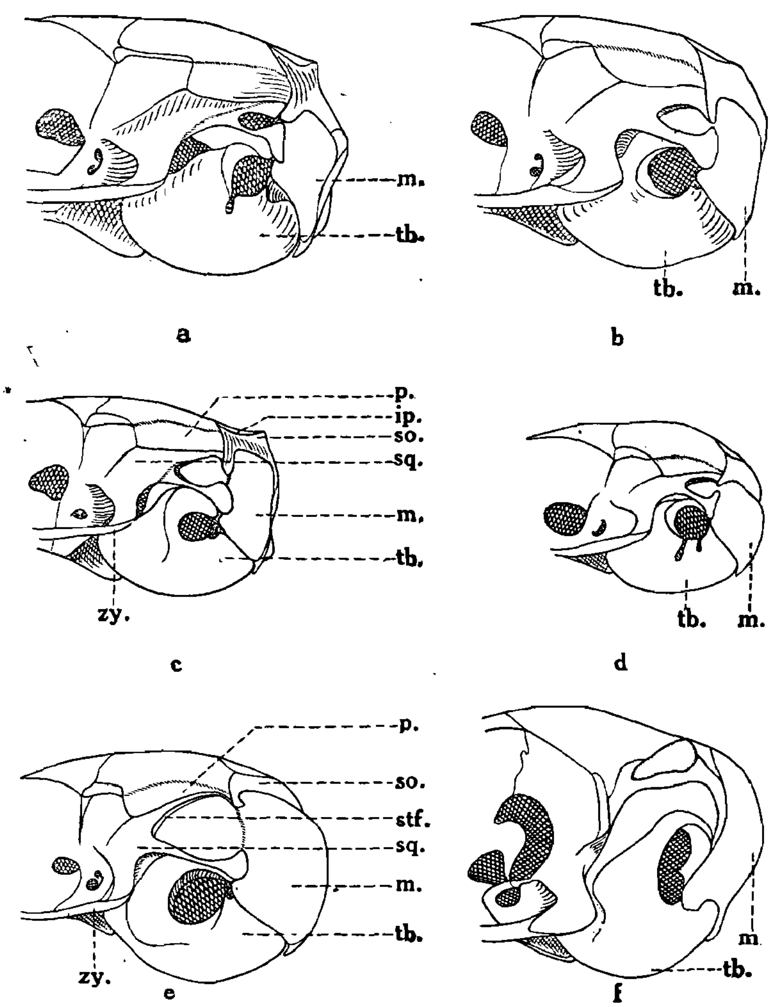

Fig. 3. Lateral view of the posterior portion of skull of desert rodents showing the enlargement of tympanic bulla & mastoid.

(a) *Tatera indica indica* (Muridae: Gerbillinae)
(b) *Meriones persicus* (Muridae: Gerbillinae)
(c) *Meriones hurrianae* (Muridae: Gerbillinae)
(d) *Gerbillus gleadowi* (Muridae: Gerbillinae)
(e) *Meriones swinhoe* (Muridae: Gerbillinae)
(f) *Jaculus jaculus* (Dipodidae: Dipodinae)

tb., tympanic bulla;
ip., interparietal;
p., parietal;
m., mastoid;
so., suproccipital;
sq., squamosal;
sft., supratympanic fenestra of squamosal;
zy., zygomatic arch.

temporalis muscles are better developed (Agrawal, 1967) the eyes have made room for themselves by pushing the zygomatic arches slightly outwards (zygomatic width 55-61% of O.N.L.). In *Jaculus jaculus* (Dipodidae) the anterior deep masseter muscle, which is particularly strong anteriorly, presses the large eyes posteriorly upon the lateral wall of the cranium, which becomes membranous and conforms to the shape of the eyes; and further the zygomatic arches are pressed ventrally so as to provide more space to the enlarged eyes and to support them from the ventral side.

SUMMARY

The effect of ecology on the morphological structure, with particular reference to the skeleton of rodents belonging to subfamily Gerbillinae (family Muridae) is discussed.

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DISCUSSION

L. S. Ramaswami: Probably the title may be made comprehensive. Have you taken any comparative data regarding the tympanic bullae of other desert mammals of similar size?

V. C. Agrawal: Data is based only on rodents.

P. C. Raheja: It will be useful to make studies in case of other mammals also.

K. G. Purohit: You have explained that tympanic bullae are inflated. Can you please tell what is the relationship of this phenomenon with arid climate?

V. C. Agrawal: It is a physiological problem and will be tackled later on.

ECOLOGY OF ANIMALS IN THE ARID ZONE[1]

by

DR. A. S. ATWAL[2]

ANIMAL and plant life in the desert areas is a marvel of adaptation for survival on this earth. Deserts are devoid of forests and thick vegetation. The climate there is deficient in rainfall, being characterized by extremely high temperature, strong winds, low humidity and excessive evaporation. Under such extreme conditions the survival of plant and animal life would seem very intriguing and yet the whole complex of life exists there. Since animal life is directly or indirectly dependent on plant life, study of their inter-relations is essential for understanding desert ecology.

DESERT VEGETATION

The desert plants are adapted structurally and physiologically. They are drought-escaping, drought-evading, drought-enduring and drought-resisting. Apart from their physiological quality of drought-resistance the desert plants have very thick cuticle which is almost impermeable. The cuticular transpiration is thus minimized. In summer, though the plants appear wilted yet they remain alive for a long time. The stomata are closed and the xeromorphic structures like thick cuticle, waxy covering, spines and hairs exert their protecting properties.

The desert plants are thus so adapted as to resume activity as soon as the season becomes favourable, which may even be for a short duration. The adaptation is thus not to benefit from dry conditions, rather the plants resist drought. The properties of the protoplasm are such that water can be bound through cell metabolism. The xerophytic plants in general have high osmotic pressure and consequently can maintain turgidity during wilting. Photosynthesis is thus possible for a longer period of time. All these factors combined determine the survival of desert plants.

Succulence and cylindrical forms are other means of drought-resistance. Water is stored during favourable period and the reserves are used when conditions are dry. On cactus, for example, there are hardly any leaves and the stems are thick and fleshy. Some of the giant cacti can store many tons of water. They have thick cuticle and sunken stomata. When the latter are closed water loss is very little.

ANIMAL ADAPTATIONS

Like the specialized xerophytic plants certain groups of animals are particularly suited to desert life. These groups include lizards, kangaroo, rats, sand grouse, gazelle, camel, numerous insects, etc. They possess such adaptive features as the impervious integument, tracheal system of respiration, water conservation by the excretion of concentrated nitrogenous wastes, deposition of dry faeces, suspended animation, nocturnal life, burrowing habits, conservation of metabolic water.

Integument of desert animals is hard. It is generally covered with scales, feathers or chitin. The desert mammals have comparatively very few sweat glands. The dry faecal deposits of rodents and antelops as compared to the liquid faeces of cattle are striking examples of water conservation. A number of desert insects, deposit even crystalline nitrogenous wastes. The remarkable character of suspended animation under desiccated conditions is common among the snails. They resume activity as soon as water becomes available. The various species of frogs and toads found in deserts burrow in the soil, reaching moist earth where they remain dormant till the rain comes. Such soft bodied and humidity sensitive insects like the termites have also adapted to desert conditions by constructing the termataria inside which requisite humidity is maintained. The moisture required is mostly derived from metabolic water as the termites feed on dry wood. The desert rodents also feed on dry food consisting of nuts, plant roots, seeds of grasses etc. They hardly take any free water. The metabolic water is utilized to maintain high water content of the body tissues. Among the higher animals camel has unique specialization of water conservation. It has a thick coat of hair, has the capacity to store water in stomach, and can also utilize the water of metabolism from the fat stored in its hump.

Of all the groups of animals adapted to desert life insects need special mention. They have small and minute body size and comparatively greater body surface. They are thus exposed to higher rate of evaporation. This shortcoming is met by other body characters which not only save them from excessive evaporation but also make them most

1. Contribution from Punjab Agricultural University, Ludhiana.
2. Now Dean, College of Agriculture, Punjab Agricultural University, Ludhiana.

suited to hot and dry atmospheric conditions. These characters are morphological, physiological and ecological in nature.

The desert insects are essentially buff, brown, sandy grey in colour, having a few patterns of black and white. These colours harmonize with the desert environment and are thus essentially cryptic in function, providing them protection against enemies. Or these help in advertising distasteful nature of the species concerned. Heavy, well developed integument, is another adaptation for desert life. The chitinous exoskeleton is almost fused segmentally in such insects as the tenebrionids, curculionids, carabids, cicindelids. In them evaporation of body fluids is prevented. A number of bombiliids and asilids are highly pilose and are thus saved from intense heat by the reflective nature of hairs and scales. Numerous orthopterons and a number of beetles in the arid zone are wingless. This morphological character saves them from winds. Elongated legs enable the insects to break contact with the hot sand surface and at the same time allow them to walk swiftly on sifting sand. There are still others that find it safer to dig into the sand. They have fussorial legs. The termination of diapause, reabsorption of water, completion of embryonic development and consequent emergence is synchronized with rainy season and the growth of grasses and other plant food in case of some grasshoppers like *Autriocetes cruciata* in Australian deserts.

Where rain and vegetation are not assured every year there may be even more subtle adaptations. In certain species of grasshoppers the eggs hatch over a period of two or three years. An example is afforded by Phadka grasshopper (*Hieroglyphus nigrorepletus*) in the Central and Western India.

Along with the morphological and physiological adaptations the commensurate behaviour patterns are essential, for securing sustenance, avoiding enemies, and for mating. As to how behaviour determines the success of an insect in reaching comparatively cool temperature in lower layers of sand is typical in Bomboicid wasps. Surface of the sand dune is too hot for them and they can tolerate the temperature there for a very short duration of time only. They fly about 6-12 inches above the surface and intermitantly make a number of attempts at digging. When the pit made is deep enough and the temperature there is tolerable the insect burrows inside. This behaviour is a clear adaptation to withstand extremes of temperature.

ECO-SYSTEMS AND ABUNDANCE OF ANIMALS

The environment of an individual in a population, constituting the physical and biological factors is the unit eco-system. Study of the individual is convenient but it is a community as a whole that makes significant impact on its environment. For instance, extension of the geographical limits of a given species may have such an impact that vegetation and the climate of that locality may be changed entirely. Near the Uganda-Sudan border there used to be very low vegetation and the grasslands were overgrazed by wild animals. Many years ago the tse-tse fly invaded that area killing a large number of animals. The subsequent undergrazing has now resulted in herbaceous stratum six feet high. In that region there are over 20 species of tse-tse fly living side by side and each one of them has a distinct behaviour and ecological requirements comprising more than one type of vegetation at a time and these types must be in contact with each other.

PLANT ANIMAL RELATIONS

An outstanding example of plant and animal relations in arid zones is that of the weed *Opuntia* and its insect parasite *Cactoblastis*. *Opuntia* was transported in a flower pot to New Southwales, around 1839. The plants were later on spread in the area through cuttings which were grown as hedges. By 1895 *Opuntia* was added to the list of noxious weeds in Queensland, and within the next 25 years it covered an area of 60,000,000 acres, with annual spread at the rate of 1,000,000 acres. For controlling this weed, the moth *Cactoblastis cactorum* was introduced in 1925.

The moth multiplied at a fast rate, quickly destroying the prickly pear over large areas around the point of liberation (Nicholson, 1947). "After sometime the point was reached at which very little prickly pear remained, whereas there were countless millions of moths which had bred upon the prickly pear got destroyed during the previous generations. Most of the caterpillars coming from the eggs of these moths died for simple lack of food, and most of the remaining prickly pear was destroyed at the same time. But this did not produce complete eradication of the prickly pear. By chance, or because of some favourable circumstances, here and there prickly pear plants survived. Similarly, even at this time some of the moths succeeded in finding odd plants on which to lay their eggs, although, because of the great reduction in the number of *Cactoblastis* in the previous generation, many plants were not found. The end result, which still persists, is that prickly pear is scattered in small isolated groups, with wide intervals between them. In a few of these *Cactoblastis* is still to be found, and these are generally doomed to complete destruction because *Cactoblastis* is able to increase rapidly in numbers on them. In the other groups of prickly pear, which have not so far been found by *Cactoblastis*, the pear tends to spread; but sooner or later is found by the moth, and the destruction of these groups is achieved shortly afterwards. In the meantime seed is scattered in new places, so maintaining the existence of prickly pear, and a low density of *Cactoblastis*, which vary little from year to year; but at the same time there is continual fluctuation in space ".

Another example of plant and animal inter-relation in the arid zone is that of the grasshopper *Austroicetes cruciata* (Andrewartha, 1943). It is distributed in Australia where rainfall is insufficient and crops are not grown. However, there are grasses and other low-vegetation on which the grasshoppers subsist. Further deeper in the desert where there is insufficient vegetation the grasshopper is not found. Even within the range of its distribution rainfall and vegetation is not the same from year to year. In favourable years the grasshoppers increase in numbers and reach pest proportions, causing damage to grass pastures meant for sheep. There is a complex relationship between the life cycle, the vegetation, and the climate of that area. In the egg stage this grasshopper has an obligate diapause and thus there is only one generation a year. The diapause is completed by mid-winter and depending upon the temperature in the spring season and the resultant development of the eggs, the nymphs hatch on various dates. Emergence coincides with the growth of the vegetation and, generally, there is plenty of food for the nymphs to develop. In the adult stage they lay eggs in the summer. At that time of the year there is intense heat, the grass withers and food supply is depleted. Large number of adults die of starvation but a good number successfully lay eggs. For the rest of the summer eggs remain in diapause and have a remarkable capacity to withstand severe drought. Apparently, the life cycle of the insect is very nicely synchronized with various seasons of the year and yet it is not free from hazards. Deaths occur in varying proportions of the population if there is excessive desiccation of the eggs during summer which is normally prevented by the occasional shower of rains. If there is drought just when the nymphs are ready to hatch during spring they are trapped under the compact surface of the soil. In years of scant vegetation the grasshoppers congregate at the favourable situations where birds prey upon them intensively.

Parallel to that is extensive predation by birds of the stragglers from locust swarms left behind at places of their visitation.

As for the dreaded locust there are no well defined outbreak areas of the world from where swarms of *Schistocerca gregaria* would originate out of the resident population. Since 1887 at least one swarm has been reported from somewhere in that vast area. It would mean that locust is in a perpetual state of swarming. In other words, swarming and recession to solitaria phase, alternate and so do the morphometric changes. Fresh swarming may arise either from carry over of the earlier swarms or from the concentration of scattered solitary locusts. The latter results from meteriological factors leading to ecologically suitable conditions for successful breeding and gregarization. There seems to be sufficient evidence against the old conception that the outbreaks commence in the areas and seasons with the most favourable conditions for the species. In other words, according to the new concept, dry conditions are not necessarily unfavourable provided, of course, the minimum requirement for breeding and gregarization are met with. The example of locust is unique in the respect that number and the phase are closely related factors, the former being independent of the phase but the phase is completely dependent upon numbers. In a given area the density per unit is important but so also is the total number scattered around there. Both these factors combined would lead to swarming, that is not to say that density is of lesser importance. A single concentrated oviposition from one swarm may give 20 times as many hatchings as the parents. As a matter of strategy, therefore, it is of great practical value to restrict the breeding areas as far as possible, by cultivation, and the use of human factor in controlling hoppers. The outstanding example is that of locust control strategy in the State of Punjab. The districts that lie north of the Rajasthan-Sind desert are just as favourable for the multiplication of locust and the formation of swarms. But the control operations carried out there, particularly at the hopper stage were so well organized in the recent years that no swarms were allowed to be formed. It was possible through well distributed village populations in the Punjab.

The animal and plant life in desert areas can be enriched by various ways. Animals being directly or indirectly dependent on plants for food and shelter, their impact on vegetation should be such that growth of vegetation is encouraged, erosion is reduced to the minimum and top soil is protected. Whatever little moisture is gained can be conserved and even agriculture can be practised by long range rotations. There are in fact vast areas in Australia, having less than 10 inch rainfall, where pastures are raised during good year and all sheeps are pulled out during dry years.

Man can have comparatively greater control over the detrimental factors. Erosion and rodents or other enemies of vegetation deserve special attention. Wind erosion can be prevented by long stretches of wind breaks and afforestation. The existing trees and shrubs can be gainfully propagated and better species can be introduced from other deserts of the world. Some selections out of the numerous species of gum trees found in Australia may prove useful in Rajasthan.

Animal destroyers of vegetation like the rodents, can be discouraged by the introduction of carnivorous predators. It is likely that the races of desert cat present in Turmeristan may do well here. Likewise other useful and beneficial animals can be introduced. After making a survey of the wild flowers of various regions of Rajasthan it may be considered worthwhile introducing the Sahara race of *Apis mellifera*, which is supposed to be the best race of honeybees. The workers of this race are known to fly up to a distance of five miles and are thus very efficient collectors of nectar and pollen.

Whatever the species, plant or animal, selected for introduction must essentially be useful. The benefit expected can be ensured only if their ecology and physiology is known. The possible interspecific relationships should be studied thoroughly lest they become terrible accidents like the notorious introduction of *Opuntia* and the European rabbit in Australia.

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EFFETCS OF WATER-STRESS ON GROSS BODY-COMPOSITION AND RENAL FUNCTION IN SMALL DESERT MAMMALS[1]

by

PULAK KUMAR GHOSH & K. G. PUROHIT[2]

INTRODUCTION

ANIMALS living in the desert are periodically confronted with the problem of maintaining the constancy of the internal environment. This constancy is mainly regulated by the maintenance of the volume and osmotic pressure of the extracellular and intracellular fluid compartments of the body which together form about 70 per cent of the body weight in mammals.

The physiology of the animals inhabiting desert regions, with particular reference to their water metabolism, has not been studied in detail until comparatively recently. The Schmidt-Nielsen (1952) reviewed the existing knowledge on the water balance of desert mammals. Recently, attention has been focussed on the peculiar adaptive and physiological mechanisms of desert mammals which enable them to live and propagate under conditions of extreme thermal load and water-scarcity. The subject has subsequently been reviewed by Bodenheimer (1957), Chew (1961), Hudson (1964) and again by Schmidt Nielsen (1964). A recent publication by UNESCO (1963) also provides valuable information on this subject.

Our present state of knowledge regarding the peculiarities of water conservation in desert animals can be summarized as follows: (1) The desert animals are broadly classified into two categories, viz., those that require water for temperature regulation and those that do not. (2) Most of the small desert mammals fall in the latter category although there are notable exceptions; (3) The rodents usually manage to escape the impact of the high radiant heat of the desert by their nocturnal habits and by living inside burrows. The microclimate inside the burrow is usually suitable for normal living during the day; (4) The most successful desert dwellers among the rodents have developed a highly efficient renal mechanism which helps in the preservation of maximum body water by forming a highly concentrated urine. Faecal and pulmocutaneous water losses also are minimized in these animals; (5) A few small mammals living in the deserts are not physiologically adapted for a xeric environment, but their food habits help them in tiding over the intermittent water scarcity periods; (6) The remarkable tolerance of some desert rodents for water deprivation is not necessarily associated with any unusual tolerance for body desiccation; and (7) The renal architecture in desert mammals has a few general peculiarities such as the preponderance of long-looped nephrons and the greatly-elongated papillae.

With this background information on the ecological and physiological adaptive mechanisms of desert mammals, in general, some of the findings on the physiological effects of water restriction in the most predominant rodent species, the Indian desert gerbil, *Meriones hurrianae* Jerdon, inhabiting the arid tracts of Western Rajasthan have been discussed.

SMALL MAMMALS OF THE RAJASTHAN DESERT

Although *Meriones hurrianae* is the most conspicuous among the small mammals in this desert, the few other rodent species are the antelope rat, *Tatera indica* Hardwicki, the hairy-footed gerbil, *Gerbillus gleadowi* Murray, and the desert mouse, *Mus platythrix*, which have established themselves here equally well. The Indian desert hare, *Lepus nigricollis* is the only other example of a herbivorous small mammal which apparently thrives well in the Rajasthan desert. Of the insectivorous mammals, two species of hedgehogs, *Hemiechinus auritus collaris* and *Paraechinus micropus micropus* are quite common in this tract. The morphological peculiarities, habitat conditions, and the feeding and breeding habits of these animals have been discussed by Prakash (1962, 1963).

TOLERANCE FOR WATER-RESTRICTION

Meriones hurrianae, hereafter referred to as the gerbil, has been found to be able to maintain its body weight for at least fifteen months on a dry diet of wheat in this laboratory. There are seasonal fluctuations in the body-weight of the water deprived animals, with low values during the extreme hot

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2. Animal Physiologist and Senior Research Assistant respectively.

dry periods. The lowered atmospheric humidity at such periods is likely to affect the moisture content of the grain and consequently, the water balance of the gerbil. The gerbil cannot possibly withstand water deprivation, at least in the laboratory, beyond sixteen months when its weight falls rapidly and the animal shows signs of general weakness. It should, however, be pointed out that in nature, these burrowing rodents hardly ever face the severity of the laboratory conditions. When the gerbil apparently reaches its limit of tolerance for water deprivation in the laboratory, provision of water produces a dramatic and quick recovery of the animal, the body weight increases and food consumption returns to normal.

Data in Table 1 would probably indicate that under natural conditions the gerbil is capable of withstanding several drought seasons in succession.

TABLE 1: Seasonal fluctuations on the average body weight of a water-deprived gerbil

	Body weight in gms.				
	Winter	*Spring*	*Summer*		*Autumn*
			Dry	*Monsoon*	
First year	41	43	24	64	50
Second year	58	51	32 (on the verge of death)	57 (water provided *ad lib*)	

HEAT TOLERANCE

When subjected to different thermal environments in the laboratory, with a view to determine the gerbil's tolerance limit for high ambient temperature, it was found that the rodent can effectively tolerate temperatures up to 40°C, but beyond that there is a sharp decline in survival percentage. The maximum and minimum periods of survival at 42°C were 320 and 120 minutes and at 44°C, 165 and 120 minutes respectively. The mean rectal temperature in these animals is 37·7°C. When subjected to heat stress, the body temperature rises and death supervenes at a body temperature of about 44°C. A marked fall in the body weight of the animals has been consistently found in all cases of heat exhaustion. There was conspicuous wetting of the fur under the chin and throat, presumably due to copious salivation. The cooling effect of this reaction is, in the opinion of Schmidt-Nielsen (1956) who observed this phenomenon in kangaroo rats, not of much significance except as an emergency measure lasting for a short period. A similar response occurs in the ground squirrel (Hudson, 1962) and in the Egyptian rodent Dipus (Kirmiz, 1962).

TABLE 2: Water evaporated during heat stress in the Indian desert gerbil

Air temp.	*Exposure time (hr)*	*Water evaporated (gm)*	*Evaporation*	
			gm/hr	*gm/hr/ 100 gm body weight*
40°C	$4\frac{1}{2}$	2·8	0·62	1·46
42°C	$3\frac{1}{2}$	2·4	0·68	1·82
44°C	$2\frac{1}{2}$	4·65	1·99	3·04

The amount of water evaporated from the body of the gerbil at three temperatures has been indicated in Table 2. From the corresponding data on the Kangaroo rat (Schmidt-Nielsen, 1964, p. 155), it would appear that the gerbil loses much less water per hour per 100 gm body weight at the very high temperature of 44°C ambient, the figure for Kangaroo rat at 43°C being 10·3. Again, none of the Kangaroo rats in Schmidt-Nielsen's study could survive for more than $1\frac{1}{2}$ hour at an air temperature of 43°C whereas in these experiments, the maximum survival period at 44°C air temperature was 2 hours and 45 minutes. In freshly captured gerbils, throughout the year, the total body water content has been found to constitute about 68 per cent of the body weight (fat included). The corresponding value for the kangaroo rat is around 67 per cent (Schmidt-Nielsen *et al*, 1948a). But unlike the kangaroo rat, the gerbil is not universally capable of maintaining its body water percentage within a narrow limit under conditions of severe water stress. There is a wide individual variation among the gerbils in their capacity to check body desiccation incompatible with physiological functioning, a body water percentage as low as 50 being encountered in an extreme case.

FAT DYNAMICS AS INFLUENCED BY WATER RESTRICTION

It has been repeatedly observed that short-term water restriction (extending over a period of from 2 to 6 months) often leads to an increase in the whole body fat percentage in the gerbil, although this lipogenic effect does not persist when water-restriction is prolonged over longer periods of time. Since there is no significant difference between freshly captured and dehydrated gerbils in respect of the cholesterol and phospholipid components of the body fat, it is apparent that only the neutral fat fraction is influenced by the reduced hydrature of the body (Ghosh, Purohit and Prakash, 1964).

There are also increasing evidences to suggest that water deprivation, irrespective of short-term or long-term durations, tends to affect the chemical nature of the body fat in these animals by making it more unsaturated than in normally hydrated animals.

TABLE 3: Effect of water-deprivation on body composition in gerbils

Treatmnet	Whole body				Iodine number of body fat
	Water %	Fat %	Choles-terol %	Phos-pholipid %	
Freshly-captured	68·17	6·64	0·158	0·359	58
Dry-fed for 60 days	59·99	11·62	0·190	0·343	72

The significant increase in total body fat of the water-deprived animals, as indicated in Table 3, is likely to be an adaptation mechanism. As reported by Strohl (1929), there are localized or general fat accumulations in most of the desert mammals at the beginning of the dry period. These fat deposits are likely to act not only as energy store, but also as very efficient water store, as 106 parts of water can be obtained from 100 parts of fat by oxidation. However, the Schmidt-Nielsens (1952) believe that the increased pulmonary ventillation needed for increased oxidation, with the resultant loss of moisture through the respiratory passages, would offset any advantage of the gain in metabolic water. Although it would be difficult, in view of theoretical considerations, to establish a causal relationship between water deprivation (or desert habitation) and body fat accumulation, yet it is surprising that a number of small desert mammals, e.g., the African rodent, *Pachyuromys steatomys* and the marsupials from the arid regions of Austrialia, *Antechinus maculatus* and *Sminthopsis crassicaudata* have fat tails (Schmidt-Nielsen, 1964). Certain desert lizards, too, have fat tails, e.g., *Uromastix* and *Heloderma*.

Table 4 gives the findings on the effect of dietary fat load on the body composition of water-deprived

TABLE 4: Body composition of normally hydrated and dehydrated gerbils as affected by 2 levels of dietary fat

Group	Treatment	Average body weight in gm		Body fat %	Body water %
		Initial	Final		
1.	2% fat diet with water	48·0	55·6	8·49	68·1
2.	2% fat diet without water	49·7	42·7	16·77	61·3
3.	15% fat diet with water	52·0	82·3	30·45	49·9
4.	15% fat diet without water	50·0	48·5	14·08	65·1
Significant t- values at 5% level		*For fat %*		*For water %*	
Between 1 & 2		2·5		2·2	
Between 3 & 4		6·3		5·7	

gerbils. All the groups of animals in this study received isocaloric diets over a period of 2 months. The pair feeding technique was employed between groups 1 and 2 and between 3 and 4.

Two aspects are clear from the data presented in Table 4, viz., (1) there is no additive effect of the dietary fat so far as deposition of body fat in the water-deprived gerbils is concerned; and (2) the body fat serves dual purpose as energy and water store depending on the exigencies of a particular situation.

The second point can be further elaborated. When the gerbil faces water crisis on a predominantly carbohydrate diet, its metabolism is directed towards establishing a fat bank to serve primarily as a water reservoir, but when its water needs are fulfilled and it is subjected to a high dietary fat load, it stores the extra fat in the body in the form of an energy bank. It may be concluded from the above studies that the enhanced loss of moisture from the respiratory passages, consequent upon the increased ventillation required for oxidizing the extra fat in the diet of the experimental gerbils, is apparently compensated by the actual gain in body water in the metabolic process. It should, however, be stressed here again that as water deprivation is prolonged, the body's fat store is slowly exhausted and the animals eventually become extremely lean. But the iodine number of the body fat steadily increases and a maximum value of 135 has been obtained in the case of an animal deprived of water for 15 months.

The significance of the increased unsaturation of the body fat of the water deprived gerbils is difficult to comprehend in the context of the existing knowledge of fat dynamics *vis-a-vis* water metabolism. There is, however, a report that in tropical merino sheep, water deprivation in summer for two days is followed by a five-fold rise of plasma unsaturated fatty acid (Macfarlane, 1963). The U.F.A. is known to spare both glucose and amino acids from catabolism. During water deprivation when the necessity for maximum body water preservation is imperative, less production of nitrogenous end products will be a distinct advantage as less water will be required to excrete them through the kidneys and in this respect an increase in the U.F.A. components of the body fat is likely to be of considerable help to the organism.

WATER RESTRICTION AND RENAL PERFORMANCE

The renal excretory mechanism of the gerbil seems to be similar in many ways to that of the Kangaroo rat as described by Schmidt-Nielsen *et al* (1948*b*). Tables 5 and 6 give the results of the findings on the renal function of gerbil when subjected to different stresses.

TABLE 5: 24-hour urinary excretion levels in mg of metabolites in gerbils.

Treatment	*Chloride*	*Total electro-lytes*	*Urea*	*Total nitrogen*
Freshly captured	11·03	57	93	82
Dry-fed for 60 days	24·3	120	168	153
p Value	0·001	0·001	0·001	0·001

Since the average 24-hour urine volume of the gerbil is 1·5 ml, the concentration of urea in the urine after two days on the high-salt high-protein diet is calculated to be 22 gm per cent, about the maximum ever recorded for any mammal.

SALT TOLERANCE IN GERBILS

Although the gerbil can effectively tolerate 1·2 gm NaCl per 100 gm body-weight daily for seven days, yet its actual requirement of salt is lower than 200 mg per 100 gm body-weight per day. Schmidt-Nielsen and Schmidt-Nielsen (1950) showed that the Kangaroo rat can maintain weight on undiluted sea water, but will drink this solution only when provided with a high protein diet. The antelope ground squirrel (*Citellus leucurus*), a diurnal desert mammal, remains in positive water balance while drinking NaCl solutions up through but not exceeding 0·8*M* (Bartholomew and Hudson, 1959). Winkelmann and Getz (1962) found that the Mongolian gerbil (*Meriones unguiculatus*) can also tolerate NaCl solutions up through a maximum of 0·8*M*. It is, therefore, noticed that desert rodents, in general, have the ability to process concentrated saline solutions. This is most likely to be more directly related to their ability to concentrate the urine in response to an arid environment than to a capacity specifically adapted to the utilization of saline solutions (MacMillen, 1964).

TABLE 6: Effect of salt load on 24-hour urinary excretion levels of metabolites in mg in gerbils

Days on dry grain	*Weight loss % after 3 days on salt-grain*	*Weight gain % after 3 days on dry-grain*	*Chloride*		*Total electrolytes*		*Urea*		*Total Nitrogen*	
			Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
15	3·5	—	11·7	61·2	82	136	99	134	85	102
30	6·9	2·2	14·3	63·4	88	165	120	128	111	117
45	8·3	2·6	16·8	53·1	101	168	139	159	129	130
60	9·7	2·5	24·5	24·3	121	195	168	188	155	176
75	12·5	3·6	27·8	66·7	136	249	129	134	124	129
90	15·6	4·2	30·5	82·7	137	240	117	128	109	120

It will be observed from the data in Table 5 that ordinarily the high level of urea excretion in these animals, can be simultaneously maintained with a very high electrolyte excretion. The excessive demand on the kidney does not leave the animals totally incapacitated, as shown by the slow gain in lost body weight when the animals are transferred from the salt grain diet to the basal dry diet (Table 6). The longer the period the animal is on the dry diet, the greater is the percentage loss in body weight when it is subjected to the heavy salt load for a short period. When the gerbils are subjected to high loads of salt and nitrogen simultaneously around the 60th day of water deprivation, it is observed (Table 7) that the additional salt load does not affect the excretion of the larger quantities of nitrogenous end products.

TABLE 7: Effect of a high-salt high-protein diet on 24-hour urinary excretion levels in mg of metabolites in gerbil

Days on dry grain	*Weight loss % after 2 days on high-salt high-protein diet*	*Weight gain % after 2 days on dry grain*	*Chloride*		*Urea*	
			Before	*After*	*Before*	*After*
60	15	10	22·8	74·2	150	330

As is established now, the renal concentrating capacity of desert animals is determined by the lengths of the loops of Henle and the extension of the renal papillae. Preliminary histological examination of the gerbil kidney, however, does not reveal any gross peculiarity in these respects (Purohit and Ghosh, 1963). The kidney structure of another rodent of the Rajasthan desert, *Tatera indica indica*, is more akin to the general desert mammal pattern.

PLASMA PROTEINS

In view of the established role of plasma proteins in regulating the distribution of body-water between blood and tissues, a comparative study of plasma protein status of four small mammals inhabiting this desert, was conducted (Ghosh & Purohit, 1965). The results have been presented in Table 8.

TABLE 8: Plasma protein composition in desert mammal species

Analysis	*L. nigricollis*	*M. hurrianae*	*T. indica indica*	*G. gleadowi*
Total proteins, gm/100 ml.	5·14	6·42	7·51	6·2
Albumin, % of total proteins	53·5	47·6	43·1	45·7
Globulins, % of total proteins:				
Alpha 1	7·8	13·1		16·5
Alpha 2	5·6	10·13		11·0
Total Alpha	13·4	23·4	20·5	27·5
Beta	14·6	13·8	12·8	11·2
Gamma	18·5	15·2	13·6	15·6

It is generally accepted that the albumin fraction of the plasma protein is largely responsible for maintaining the colloid osmotic pressure. The recent finding of Khalil and Abdel-Messeih (1963) that the blood of the desert lizards, *Varanus griseus* and *Testudo leithii*, possess higher albumin and lower globulin fractions in comparison to aquatic and semi-aquatic reptiles suggests that the higher osmotic pressure of the blood of the desert reptiles enables the blood of such animals to absorb more water when available and to retain a part of it. Such a physiological mechanism is likely to be of great ecological significance. The higher albumin percentage in the plasma of the hare in comparison to the rodents, as indicated in Table 8, is probably related to the different living habits of these animals. The rodents are all burrowing animals and *T. indica indica* and *G. gleadowi* are strictly nocturnal in their habits. All of them avoid the intense heat and radiation of the day by remaining inside their burrows where the micro-climate throughout the year is such that no evaporative cooling is necessary for the maintenance of body temperature. Thus, their actual water requirements is meagre. In contrast, the hare remains almost wholly exposed to the hot, dry atmosphere of the desert and as a consequence, it has to expend a good deal of water for evaporative cooling of the body. The high albumin percentage in its plasma, then, may be a water economy measure to fight heat stress.

BLOOD PICTURE IN WATER RESTRICTED ANIMALS

Short term water deprivation is often associated with considerable haemo-concentration in the gerbil. This is apparently due to a reduction in plasma volume consequent upon a general reduction in body water content. In prolonged water deprivation, however, normal haemo-concentration prevails. The normal blood specific gravity of the gerbil is around 1·065. This may go up to 1·075 during short term water deprivation, but the normal level is regained as the dehydration period is prolonged. These findings are in accord with the observations of Henschel (1964) in man.

BODY AND ORGAN GROWTH AS AFFECTED BY WATER DEPRIVATION

The organ: body-weight relationships in the gerbil, as affected by prolonged water deprivation, have been studied and the results are summarized in Table 9.

TABLE 9: Effect of gater-stress on the organ: body weight relationships in the gerbil

Organ	*Weight in gm per 100 gm body weight*	
	Freshly captured	*Water deprived for 8½ months*
Heart	0·35	0·22
Lung	0·41	0 34
Brain	1·25	1·32
Kidneys	0·74	0·94
Liver	4·12	3·96
Alimentary Canal	3·94	4·58
Pancreas	0·26	0·43
Reproductive tract	2·14	1·74
Spleen	0·29	0·37

Obviously, the water stress does affect the different body organs, but the exact implications of these findings are not yet clear.

Body growth as a whole has been studied in sub-adult gerbils under conditions of water restriction and protein supplementation. The results are given in Table 10.

The data in Table 10 is self-explanatory and these emphasize the role of moisture for the growth process of the gerbil. It has been observed in this laboratory that water restriction, from the weaning stage, retards body growth in the gerbil considerably and the maximum body weight of such an animal has not been more than 40 gm, whereas normally hydrated animals of the same age may attain anything up to 65 gm. A striking effect of water restriction in a gerbil since weaning for a period of

TABLE 10: Effect of two different levels of dietary protein and of water restriction on growth of gerbils over a 7-week period.

Group	*Treatment*	*Percentage increase (+) or decrease (−) in body weight over initial body weight*
1	20% protein diet with water	+171
2	20% protein diet without water	−24
3	5% protein diet with water	+120
4	5% protein diet without water	+35

fifteen months has been the extreme brittleness of the bones. The kidney in this animal showed extensive internal haemorrhage.

It has further been observed that the activity of at least one Krebs Cycle enzyme, viz., succinic dehydrogenase is significantly reduced in the liver and kidney tissues of water deprived gerbils. This might be indicative of a partial block in the tricarboxylic acid cycle at the succinate-fumarate step. Further work in this respect is likely to yield valuable information on the metabolic effects of water restriction.

SCOPE OF FUTURE RESEARCH

The exploratory studies, discussed here, have brought out certain general information on the physiological peculiarities of the Indian desert gerbil. Much, however, remains to be known, especially the breeding behaviour of this rodent in relation to the moisture status of the organsim. Since both water-metabolism and reproductive physiology are closely associated with hypothalamic and hypophyseal control systems, it may be worthwhile to study the correlation between these two processes. Further, the gerbil's inability to breed in captivity, even when maintained on a nutritionally adequate diet, poses a problem which may require a team of scientists comprising of a nutritionist, an endocrinologist and a photobiologist, to elucidate.

CONCLUSIONS

As with all desert animals, the gerbil is primarily concerned with maintaining its water balance under severe water stress conditions. In consequence, it has to deal with two problems: (1) how to reduce water requirement; and (2) how to increase water conservation. The rodent tries to tackle the first problem by habitually avoiding the intense heat and radiation of the day. It overcomes the second problem on physiological bases (i) by minimizing pulmocutaneous moisture loss, (ii) by concentrating its urine to a great extent, and (iii) by depositing excess body fat as a potential source of metabolic water.

It is probable that the gerbil's capacity to thrive well under desert conditions is linked with its ecologically and physiologically balanced evolutionary progress.

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DISCUSSION

J. J. Chinoy: Dr. J. Levitt of U.S.A. has shown that even in plants water stress is associated with lipoid metabolism. Has any work on lipoid metabolism been carried out in water-deprived gerbils ?

P. K. Ghosh: Although no detailed work on lipoid metabolism has been done yet in view of the fact that phospholipid and cholesterol contents of the body remain unaffected by water deprivation, it is apparent that only the neutral fat fraction is affected.

H. P. Nath: Study may be profitably carried out of detailed fat metabolism in these animals. Studies may also be conducted on the large intestines of these animals to find out whether there is any difference in the structure of that organ due to water deprivation.

L. S. Ramaswamy: Is increased fat deposition in water deprived gerbils comparable to the accumulation of body fat in bats prior to hibernation ?

P. K. Ghosh: The bats use the extra body fat as a source of calories during the period of inactivity. But the extra body fat in dehydrated gerbils is probably meant to be a source of metabolic water.

ECOLOGY OF THE INDIAN DESERT GERBIL *MERIONES HURRIANAE* JERDON[1]

by

ISHWAR PRAKASH[2]

INTRODUCTION

PERHAPS the most important species of mammals in the grass lands of Rajasthan desert is the Indian desert gerbil, *Meriones hurrianae* Jerdon. Because of its abundance this rodent exerts a great influence on the vegetation by its feeding and burrowing activities. It is also an important agent of soil erosion as its burrow system is most extensive and is found in almost all types of habitats. Its devastating propensities were known as early as 1899 (Jodhpur Administrative Report) when it was recorded that a large number of saplings were eaten away by antelope rats. Wagle (1927) regarded it as harmless in the rice fields of Lower Sind, but an evaluation of its feeding habits (Prakash, 1959, 1959a, 1959b & 1962) indicates that it is extremely injurious to desert vegetation. This paper embodies results of some aspects of the investigations conducted on this rodent during 1953-63.

HABITAT

The Rajasthan desert covers an area of 1,28,000 sq km and is bounded on the east by the Aravalli ranges and on its west it merges into the deserts of the Palaearctic region. It is partly arid and partly semi-arid. About 90 per cent of the annual rainfall occurs from July to September. The total annual precipitation varies from 100 to 500 mm. May and June are the hottest months and December and January the coldest. Blatter & Hallberg (1918-21) have classified the vegetation of this zone into five categories, namely, Aquatic, Sand, Gravel, Rock and Ruderal. Since no aquatic rodent occurs in this region, the other four formations are considered here. The sandy region is dominated by loose soil which is easily air borne and deposited as sand dunes. The most conspicuous vegetation of sandy region consists of *Calotropis procera, Leptadenia spartium, Crotalaria burhia, Indigofera argentea, Aerva tomentosa, Citrullus colocynthis, Farsetia jacquemontii, Eleusine* sps., *Panicum turgidum* and *Aristida* spp. According to these authors gravely regions are those which have a coarser sand or gravel which are sorted out by wind action. The chief plants of this habitat are *Boerhaavia diffusa, Corchorus antichorus, Tribulus terrestris, Leptadenia pyro-technica, Sericostema pauciflora, Blepheris sindica, Haloxylon salicornicum* and others. Rocky outcrops are distributed all over the desert. Some of these rocks are volcanic in origin whereas others are sedimentary. The main plant association here is *Euphorbia caducifolia, Calligonum polygonoides, Panicum antidotale, Capparis decidua, Commiphora mukul, Acacia* spp. Ruderal is the association affected by man. Plants growing in villages have been grouped under this category.

ECOLOGICAL DISTRIBUTION OF THE DESERT GERBIL

Burrow habitat: The desert gerbil is extensively distributed throughout the desert. Its burrows occur in sandy barren land, near and under bushes, in dried salt lakes, in mud walls and in open plains. These do not exist in loose soil, over sand dunes, unlike the burrows of *Gerbillus gleadowi* (Prakash, 1963a). During the surveys it was, therefore, though desirable to study the distribution of burrows in different tracts in relation to composition of vegetation and soil compactness. This study is not yet complete but it appears that Blatter and Hallberg's (1918-21) "formations" are too broad for considering the ecological distribution of this rodent.

Data in Table 1 indicate that gerbils are not much influenced by the vegetation cover of the habitat when their distribution is considered in the entire desert but the soil compactness is a limiting factor in their distribution. At Bisalpur, *Dicanthium annulatum* comprises 65·2 per cent of the vegetation cover and it is highly preferred as a food by the gerbils (Prakash & Kumbkarni, 1962), yet the density of gerbils here is the lowest. The sticky point of soil at Bisalpur is 23·6 per cent which indicates that it is very hard for tunnelling activities. The sticky point of loose soil, where burrows do not occur was found to be below 8 per cent. From table 1 it is observed that the optimum sticky point for gerbil habitation ranges from 10 to 12·5 per cent. However, when we observe their distri-

1. Contribution from Animal Studies Division, CAZRI, Jodhpur.
2. Animal Ecologist.

TABLE 1: Showing rainfall, soil condition, dominant vegetation and number of gerbils at four different localities in Rajasthan

Quality/particulars	*Jaisalmer*	*Barmer*	*Palsana (Sikar)*	*Bisalpur (Erinpura)*
Annual rainfall	178·5 mm	79·4 mm	441·4 mm	462·4 mm
Soil texture	Coarse	Coarse	Coarse	Medium
Sticky point of soil	15·5%	10·2%	12·5%	23·6%
Per cent plant cover	13·3%	9·9%	5%	10%
Dominant vegetation	*Eleusine flagellifera*	*Dactyloctenium sindicum*	*Aristida* sps.	*Dichanthium annulatum*
	Lasiurus sindicus	*Crotalaria burhia*	*Cenchrus ciliaris*	*Eremopogon* sp.
	Crotalaria burhia	*Leptadenia spartium*	*Cenchrus catharticus*	*Cenchrus ciliaris*
	Blepheris sindicum	*Cyperus* sps.	*Zizyphus nummularia*	*Aristida* sp.
	Citrullus colocynthis	*Citrullus vulgaris*	*Justicia diffusa*	
	Aristida sps.	*Aerva* sps.	*Gymnosporia montana*	
		Panicum antidotale		
Estimated number of gerbils in a quadrat of 30 meters × 30 meters	70	114	350	0·3

bution in a particular habitat, it is found that the gerbil density changes in relation to the abundant plant species. At Barmer it was observed that there were no gerbil burrows under *Prosopis juliflora* in the summer but during the winter when its seeds were ripe and the pods were falling a large number of burrows were observed under these tall shrubs and hundreds of *M. hurrianae* were observed feeding upon the fallen pods. At Palsana their density was higher at place where *Justicia diffusa* was abundant as they feed upon its infloresence. At Gadra Road, where the gerbil numbers was high, their burrows were conspicuously absent from patches where there was a dense cover of *Cenchrus biflorus* as the seeds of this plant are very spiny and they stick to the body of the gerbil causing injury to the rodent.

The desert gerbils also shift their burrows in different seasons. In winter they are scattered in the plains. In the rainy season they locally migrate to the higher portions of the locality thus avoiding the flooding of their burrows by rainwater. In summer the openings of their burrows are found under the hummocks around shrubs, as here the roots of plants provide them moisture which assists in maintaining the water balance of their body. The burrow openings are situated on the side of the hummock which is opposite to the wind direction (SW-NE) so that the hot wind does not bring about the imbalance in the burrow temperatures.

Burrow temperatures: Burrows of *M. hurrianae* are most extensive and their plans have been described by Wagle (1927), Petter (1961) and Ganguli and Kaul (1962). Burrows play an important role in the life of this subterranean animal particularly when it is diurnal in habit and is exposed to the high temperature of the day. The temperatures inside their burrows were studied from 7 a.m. to 7 p.m. throughout the year. Fluctuations inside the burrows vary from 1·2°C to 1·5°C in winter, 1·1°C to 2·4°C in summer, 2·9°C to 8·2°C in monsoon and 0·8°C to 1·1°C during the post-monsoon season. These fluctuations are very small as compared to range of temperatures on the soil surface which are 25·1°C in winter, 28·8°C in hot weather, 14·3°C in monsoon and 26·6°C during the post-monsoon seasons (Prakash *et al*, 1965). It is obvious from these data that the gerbil is not exposed to the vagaries of external temperatures and burrows have a rather constant temperature throughout the year which is considerably lower than the soil surface temperature (Prakash *et al*, 1965).

GERBIL, A FACTOR OF SOIL EROSION

The burrows of the gerbil extending over vast areas make the soil very loose and due to over aeration the roots of plants are exposed to hot winds and the vegetation is adversely affected. Besides making the fields useless by its burrowing activity, a single gerbil excavates on an average one kilogram of soil when it digs one burrow opening. As many as 15,000 openings have been observed per hectare. In other words 15,000 kg of fixed soil per hectare is loosened by the gerbils which accumulates outside their burrow openings and is quickly blown away by the strong winds. Thus the gerbil assists in maintaining and spreading the desert.

FOOD OF GERBIL

Seasonal food-cycle — The food of *M. hurrianae* was studied by examining the stomach contents during each month of the year (Prakash, 1962). The food items were sorted out and their volumes were measured by displacement method. A considerable portion of the stomach contents was in a state where identification of plant parts and plant species was not possible. The food items were grouped into 4 categories: seeds, stems and rhizomes, leaves and flowers and insects. It was observed that seeds are eaten up to 60 per cent in January, thereafter their percentage decreases to 10 per cent in July but again increases to 60 per cent in December. The decrease in seed consumption is balanced by the increase in the percentages of stems and rhizomes, which reaches 45 per cent in June. Decrease in seed food is also compensated by the increase in insect food. *M. hurrianae* feeds on insects only during March-October period when other food is scarce and locusts are abundantly available. This study also points out that the feeding habit of the gerbil depends on the availability of the various food materials in different seasons.

Feeding periods and daily requirements: The feeding period of the desert gerbil changes according to the seasons in nature. In winter they come out of their burrows after 8 a.m. and cease their feeding activity at 6 p.m. In summer, however, they are out of their burrows again at about 6 p.m. and retire at 7·30-7·45 p.m. Hence in summer their feeding activity is divided into two rhythms (Prakash, 1962) whereas in winter it is continuous one.

In our laboratory experiments it was found that human presence influences their feeding period. The laboratory personnel work between 10 a.m. and 5 p.m. Accordingly, the laboratory population of gerbils used to feed 62 per cent of the daily requirements from 6 a.m. to 10 a.m. and the rest between 6 p.m. and 7 p.m. (Prakash & Kumbkarni, 1962). The *Meriones hurrianae* has a lower calorific requirement as compared to other rodents (Prakash & Kumbkarni, 1962). It was calculated that with food providing 12-15 calories of energy per day, a gerbil of the 45-55 grams weight group can maintain its body weight.

Seed Consumption: In view of their seedivorous propensity preliminary seed consumption and palatability experiments were conducted (Prakash & Kumbkarni, 1962). Consumption of all the seeds was significantly less than that of grains of wheat, millet, *Sorghum* etc. Further work (Table 2) shows that grass seeds are preferred as compared to seeds of shrubs and trees. The grass seeds and other

TABLE 2: Seed consumption by desert gerbils in relation with sheep preference of plants and their utility in soil conservation practices

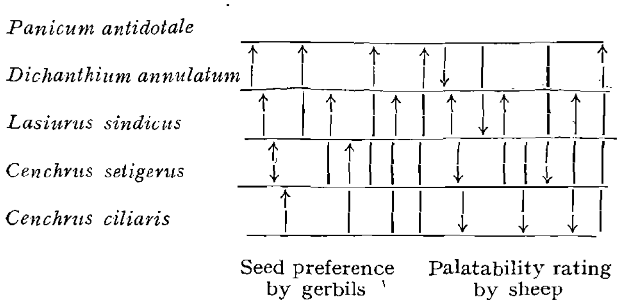
Plant species	*Seed consumption desert gerbil*	*Seed consumption categories desert gerbil*	*Sheep preference categories*	*Plants used for*	
				Sand dune fixation	*Afforestation*
GRASSES					
Panicum antidotale	3·25 ± 0·79	A	A	+	
Dichanthium annulatum	2·5 ± 0·76	A	A		
Cenchrus setigerus	2·1 ± 0·41	A	A	+	
Lasiurus sindicus	2·1 ± 0·48	A	A	+	
Cenchrus ciliaris	0·85 ± 0·25	C	A	+	
Perotis hordeiformis	0·33 ± 0·01	D	C		
Saccharum munja	0·20 ± 0·01	D	D	+	
Eragrostis ciliaris	0·15 ± 0·03	D	B		
TREE AND SHRUB SPECIES					
Ricinus communis	2·42 ± 0·11	A	—	+	
Zizyphus nummularia	1·75 ± 0·65	B	A	+	
Calligonum polygonoides	1·54 ± 0·97	B	—	+	+
Tecomella undulata	1·50 ± 0·33	B	B	+	+
Dodonea viscosa	1·25 ± 0·31	B	D		
Prosopis juliflora	1·21 ± 0·36	B	A	+	+
Albizzia lebbek	1·20 ± 0·04	B	B		+
Haloxylon salicornicum	1·66 ± 0·77	B	C		
Atriplix sp.	1·12 ± 0·20				
Aerva tomentosa	1·06 ± 0·23	B	A*-D		
Parkinsonia aculeata	1·00 ± 0·01	B	C	+	
Prosopis spicigera	0·66 ± 0·30	C	A*-C	+	+
Eucalyptus camaldulensis	0·50 ± 0·21	C	D		
Azadirechta indica	0·50 ± 0·13	C	D		+
Acacia senegal	0·40 ± 0·05	D	B		+
Acacia arabica	0·37 ± 0·16	D	B		+
Acacia spirocarpa	0·33 ± 0·09	D	C	+	+

Category A: Most preferred, B: Preferred; C: Less prefered; D: Not preferred.
+ usage of plant species.
*seed and pods.

plant seeds are classified according to the amount consumed by a single gerbil in 24 hours in four categories. A: Consumption level above 2 gm per day, B: above 1 gm, C: 0·5 gm to 1 gm and D: up to 0·5 gm.

Seed palatability in relation to feed available for sheep: It will be observed from the Table 2 that all the grasses, the seeds of which fall in category A of seed consumption by gerbils, are also most preferred by sheep. The seeds of *P. antidotale* are most preferred by *M. hurrianae* whereas this grass is lowest in the hierarchy of preference by sheep amongst these five grasses (Table 3). *Cenchrus ciliaris* seeds fall in category C in seed preference by the rodent whereas it is No. 2 in grass as chosen by sheep. It is, therefore, suggested that *Cenchrus ciliaris*, which is very palatable to sheep and seeds of which are not preferred by *M. hurrianae* should be grown more for sheep patures as it will be least affected by rodent devastation. Another grass, seeds of which are least eaten by this rodent, is *Eragrostis ciliaris* and it is quite palatable to sheep. It might, therefore, be worth trying to develop pastures of *Eragrostis ciliaris*.

TABLE 3: Comparison of seed palatability rating by gerbil and sheep preference of five grasses. Arrow points towards preferred item



As regards other plant species (Table 2) there is not a very serious competition between the desert gerbil and sheep. The pods of *Acacia senegal* and *A. arabica* are quite preferred by sheep whereas consumption by rodents of the seeds of these two tree species is considerably low. Comparison of palatability of plants and seeds is difficult in this group as preferences of sheep have not been fully investigated.

Seed palatability in relation to soil conservation practices: One of the chief methods of soil conservation is to cover the shifting dunes with adequate plant cover and set up shelter belts. Rodent depradation of seeds reduces the germination per cent considerably. Moreover, when some vegetation establishes and stabilizes a sand dune, the soil becomes suitable for gerbil tunnelling and the population of gerbil rapidly increases. Considering these facts, selection of plants, seeds of which are lower in the palatability rating by gerbils, is very important. It is obvious from Table 2 that seeds of *Ricinus communis, Z. numularia, C. polygonoides, T. undulata, D. viscosa, P. juliflora A. lebbek* and *P. aculeata* which are used for either sand dune fixation or for establishing shelter belts fall in category B of hierarchy of preference by *Meriones hurrianae*. Therefore, these plant species may be sparingly used in localities where the gerbil number is comparatively higher. Seeds of *P. spicigera, C. fistula, C. nodasa, Chorchorus antichorus, E. camaldulensis* and *Azadirechta indica* fall under category C whereas seeds of *Acacia senegal, A. arabica* and *A. spirocarpa* are categorized as lowest in preference by the desert gerbil. Thus *Acacias* may be ideal for soil conservation practices as far as damage to their sown seeds is concerned. It might be worthwhile to consider the use of such plants in soil conservation practices, seeds of which are low in the palatability ratings by the gerbils.

Seeds of most of the grasses are very palatable (Table 2) to gerbils and may not stand their attack sown for sand dune fixation. *Sachharum munja* and *Eragrostis* seeds are, however, not much preferred by gerbils and could be tried for the purpose.

PREDATORS

While discussing the food centres of mammals of Rajasthan desert (Prakash, 1957) it was observed that the gerbils form a very busy food centre. The mammals which depend on the gerbil as food are the Desert Cat, *Felis libyca ornata;* Jungle Cat *Felis chaus prateri;* Desert fox, *Vulpes vulpes pusilla;* Bengal Fox, *Vulpes bengalensis*; Small Indian Mongoose, *Herpestes auropunctatus pallipes*; and Indian Grey Mongoose, *Herpestes edwardsi ferrugineus*. There is not much information about bird predators of this gerbil except that the Taway eagle, *Aquila rapax* and Shikra, *Astur badius* have been observed feeding on *M. hurrianae.*

Dave (1961) stated that out of 21 species of snakes found in the Rajasthan desert, 19 feed on gerbils but he found conclusive evidence of gerbil predation by snakes of the following species. Sand boa, *Eryx johni* and *E. conicus; Rat snake, Ptyas mucosus; Lytorhynchus paradoxus*: Four stripped sand snake, *Psammophis schokari;* Common Indian Krait, *Bungarus caeruleus*; Indian Cobra, *Naja naja* and Saw scaled viper, *Echis carinata.* While discussing food centres for desert reptiles, he observed that *Varanus* sps. also feed on this gerbil.

REPRODUCTION

Sex ratio: It appears that the sex ratios of *Meriones hurrianae* fluctuate considerably. During 1954-56, the male to female ratio was almost equal but the monthly collections during 1963-64 showed a significant (at 5 per cent level) preponderance of female gerbils (Table 4). During the latter period the females outnumbered males in most of the months but the proportions were equal in July and September. However, in May and July, the male number was more than the female number. These fluctuations within a year and between years are quite large.

TABLE 4: Sex ratios of *Meriones hurrianae*

Months	1954-56		1963-64	
	Male	*Female*	*Male*	*Female*
January	22	26	2	29
February	8	9	19	26
March	8	11	14	55
April	5	4	—	—
May	4	5	8	3
June	2	2	3	3
July	5	6	6	2
August	10	7	40	55
September	13	12	25	24
October	9	4	—	—
November	10	8	—	—
December	8	8	13	31
Total	104	102 (49·2%)	130	228 (63·7%)

Breeding season: The desert gerbil breeds all the year round (Prakash, 1964). The littering activity is minimum during the summer months but reaches the peak during monsoon and declines during winter. A smaller peak is again shown during February which may be due to the enhanced reproductive activity after the winter. In the desert region conditions are optimum during and soon after monsoon season (Prakash, 1960) and, therefore, the littering activity of desert gerbil was at its height during this period. Another factor which might be affecting this peak is the availability of green food during and after rains which is more nutritive. Day length does not appear to play an important role since during the summer, when days are longest, the littering activity was at its minimum.

Post-natal Development: The gestation period, lactation time, litter size and post-natal growth of *M. hurrianae* were recently reported (Prakash, 1964). The period of gestation varies from 28 to 30 days. The mother suckles her young till 18 to 20 days after birth. The litters delivered in the laboratory varied from 1 to 9 in their size; 7 each of 3 and 4 young, 3 cases of 5 young, 2 cases each of 6 and 7 and one each of 1 and 9 young. The average litter size is 4·30. The growth of the desert gerbil is discussed here with respect to the following external characters. This study provides an index to determine the age of individuals when captured from nature and becomes a basis for proper evaluation of age structure in a natural population.

Pelage: At birth the young is hairless except for the vibrissae which are only 3-4 mm long. The body is light pink in colour. From the third day the dorsum of the young starts darkening, beginning as a mid-dorsal line which gradually broadens and extends on lateral sides. Short hair cover appears first on the dorsal side early in the second week and by the end of it hair extend on flanks also. A thin pencil of hair appears at the tip of the tail. At this stage the young looks sepia in colour. During third week the hair cover becomes complete. The bush of hair at the tip of the tail is also fully formed during this week. The mature colour is, however, attained between 8 to 10 weeks of age.

Eyes and Ears: At the time of birth eyes are closed and appear as dark spots. At the end of the second week, however, a groove appears slitting the two eye lids. The eyes open after 15 to 16 days of birth. Similarly the ears of the newly born young are folded and wrapped in a thin membrance and these unwrap after 3 to 4 days. Ear growth is very fast. By the fourth week it attains 81·5 per cent of the final dimensions and full growth is reached by the sixth week.

Tail: Tail length of the young at birth averages 12·8-1·21 mm. Its growth during the first week is meagre but during the second and third week it is very high. The rate declines during the fourth to eighth week and by the eighth week 97 per cent of growth is accomplished. Rest of the development is completed by the 17th week.

Hind foot: Growth rate of hindfoot is maximum in the first week and decreases thereafter till the sixth week. 80·9 per cent of the development takes place within 4 weeks of birth, further 17·2 per cent within 8 weeks and the rest is completed in 13 weeks after birth.

Weight: Average weight of the newly born is $4{\cdot}1 \pm 0{\cdot}21$ gm. Increase in weight is gradual till the sixth week after which steep rise is noticed. During the ninth week the animal lost weight but during subsequent 4 weeks the growth was restored. It again declined during the thirteenth and seventeenth weeks but increased thereafter. Body weight is not regarded as a very suitable criterion for age determination as it keeps fluctuating under the influence of social interactions and availability of food.

Plantar pads: Soles of the fore paw and hind foot are soft and light pink in colour just after the birth of the young one. During the first week of growth there was no appreciable change in the soles of the manus and pes but during the second week plantar pads appeared on the hind foot but these were feeble on the fore paw. By the end of the third week the plantar pads of the hind limbs developed fully but those on the fore paws were still growing and reached their full growth by the fourth week. The claws are feeble at the time of birth and start darkening in the second week and the full length of nails darken by the fifth week.

ZOOGEOGRAPHY

It is now well established that the Rajasthan Desert is not more than 10,000 years old (Krishnan, 1952; Wadia, 1960). It is a very short period from the evolutionary point of view. Even then, 56·4 per cent of the mammalian fauna of this desert is found to be Palaearctic and only 41 per cent Oriental or Indo-Malayan (Prakash, 1963). It has been speculated (Prakash, 1962 and 1963) that *Meriones hurrianae* originated in the deserts of the Middle East and then migrated to this region when aridity established in this part of India.

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DISCUSSION

D. R. Bhatia: What insects were found among the stomach contents of the desert gerbil?

Ishwar Prakash: *Schistocerca gregaria*, *Chrotogonus* sp. *Helicopris buciphalus*, *Blaps orientalis* etc.

K. S. Sankhala: You have recommended *Acacia sp.* for afforestation of the areas which are effected by desert gerbils. The lack of seedling is not a problem as these can be transported to afforestation sites. The problem is that the seedlings are killed.

Ishwar Prakash: There are two principal methods of growing plants for afforestation i.e. by direct seeding or raising plants in nursery. Damage to seedlings compared to seeds is very small.

P. K. Sen-sarma: How was temperature measured in the burrows? Did you make any measurement of relative humidity in burrows?

Ishwar Prakash: By the Philips rod type thermistores and soil temperature-moisture bridge. No. We are getting Krogh's microclimate recorder and then only it will be possible to measure relative humidity in burrows.

THE EFFECT OF CADMIUM AND SELENIUM ON THE TESTES OF THE DESERT GERBIL *MERIONES HURRIANAE* JERDON[1]

by

L. S. RAMASWAMI & D. K. KAUL

A SINGLE sublethal dose of cadmium chloride (0·55 mg-0·03 m mol/100 g) and of selenium oxide (0·56 mg-0·06 m mol/100 g) separately and in combination was injected into young sexually active male desert gerbils.

1. (i) The cadmium injected testes showed an increase in weight from 6-24 hours and then showed a decrease.
   (ii) Hyperaemia is seen after 12 hours and haemorrhage takes place after 24 hours in the testes and they become dark violet in colour 48 hours after the injection.
   (iii) Disintegration of cells start in the cadmium injected gerbils at 12 hours after injection. Leydig cells and seminiferous eopithelium show necrosis and cells from the latter migrate into the interstitium. The tubules show a complete break down resulting in an eosinophil debris. The tunica is thickened.
   (iv) In the 69 — day testis, no regeneration of tubule cells is seen, the amorphous mass inside is now basophilic. Modified fibroblasts from beneath the tunica are becoming prominent and will probably become leydig cells.
2. In the selenium oxide injected gerbils, no exchanges are noticed in the first 48 hours. A week after, there is reduction of weight and atrophy of Leydig cells and of seminiferous cells; a few animals showed inhibition of spermiogcnesis also. Selenium is not as effective as cadmium in its destructive effects.
3. The joint dose of cadmium and selenium (0·03 m mole/100 g plus 0·06 m mole/100 g) showed an increase in testis weight after 24 hours and there was destruction in the tubule tissue; after a week, the testes were reduced in weight and showed considerable necrosis. Clearly selenium was not able to give protection as in the rat against cadmium.

1. Contribution from the University of Rajasthan, Jaipur.

DISCUSSION

V. Mahadevan: Are selenium and cadimium studied as internal toxic elements as playing an essential role in the nutrition and optimum function of semeniferous tubules and kidneys ?

L. S. Ramaswami: They are employed only with the purpose of population control of animals, to find out their importance in breeding. It was not known if they were essential elements.

K. S. Sankhala: Have any experiments with selenium and cadmium been conducted on females ?

L. S. Ramaswami: They were not effective.

L. D. Ahuja: When the injections result in chemical sterility of male gerbils what is the status of hypophysis ? What is the threshold of F.S.H. and I.C.S.H. in treated males ? After giving injections what is the level of sex drive and sperm production ?

L. S. Ramaswami: The condition of hypophysis remains the same as in normally castrated males. Work has not been conducted on sperm production.

PHYSIOLOGICAL AND TOXICOLOGICAL METHODS IN INSECT RESEARCH, AS INFLUENCED BY DIFFERENT TEMPERATURES AND HUMIDITIES[1]

by

K. GÖSSWALD[2]

INTRODUCTION

MAY I express my heartiest thanks for the kind invitation to take part in this Symposium on Arid Zone Research. The memory of a Symposium in New Delhi, on the Termites in Humid Tropical Climate, is closely associated with the nice impression of the high standard of your researches, rich old art and culture, the uncomparable hospitality of the nice Indian people and the close cooperation of so many colleagues of your country. So inspite of my preoccupations with my professional engagements, I preferred to come here with all the good wishes and greetings of my country, Germany. Indeed the kind invitation of my colleague Dr P. C. Raheja to deliver a lecture on the "Methods of Physiological and Toxicological Insect Research, with possibilities of their application in Arid Climate" disturbed me a little because it was rather not possible in a short time at my disposal to perform some experiments specially for this Symposium, so I would like to unreveal a trend of research work from Ecology to Physiology and from there to Toxicology, by citing the examples also of some of my students and collaborators. The application of this trend to the problems of Arid Zone will be of special interest to this Symposium.

Comparison is one of the best tools to extend the horizon of our knowledge. As is well known, there are insects which prefer arid conditions on the one hand and the humid conditions on the other. Both ecological extremes may be existing close to each other according to the micro-climatic peculiarities. Or they may lie apart in the humid or the arid tropical regions. If we know the morphological, ecological and physiological characteristics of the animals in humid or in arid areas then we can understand their existence under the influence of micro and macro-climatic limiting factors. In the insects the ascertainment of their morphological, ecological and physiological characteristics due to the humid or dry regions leads to the understanding of their existence under the influence of macro- and micro-climate limiting factors. Further it is important to investigate the complex structure of metabolism which is adapted according to the humid and dry environments, for the success in the control of the harmful insects and in the promotion of beneficial insects depends solely on the understanding of biochemical and biophysical changes inside the insect body.

We begin now with simple methods to investigate the ecological peculiarities of individual species which were compelled to live under specific conditions and which were allowed to live under the conditions of their choice. The temperature factor is also to be considered along with the humidity because both of them affect the physical and physiological changes.

ADAPTATION IN SOLITARY INSECTS

The temperature can be accurately set in a Bridge Thermostat between 5°-50°C in the multiples of 2°C. A humidity gradient of 0-100° R.H. can be attained in every temperature range, by adjusting the proportion of the saturated solutions of different salts of different vapour pressure in hygrostatic dishes. By this one gets for example a glimpse into the sphere of temperature and humidity optimums, for instance: the survival rate, sexual index, fecundity and rate of development. Such effects were observed in Pine Saw Fly, *Diprion pini* (Gösswald, 1935). We can also determine the sum of the effective temperature positively influencing the development, the former being necessary for the progress of insect generations. We also get a casual analysis from insect calamities and a glimpse in the extent to which they can possibly occur. Besides this, we can also predict the expected number of generations and their maximum population depending on the temperature and humidity conditions. Due to these predictions we can arm ourselves in time for the control of insect pests.

By such investigations it becomes apparent that there are climatically sensitive species, which react intensively to changes by the increase and decrease of population density. Such insect species are put in the category of serious pests, whose in the favourable nutritional and weather conditions population multiplies so fast that the natural enemies like the parasites are not able to keep pace with the multiplication of the hosts resulting in popu-

1. Contribution from the Institute of Applied Zoologie of the University, Wurzburg. (West Germany).
2. Director of the Institute.

lation explosion. These species which are more or less passive in temperature and humidity experiments — which are large in number; exist in every weather conditions in practically the same population density. With that follows that the population of their natural enemies is similarly low in number and if this population relationship is not disturbed by man then a natural biological equilibrium is maintained in Conifer Sphingid, *Sphinx pinastri* L. (Gösswald, 1936).

ADAPTATION IN SOCIAL INSECTS

After these simple examples of solitary insects we turn our attention now to the ecologically different ant species to introduce the methods. There are ants which nest in the ground and can penetrate deeper in dry conditions to a moisture strata of the soil. In such insects the difference between hydrophilous and xerophilous species in the range of the same macro-climate is not important. On the other hand there is a remarkable difference between the soil inhabiting ants, and the ants living between stones scattered over the soil surface, the species living in stone crevices where they withstand the extreme weather conditions of summer and cold winter. By the experiments in which the insects were forced to live in predetermined temperature and humidity conditions it was shown for these Stone Nesting Ants that the high Relative Humidity is optiming but contrary to this the soil inhabiting ants have a much higher resistence to arid conditions (Gösswald, 1938a). When we allow the ants to choose between the different R.H. range, the soil inhabiting ants, as expected, prefer in normal temperature the highest R.H. range. But, in higher and lower temperature ranges these species tend to show their hydrophilous and xerophilous characteristics. Contrary to this the stone inhabiting ants concentrate in the dry regions in the Humidity Preference Experiments. So the stone inhabiting ants strive to go to a region which is not at all physiologically optimum, the region being tolerated only because of their ecological resistence. The stone inhabiting ants, *Leptothorax unifasciatus*, are little peaceful insects living in very small colonies comprising 100-150 workers. *Leptothorax* ants are biologically weak and seek rufuge in the left-over ecologically unsuitable nesting spots, as the occupants of the space unoccupied by biologically strong and individually rich species of ants. By this the entire biotop is occupied by various ant species (Gösswald, 1947a).

Comparable differences are found also between the individually poor Dry Wood Termite, *Calotermes falvicollis* and individually rich Moist Wood Termite, *Reticulitermes lucifugus*. Both the species are distributed in Mediterranean Region. They can live together in the same log, the Moist Wood Termite occupying the lower region of log near the moist soil, whereas the Dry Wood Termite occupying the upper drier portion (Gösswald, 1947b).

The Moist Wood Termite requires a higher relative humidity as it can live only for couple of days in the 90 per cent R.H. and there is no possibility of its remaining for a long time. In the Humidity Preference Experiments it always chooses immediately the highest humidity range regions. Contrary to this, the Dry Wood Termite, *Calotermes flavicollis* can remain hungry for weeks and can withstand the extreme drought conditions. Both the qualities, of remaining hungry and the resistence to the drought conditions, make *C. flavicollis* a suitable testing insect in Termite Proofing Experiments, as reported earlier (Gösswald, 1941c, 1942, 1956). It is remarkable, that a comparison of both termite species reveals that ecologically more resistent species is biologically weaker and is also individually poorer; while, the individually richer and biologically stronger species occupies the proper moist earth regions or the moist wood. Here also the biological weakness is compensated by ecological vigour. These are the reflections to be considered for ecological and physiological researches on insects and other animals from arid zone.

DISCUSSION

The physiological disposition of an insect is primarily inherited as being a member of a particular species, nevertheless it can be changed secondarily by temperature and humidity factors. The later fact is shown for example in the hydrogen ion concentration or if expressed in other word the *p*H level of haemolymph and tissue. The effect of certain insecticides can be very strongly influenced by these factors. By the investigations on ecologically different species of Lepidoptera and Tenthridinids (leaf feeding Hymenoptera) and on large number of other species it can be proved, that in closely related species living in more humid biotops there is a relatively higher *p*H (alkaline), than in the insects living in drier conditions. During development *p*H can increase in bolometabolic insects with the aging. The females have a somewhat higher *p*H than the males. The insect species having a higher *p*H show more resistence to the insecticide Pyrethrum obtained from the plant *Chrysanthemum cinerariaefolium*.

We have noticed a relation between the locality influences and the *p*H of an insect; the caterpillars of the sphingid moth, *Sphinx ligustri* L. and the double horned caterpillar of *Dicranura vinula* from the relatively dry and warm wine growing area of Würzburg have a lower *p*H than those from the higher rainfall area of Munich. The experiments suggest that an association exists between the weather conditioned physiological disposition and the toxic affect of Pyrethrum. The caterpillars of Nun-Moth, *Lymantria monacha* L., Gipsy Moth, *Lymantria dispar*, and the Pine Fly, *Diprion pini* L. were reared from egg in many thousands in 50 different combinations of temperature and humidity, their *p*H determined and finally exposed to insecticide. After the exposure the insects were transferred to clean original ecological conditions.

The aforesaid insects prove that when *p*H level was secondarily induced by rearing the insects at optimum temperature and humidity they additionally become a higher *p*H level and by this all species become more resistent to insecticides. In Nun Moth caterpillars, in which the higher *p*H was secondarily induced the mortality decreased by 60 per cent. Therefore, in moist and rainy weather conditions in laboratory and so also in natural biotops, the chances of successful insect control was essentially reduced (Gösswald, 1934a, b). During the process of poisoning the *p*H level of insect decreased and it was assigned to the probable heavy loss of water and carbondioxide acidose. The diseased and parasitized caterpillars also showed a lower *p*H level. The exact *p*H should always be ascertained from the literature.

The influence of modern insecticides on the hydrogen ion concentration is measured these days by my student Mr. Schulze. The Beckman-*p*H-Meter Model G, together with One-Drop-Glass-Electrode (Nr. 40316) and *Calomel-Reference* Electrode (Nr. 39270) has been assembled to investigate in short time the *p*H of liquid quantities of drop size 0·02-0·03 ml approximately. A very quick measurement is very important as the CO_2 goes out of the haemolymph and the *p*H shifts to the alkaline side in a short time. Normally insects and other arthropods are able to regulate in a very limited range their hydrogen ion concentration in haemolymph; but they can suffer partially greater reversible *p*H changes during the periods of oxygen scarcity without the damage to the organs, in a way better than some of the mammals. This acidose is attributed to an accumulation of metabolic end products along with CO_2 and lactic acid during anaerobic respiration. Based on the same effect is perhaps the fact that the hydrogen ion concentration rises after the action of organic chemical insecticides. For example if we poison the larvae of *Diprion pini* by E 605, DDT, Pyrethrum or Thiodan then it is possible to record different *p*H levels during toxicity phases. The normal *p*H of *Diprion pini* larvae is about 6·75. In stage of early excitation the *p*H sinks to 6·65 and after high excitation in the stage 3 it comes down to 6·55. Shortly before the death in the stage 5 the *p*H falls finally to 6·2. In this case we have CO_2 acidose, as the originally measured *p*H 6·2 reaches to neutral 7 in 60 seconds.

In the first instance the relation between the high R.H., *p*H and insecticide resistence suggests that the lowering of *p*H level is directly proportional to the water lost during the excitation of the insecticide poisoned insects. Perhaps a CO_2-acidose enhances this effect which is caused by the contraction of the poisoned insect resulting in the closure of spiracles. The insects exposed to Potassium Cyanide do not show these symptoms because the respiratory metabolism is immediately paralysed by the cytochrome oxidase inhibition.

It is very interesting to compare data of moisture content, hydrogen ion concentration and poison effect obtained from solitary and social insects. In the ants also it is true that the species from moist biotops have firstly, a higher *p*H level and secondly, they are more resistent to insecticides than the ants from the drier biotops. Such experiments were conducted with stomach and contact insecticides employing different species of the subfamilies Formicinae and Myrmicinae (Gösswald 1937a, b, 1938b). In the ants in consequence to the different physiological disposition of the female castes, i.e. the fertile queens and the sterile workers, there comes a factor, which supplements the already known results: the queens have a higher *p*H level than the workers, so they are significantly more resistent than the workers. There are species for example, *Serviformica rufibarbis* in which the workers have relatively well developed gonads and since they possess ovarioles they can easily start oviposition. Workers of such species are distinctly more resistent to insecticide than the workers of related sp., *Serviformica fusca*, which have much less ability to oviposit and consequently they have a lower *p*H than the workers of aforesaid species, *S. rufibarbis* (Gösswald, 1938c).

Researches on the effect of poison depending on the humidity factors were done by my student Dr. Klee (1957, 1958) in termites and stored product pests.

In many cases it is difficult to distinguish the stomach and contact toxicity of an insecticide. This differentiation is easier to be made in ants, as these social insects feed their crop contents by regurgitation to their counterparts. A definite dose of insecticide marked with radio-active isotope for example Thiodan with Sulphur (half lifetime 87·1 days) can be administered along with honey-water. The fed worker of the dark grey ant, *Lasius niger* L., was washed after full feed in order to remove the radioactive insecticide sticking to body. After measuring the radioactivity of the ant, it was marked by a coloured spot and put amongst the 30 normal hungry members of the colony. After 15 hours of food exchange the radioactivity of all the ants was measured by Geiger Muller Tube (G.M. tube). On an average the food containing Thiodan was distributed to 25 workers. It could be shown that 0·5-5 g or incorporated thiodan emulsion lead at the maximum only to a temporary damage, if the contact action of the insecticide was avoided. In the contact action much smaller quantity lead to the death of test insects, proving that the insecticide is mainly a contact poison. Similar results were obtained in termites, while the duration of contact action was tested in soil (Gösswald, 1958).

To get a deeper insight in the working mechanism of the insecticides, the oxygen consumption was determined at different humidities and temperatures. Experiments were carried out employing special flasks of the well known Warburg Apparatus. Thiodan application to the termite, *Calotermes flavicollis,* resulted in 2·5-3 times increased respiratory activity than the normal (Gösswald, 1958). This increased respiration is explained as the repurcusion of Thiodan caused excitation. In addition, a higher metabolic activity is evident, as the animals, slowly moving the extremities in " Knock-out " stage, show an increased respiratory rate, which continues till death.

In this reference the histological investigations of thoracic ganglia were carried out. Till 24 hours after poisoning with Thiodan up to 1 per cent concentration no pathological symptoms developed. But the nuclei showed clear degenerating symptoms after 48 hr. Effect of this insecticide; the agglomeration of chromatin granules was particularly noticeable.

Now I will explain in short the oxygen consumption of the Corn Weevil, *Calandra granaria* L. under the influence of different Thiodan isomers at different temperatures. At 25°C the O_2-consumption of the unpoisoned control remains constant during the entire experiment period of 24 hours. The O_2-consumption of Thiodan poisoned insects rises sharply after 3 hours. The highest oxygen consumption lasting for few hours corresponds to the knock out stage. After about 15 hours the oxygen consumption curve shows a steep fall till below the normal and after 24 hours the respiratory activity ceases. All these results were obtained at 25°C. At 15°C a stretched curve was obtained. The low toxic activity is mainly due to poor Thiodan uptake ability as the insecticide seems to act mainly in vapour phase. In addition the unpoisoned insects show a lower exchange of gases at lower temperatures (for further information refer to Gösswald and his collaborators, Kloft, Köhler, Klee, Schulze and Voss, 1962) further Gösswald, Kloft, Schulze, 1963).

As we have learnt earlier, consequent to the poisoning there occur different phases of excitement; how these phases manifest can be illustrated by the Thiodan poisoned larvae of *Diprion pini* L. The temperature of poikilotherm insects, specially during the poison enhanced activity, rises slowly with the increase of respiration and muscle activity. Therefore, it is possible to record also toxicity process, for example that of Thiodan by temperature measurement in sufficiently big insects like, the cockroach, *Periplaneta americana.* By this the intensity of movement and the rate of metabolism etc., which depend on the effectiveness of poison, can be estimated.

The surrounding temperature of the insect including that of thermocouples was adjusted by keeping them in a constant temperature water container. The desired humidity was regulated by the already known methods of employing super-saturated inorganic salt solutions. To measure the temperature fine thermocouples are used, which are made of copper and konstantan wires of 0·1 mm diameter. After connecting the thermocouple to a mirror galvanometer, it is standardized, and the temperature potential is permanently recorded. After the successful standardization one terminal of the thermocouple which is only 50 μ in diameter is introduced in second thoracic spiracle very carefully to avoid injuries. At the same time the measurement of rectal temperature is also possible.

To the thorax of the experimental animal the pin head is fixed by a mixture of wax and resin, which in turn is pinned to the cork serving as a stopper of the reaction vessel. The insect holds a paper circle in its legs which rests on a small plastic block to avoid falling in the salt solution. The other terminal of the thermocouple hangs freely in the reaction vessel to measure its temperature. That means that we measure a difference between the body temperature and the surrounding temperature and by this method we have obtained very exact and reproducible values. The experiment can be so arranged that the free end of the thermocouple is stucked in a freezing mixture maintained at 0°C, so one gets the absolute value.

As soon as the experimental animal has settled down to rotate continuously the paper circle, the latter is replaced by a paper impregnated with known quantity of insecticide.

Under these conditions in the unpoisoned animals the temperature difference between the body and surrounding is negligible, whereas in the poisoned insects the body temperature changes immediately after the treatment with insecticide: in the first 10-20 minutes the body temperature sinks very little and at this moment it is characteristic that the rectal temperature is lower than the thoracic temperature. In the 1st and 2nd hours the temperature in relation to the surroundings falls more rapidly in the poisoned insect rather than in the unpoisoned one; between 2nd and 4th hours it rises considerably and then remains stand still for 1-2 hours save a little fluctuations. The maximum movement of the poisoned insect corresponds to the same period, which can be observed by the speed with which the insect rotates the impregnated paper. From 4th-5th hours after the insecticide application the body temperature lowers and finally falls below the surrounding temperature. The movement of the animal stops shortly before the body temperature sinks below the surrounding temperature and the insect usually allows the paper circle to fall. Now the body temperature, already sunk below the surrounding, remains stand still till 9th hour, and then finally comes to the level of surrounding temperature. This point coincides with death. The higher thoracic temperature than that of rectal may be the result of high muscular activity. The sinking of temperature below that of surrounding can be assigned to the cooling effects of transpiration and to the greater loss of water, as we have seen earlier. In the end of the experiment the weight of cockroaches is reduced by 50 per cent than the original weight.

The body temperature of insect is in close relation to their water balance since both influence each other. Therefore it might be of interest to mention a new method for transpiration measurement.

The study of insects and other arthropods which are adapted to live in arid areas needs also a more exact knowledge of their water balance. It is a basic problem of ecological physiology to find method being enough sensitive to measure the rate of transpiration of such small animals. The classic methods of gravimetry don't allow to follow without any interruptions the dynamics of water loss under varying conditions as for example temperature, relative humidity, velocity of the air, intoxications and so on. My collaborators *W. Kloft* and *E. F. Schulze* by studying this problem regarding to its technical and biological aspects were able to work out a modern method using tritiated water.

The principle of this not yet published method is following: Tritiated water (THO) is injected or fed, which exchanges rapidly with all tissues and body fluid and is transpirated together with normal H_2O. Putting the insect in a chamber through which an air-stream of varying velocity, temperature and relative humidity, achieved by introducing in the stream a number of glass tubes, Calcium Chloride and wet filter papers, passes over the insect and goes into an Ionization chamber, in which one is able to measure the rate of ionization. The ionization is proportional in certain limits to the amount of tritiated water vapour given off by the insect. In connection with the ionization chamber works an amplifying electrometer. The rate of ionization is permanently recorded by a recorder. The continuous air-stream is produced by a " Mariotte' sche Flasche "†. The air humidity is measured by two dewpoint-hygrometers after the method, developed by Jakovlev and Kruger (1953). The entire experiment gives for the first time an insight in the process of transpiration after THIODAN-poisoning.

Now we come to the end. The temperature and humidity factors in general are of great importance to the insect (Schmidt, 1961). More particularly their investigations are necessary where the climatic conditions are so extreme as in arid zones. In this communication I have tried to reveal by some examples the biophysical and biochemical methods which can help us to explain the influences of ecological and physical characteristics of a region on the physiological disposition and metabolic functions of the insect and also how they affect the working mechanism of insecticides.

The aim of such investigations is to get a maximum possible harvest in arid zones and to protect the crop from the damage by pests. With the betterment of nutritional standards we have also to pay attention to the health of our neighbours while using the insecticides and chemicals when necessary to control the particular serious pest, and to consider the specialities of arid climate and soil.

It is much more necessary to have a close harmonic collaboration of all scientific disciplines in an area where the yield from agriculture and forests is practically nil than in an area where the soil and climatic conditions are more favourable.

To meet all these ends we have assembled here and I am very much obliged to Government of India, the presidium of this meet, UNESCO for financing the visit and to all colleagues for the kind invitation to attend this Symposium. I thank cordially for the inspiration I received at this multiphased Symposium and everywhere in your nice and hospitable country.

†A term used in all languages.

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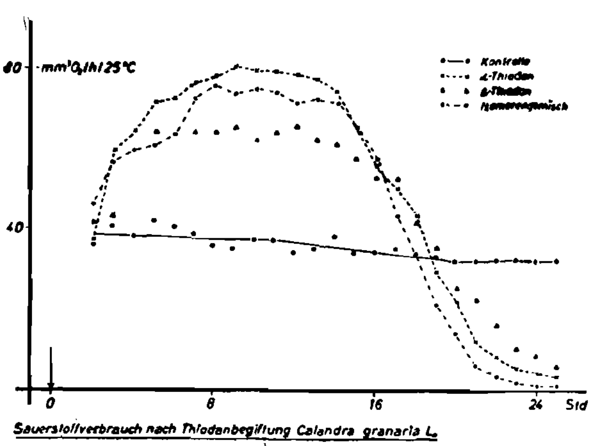
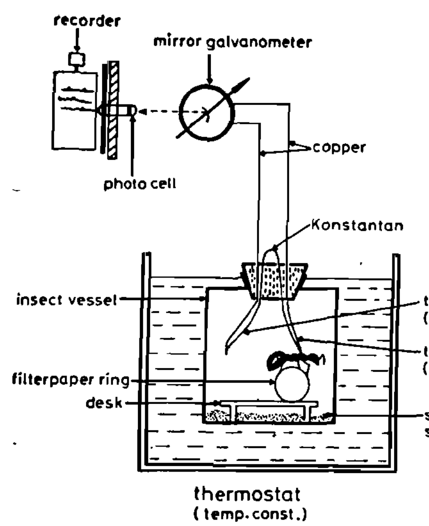


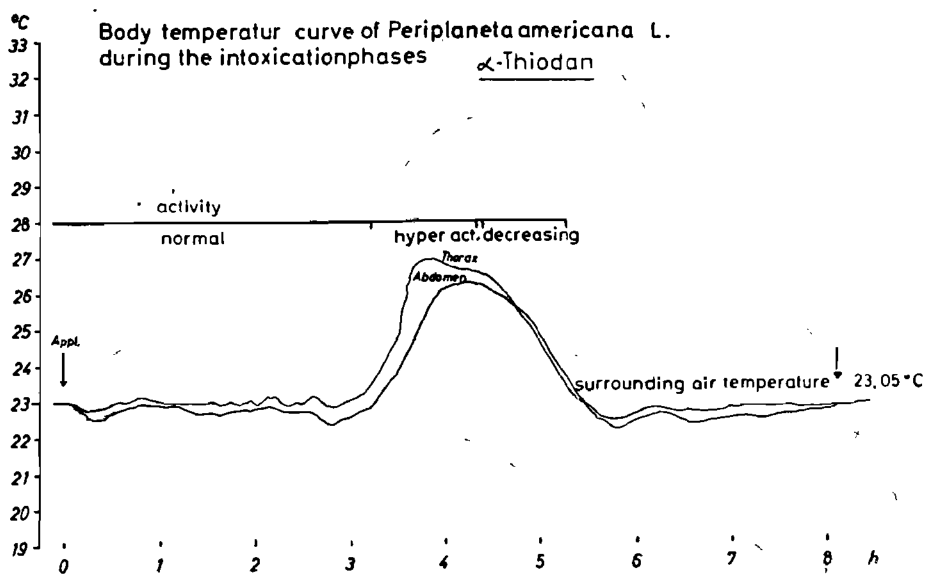
TEXT-FIG. 1

Oxygen consumption in mm³/per liter at 25°C. of the corn weevil, *Calandra granaria*. The unpoisoned controls show during 24 hours of testing period a similar oxygen consumption. In the insects poisoned by α-isomer, β-isomer and a mixture of α and β-isomers of Thiodan we notice a clear enhancement of O_2 consumption. A maximum which lasts for some hours falls with the knock out stage. After about 15 hours the curve of oxygen consumption falls below the normal and after 24 hours the respiration stops.



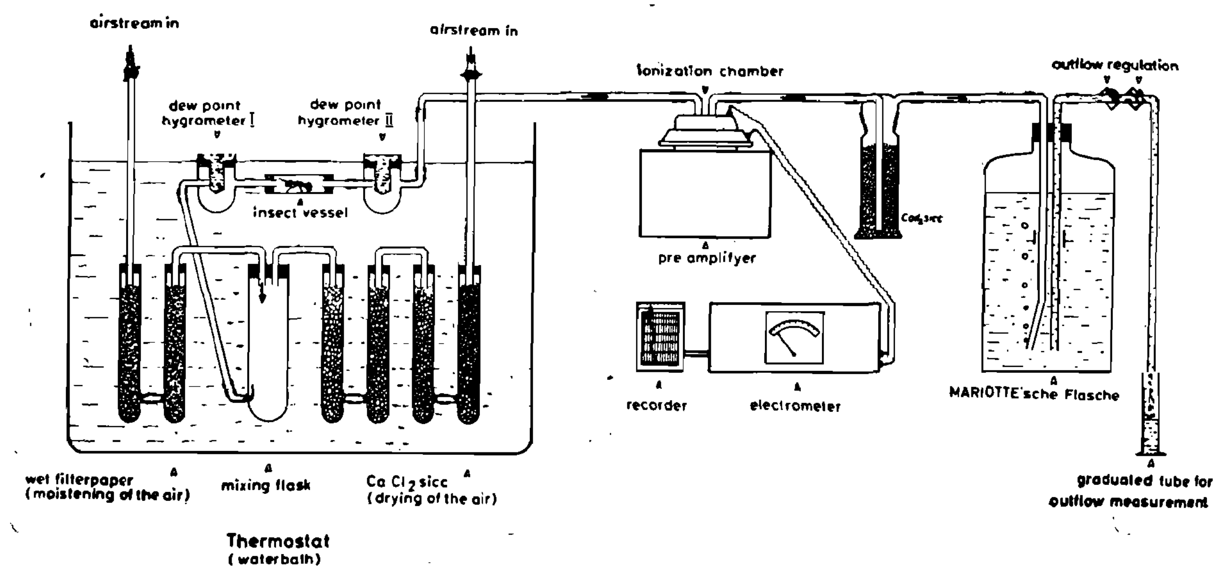
TEXT-FIG. 2

The surrounding temperature of the insect and of the temperature measuring equipment is maintained by the surrounding water at constant temperature. The desired air humidity is regulated by the already described methods of employing different salt solutions. For measuring the temperature we use very fine thermocouples which are made from 0, 1 mm thick copper-konstantan wires. The thermocouples are standardized after connection with the mirror galvanometer. The measured temperature potential is automatically permanently recorded. After standardization 50 μ thick one end of the thermocouple is introduced in the 2nd thoracic spiracle very carefully to avoid injuries.



TEXT-FIG. 3

On the abscissa is recorded the time in hours, on the ordinate is the temperature in °C. Application of insecticide Thiodan to the experimental animal begins at the point 0. The Air temperature in reaction vessel is about 23°C. In the upper line the different reaction stages during poisoning are noted. At first the movement is normal; after 3 hours the animal shows quick movements; after 4½ hours activity decreases. The temperature changes in insect are: in first 10-20 minutes body temperature is little lower than air temperature, and it is very characteristic that the rectal temperature is lower than the thoracic temperature between 1st-2nd hour temperature changes in poisoned animal are much more than in the unpoisoned animal; during 2nd-4th hour it increases remarkably and rises to a maximum which stays for 1-2 hours. At this time we see a very higher activity of poisoned animal which is evidenced by the speed of rotating paper disc; from 4th-5th hour the body temperature decreases and falls finally below the air temperature.



TEXT-FIG. 4

Tritium Measurement equipment. The THO is injected or fed. With the help of Mariottesche Bottles a continuous air stream is sucked through the entire apparatus. By passing over Ca CL_2 or moist filter paper the air can attain different humidities. Before entering in animal vessel and after leaving the humidity is measured by means of Dew Point Hygrometer I and II. During the transpiration the experimental animal releases at the same time THO, which ionises the air in the Donization chamber. The ionized air stream is amplified by a preamplifier and then the result of measuring comes to an electrometer. A records drawn continuously a transpiration curve.

DISCUSSION

M. L. Roonwal: Was Warburg's apparatus used for these studies?

K. Gösswald: The Warburg's apparatus was not mentioned as it is in very common use; like the bridge thermostat. For every animal there is need for very specific reaction vessels with standardization of the level and the measurements it is proposed to take. The observations are recorded when the experimental animals are more or less at rest.

MINERAL RESOURCES AND THEIR EXPLOITATION

NEW UTILIZATION OF SOME MINERALS FROM RAJASTHAN[1]

by

M. A. Hai, M. K. H. Siddiqui and E. R. Saxena

INTRODUCTION

Important uses of gypsum, limestone, felspar and fuller's earth which are available extensively in Rajasthan, have been found out in the manufacture of desiccant, white cement and bleaching earths respectively.

DESICCANT

Desiccation constitutes an important unit operation encountered at one stage or the other in the chemical industries. An efficient desiccant having regenerative capacity is, therefore, specially suited for industrial applications. The usual drying agents employed in the industry are calcium silica gel and activited alumina. Calcium chloride cannot be regenerated, and hence is considered uneconomic. Silica gel and activated alumina are desiccants which can be regenerated but are expensive. Investigations (Hai *et al*, 1961) were undertaken at the Regional Research Laboratory, Hyderabad, for preparing a versatile desiccant from gypsum at low cost. Gypsum from Bikaner (Rajasthan) was used for the above study. The main object of the work is better utilization of the mineral with immediate benefit to the growing needs of our chemical industry.

On dehydration at 250°-300°C gypsum ($CaSO_4 \cdot 2H_2O$) losses two molecules of water. This anhydrous calcium sulphate, also known as soluble anhydrite, possesses remarkable properties of a desiccant and can be repeatedly regenerated.

Since it is completely inert towards organic compounds, it does not decompose or catalyse reactions. For these reasons anhydrous calcium sulphate is used for dehydrating a wide range of organic compounds, like alcohols, ethers, aldehydes, ketones and hydrocarbons. It is also used for the drying of refrigerated and industrial gases like oxygen, hydrogen, carbon dioxide and chlorine. It efficiently removes moisture from vegetable, mineral and essential oils. As a rust preventive it can be used for the protection of machinery and accessories in packages during transport. Its use keeps the internal parts of precision instruments and scientific equipment dry ensuring a better performance and prolonged service. Being neutral, inert and non-toxic, it can safely be used for the preservation of sera and pharmaceutical products. It is also useful in the food packing industry.

Experiments were conducted to find out optimum conditions for the preparation of the desiccant. By using cobalt chloride, a self-indicating type of desiccant of blue colour turning to deep pink on absorption of moisture can be prepared. Strict control over the experimental conditions, choice of a suitable crystal-habit modifier are the important factors that greatly influence the quality of the final product. The desiccant prepared in pilot plant (100 kg scale) was found to have all the essential characteristics. The capital investment for a 0·5 ton plant per day works out to be Rs one lakh. The desiccant is found to have sufficient mechanical strength and resistance to withstand a pressure of 3000 p.s.i. and thermal shock during successive cycles of regeneration. It maintains its absorption capacity upto a temperature of 100°C and dries gases to a dewpoint of −80°C.

Its use is bound to increase with the rapid growth and development of the industries in the country.

WHITE CEMENT

White cement is extensively used in the manufacture of mosaic tiles for decorative fixtures and as a base for making coloured cements. Since ordinary Portland cement has a greenish grey colour and after setting yields a buff coloured mass, it cannot be used for decorative purpose. Raw materials used for white cement manufacture have to be carefully selected since they have to be quite low in iron. White clay with a low iron content is one of the raw materials currently used in the production of white cement. This clay having limited occurrence is expensive.

Till recently, the entire requirement of white cement was being imported. In 1958, A.C.C. started production of suitable quality of white cement using white clay and pure limestone. Travancore Cement Works who started their production of white cement in 1959, based their production on sea shells and good quality clay. The installed capacity of A.C.C. is 25,000 tons and that of Travancore Cement Works is 5,000 tons. The production during 1960-61 has been about 8,000 tons, while imports have been to the tune of 800 tons.

1. Contribution from the Regional Research Laboratory, Hyderabad.

Recently licence has been issued to V. Ramkrishna and Sons (Madras) to manufacture 16,500 tons of white and coloured cements.

A process has been developed at our laboratory (Saxena *et al.*, 1956) for the manufacture of white cement using potash felspar which is abundantly available in the country, instead of clay. Felspar is found in Rajasthan, at Jodhpur, Alwar, Jaipur and Ajmer. Limestone occurs at Jodhpur and Alwar. Gypsum is available abundantly in Barmer, Bikaner and Jaisalmer districts. Since white cement factories already exist in Kerala, Gujarat and Madhya Pradesh, new factories to meet the demand could profitably be located in Rajasthan, since it has good quality limestone, felspar and gypsum.

In view of the huge constructional work in the country and the expansion programme of the existing cement production, the potential demand for white cement appears to be considerable. Based on the process developed (Baquer Ali *et al.*, 1962), pilot plant was set up at the laboratory to investigate its commercial feasibility. The plant (300 kg/day) consisted of all the equipment used for making cement by the conventional method. However, the procedure consisted of double sintering in which potassium sulphate, a valuable fertilizer is obtained as a by-product, Felspar, limestone and gypsum required for the experiments were all obtained from Rajasthan.

The raw materials in a definite proportion are subjected to crushing, grinding and nodulizing with 12 per cent water. The nodules are then sintered in an oil fired rotary kiln at 900-1,050°C, ground and leached at boiling temperature for about an hour. The leached liquor is neutralized with sulphuric acid and potassium sulphate recovered by concentrating the liquor. The sludge is clinkered in an oil-fired rotary kiln at 1,430°C, ground to pass 120 mesh and mixed with required quantity of gypsum. The cement thus produced is comparable to imported white cement from Germany and superior to indigenous product in quality.

Project costs of a plant having 50 tons of white cement per day work out to about Rs. 205—per ton compared to the market price ranging from Rs 300-400 per ton. The total capital outlay being Rs. 62 lakhs.

BLEACHING EARTHS

By virtue of their adsorption power, fuller's earths and bentonitic clays find various applications in industry. In India these earths are used chiefly in the bleaching of vegetable oils, which are extensively used in the manufacture of *vanaspati*, soaps and paints. Of late, there has been a great demand for such earths in refining and reclamation of lubrication oil also. There are vast reserves of these earths in the country (Sethi, 1956). Of the many occurences of such earths, Rajasthan ranks first in production of this important mineral. Bentonites occur in Barmer and Swai Madhopur districts of Rajasthan and fuller's earth in Bikaner, Barmer and Jaisalmer districts. The most important deposit in the whole of Bikaner division is about 6 km east of Mudh village spread over an area of 2·5 sq km with an overburden of 3-4 metres. The total quantity of the earth available is prospected as 5-6 million tons. The earth is yellowish in colour, flaky in texture and has soft and soapy feel.

The bleaching earth industry in India is comparatively of recent origin. Till recently all the requirements of bleaching earths were being imported. Only 20 years back the first plant in the country for the production of bleaching earths was started in Bombay. Considering the large deposits of bentonites and fuller's earths available in the country, the Government curtailed the imports to encourage indigenous production as a result of which two more units were set up, and the total production capacity by the end of 1963 was 4,500 tons. All this was consumed by the Vegetable Oil Industry, mostly for bleaching of light coloured oils like groundnut. In spite of the fact that the production and consumption of bleaching earths have been steadily rising during the last few years, the fact remains that earths have not yet been developed for bleaching of dark coloured oils like cotton seed. Even for bleaching light coloured oils the indigenous earths are not up to the mark in quality, oil retention and filterability. This has resulted in importing earths specially for bleaching cotton seed oil. With the growing *vanaspati* industry switching more and more to the cotton seed oil, there is need for the production of suitable earths for bleaching dark coloured oils. Estimated requirement of earth for this purpose is about 2,000 tons. Bleaching earths required for lubricating oil refining are all imported. Annual capacity of the refineries for producing lubricating oil is estimated to be 3,40,000 tons requiring about 10,00 tons of adsorbent earth (Gopalkrishnan and Saxena, 1964). Similarly requirement of earth for reclamation of used lubricating oil has been estimated to be about 3,000 tons. Thus the total requirement of bleaching earths for dark coloured oils and for lubricating oil by 1965 will be 16,000 tonnes which has to be imported.

Regional Research Laboratory, Hyderabad, pioneered the work on evaluation of fuller's earths and bentonites from Andhra Pradesh, Mysore and Rajasthan and found out optimum conditions for their activation (Joshi *et al.*, 1961, Siddiqui 1964). The studies on Mudh earth have shown that it contains illite as the major clay mineral. Experiments were conducted to find out the suitability of this earth specially for bleaching of cotton seed and lubricating oils. In its natural form the earth exhibits decolorisation capacity for lubricating oil, which is enhanced after acid treatment. The activated earth also shows marked improvement in importing thermal stability to the bleaching oil (Saxena *et al.*, 1962). Acid activated earth was found suitable for bleaching vegetable oils, specially cotton seed oil. These observations are very important in view of the potential demand of earth for bleaching of lubricating and cotton seed oils which is still being imported and provide an ample scope for the setting of new production units in Rajasthan.

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MINERAL RESOURCES OF RAJASTHAN[1]

by

M. L. SETHI[2]

INTRODUCTION

THE State of Rajasthan lies in the north-western part of the Indian Union covering an area of 1,31,943 sq miles. It was politically born in 1949, after the merger of 22 former princely states. Later on the Union territory of Ajmer-Merwara was also merged with it in 1956.

With the formation of this new State, its economic development and general uplift along with the rest of the country have become the principal objectives which need to be achieved. It exhibited a low level of industrialization and its economy had remained underdeveloped so far.

GEOLOGY

Though a large tract of the State in the north-north-western sector is covered with desert, a sizable extent is left where pre-cambrian geological formations exist with exposures of some Palaeozoic, Mesozoic, Tertiaries and Recent formations. These rock formations contribute valuable minerals, which undoubtedly form an important base for the economic development of this region. The last two five year plans and the present Third Five Year Plan adopted by the Union Government have helped to promote an urge for harnessing these.

Geologically, the older rock formations in Rajasthan representing the pre-cambrians are known in Indian stratigraphy as "Pre-Aravalli", Aravalli and other "Delhi systems" each separated by an erosional unconformity. The Aravalli range intersects the State in the north-east direction, almost from end to end. It divides it so that about 3/5th of State lies towards the north-west and about 2/5th on its south-east. The north-western side is a sandy terrain where desertic conditions have grown up during the past centuries. The south-eastern side on the other hand, comprises a hilly terrain and fertile tablelands.

The Aravalli range extends over a length of nearly 700 km and has some peaks exceeding 1,000 m in height above sea level. It is chefly composed of igneous and metamorphic suites of rocks, such as granites, quartzites, biotite schists, composite gneisses, etc. The Delhi system, which is overlying the Aravallis through an unconformity consists of the Alwar and Ajabgarh series, named after the type areas. The basement rocks are generally believed to be granites, schists and gneisses of older age.

Towards the south-east of Rajasthan there are sedimentary rocks of late pre-cambrian to early Palaeozoic, known as the Vindhyan System. These are overlain at many places by basaltic flows; or the "Deccan Trap". Exposures of Jurassic, Tertiary, sub-Recent and Recent formations occur in the north-western part of the State.

The Aravalli system is characterised by extensive pelitic schists and phyllites, Raialo Series which intervene between the Aravallis and the Delhis by their marble and crystalline limestone, the Delhi System by the enormous development of rudites and also pelitic and carbonate rocks, all highly metamorphosed. This was followed by extensive igneous activity and orogenic movements.

The subsequent formation of the Vindhyans comprising several series of sandstone, shale and limestone were deposited in a comparatively tranquil tectonic conditions and shallow basin.

A characteristic feature of the pre-Cambrian geological history of Rajasthan is that it presents continuous sequence of rock formations. The statement given below is based on Dr A. M. Horon's interpretation.

Recent and sub-recent		Alluvium and Blown sand
Tertiary		Nummulitic limestone, shales, lignite and fuller's earth
Jurassic		Limestone and sandstone
Vindhyan		Sandstone, limestone, shales, Malani volcanics, Siwana and Jalore-granite and Erinpura granite
Delhi system	Ajabgar series	Phyllites, limestone, calc-gneisses and schists, biotite schists and composite gneisses, quartzite, arkoses, grit etc.
	Alwar series	Quartzite, arkose, grit and conglomerate
	Raialo series	Garnetiferous biotite schists, limestone (Marble) and local basal grit
Aravalli system		Impure limestone, phyllites quartzite, biotite schists, conglomerate and composite gneisses
Pre-Aravalli; Granites and bended Gneissic complex		Schists, gneisses, composite gneisses and Bundelkhand gneisses

1. Contribution from the Department of Mines and Geology, Rajasthan, Udaipur.

2. Director of the Department.

In the north and north-western region the geology has, however, become obscure due to the blanket of a thick cover of sand. Some exposures of Mesozoics and Tertiaries are represented by sandstone, limestone and fullers' earth, which are fossiliferous. Numulitic limestone bands, north-west of Jaisalmer are typical of the Eocene.

Looking to the large variety of mineral resources available in the State, it is felt that almost all the geological formation represented here have contributed something or the other.

The annual mineral production of the State has reached seventy-three million rupees in valuation during 1963 and the income from rents and royalties to the State amounted the 10·9 million rupees in the same year. These figures are significant when compared with twenty-one million rupees valuation of the mineral production in 1955 and the corresponding income of rents and royalties amounting to 5·3 million rupees only.

MINERAL RESOURCES

It is proposed to deal with the mineral resources here under three major heads: (i) Fuels; (ii) Metallic minerals; and (iii) Non-metallic or industrial minerals.

I. FUELS

(a) Lignite: Amongst the fuels, Rajasthan has not been fortunate enough to possess any resources, except those of lignite in which field also the reserves indicated so far are about 23·5 million tonnes near Palana, Bikaner, Prospecting however, is continuing. No coal has been found anywhere in the State.

Lignite has been worked by underground mining method, chiefly by the pillar and stall method for the last about half a century near Palana, about 14 miles south of Bikaner. It occurs under varying thickness of overburden, the average may be taken at about 60 m. The thickness of lignite seam also varies, the average being about 8 m. The mining method followed was such that the two shafts used for underground mining were abandoned after six to eight years of total life and a new pair of shafts used to be sunk. The extraction in the underground mining and averaged hardly 12 per cent, which means that nearly 88 per cent of the lignite was left in the ground, and could not be safely extracted. It is highly susceptible to spontaneous combustion when exposed. Till 1962 it was used as the fuel for the steam raising in the Government Power House at Bikaner. But since the commencement of the supply of electricity from the Bikaner grid line to Bikaner and the consequent closure of the local power house, other avenues of the uses of lignite such as for brick manufacture has become important.

During 1951-52, a stage had reached when virgin lignite area available for underground mining practically came to an end. A systematic prospecting programme was soon initiated with the help of rotary core drills. It is fortunate that this has resulted in the discovery of two new lignite bearing areas not far from Palana, carrying about 9·3 and 1·5 million tonnes respectively. Systematic proving is continuing near Khari, about 20 miles south-west of Bikaner.

A total of about 35,000 m of drilling has been completed since 1950. Near Khari, however, a shaly type of lignite formation has been encountered in most bore-holes. Analysis of a core sample gave the following results:

Moisture	10·3%	Calorific value: 2,950 Cal/gram., i.e. (60% of that of Palana lignite).
Ash	45%	
Volatiles	28%	
Fixed Carbon	16·7%	

It is now proposed to sample and analyse all the cores obtained near Khari at the Central Fuel Research Institute at Joalgora. Indications are available that lignite may possibly be encountered also at Chenneri (27°45′ : 42°48′) and Gangasarowar (27°56′ : 72°54′). Possibility of locating lignite in the Barmer and Jaisalmer districts is also indicated.

(b) Oil and natural gas: With regard to oil and natural gas, the discovery in the neighbouring country in Pakistan has raised considerable hope for similar find in the border district of Jaisalmer. Systematic work has been in progress under the aegies of the Oil and Natural Gas Commission for the last few years. Geophysical surveys have been conducted over a vast territory in this district. The data collected so far has been encouraging and drilling operations would shortly be started.

II. METALLIC MINERALS

In the field of the metallic minerals, Rajasthan enjoys a very fortunate position. There have been ample evidences of metal mining and smelting, carried out by the ancients at several places in the State.

(a) Lead, zinc: One of the most significant examples of this activity has been the Zawar Mines area, about 25 miles south-east of Udaipur where lead, zinc and silver ore had been worked and melted. The remnants of a small village near the Zawar Mines show a number of temples, streets, housing, smelter walls, all lying in ruins now. However, this lends to a conclusion that a prosperous community existed there subsisting primarily on the mining and smelting of the lead, zinc, silver ores. It is said that the industry thrived till about 1298 A.D. during the reign of Rana Lakha, when recurring famines spelt disaster and abandonment.

Encouraged by the surface evidence considerable exploratory work was carried out by the Utilization Branch of the Geological Survey of India during 1942-45. Later, on cessation of war, the operations were discontinued and the deposit was leased out to a company. During the course of working the existence of a large and valuable deposit in this region has further been confirmed.

Several hillocks, such as the Balaria, Zawarmala, Barol, Sonaria, etc. carry old workings. Slag heaps left by the ancients are scattered close to the Zawar village. Some samples of it have analysed as under:

Zn	13·761%	Ash from old pots at Zawar assayed at 7·029% Zn and 0·150% Pb. B. C. Roy 1959 Mem. G.S.I., vol. 86, p. 305
Pb	3·538%	

The Zawar deposit is reckoned today as the only known major source for lead-zinc-silver in the country.

The programme of development envisages mining of 2,000 tonnes of ore per day carrying about 5 per cent metallic values; milling capacity is being raised to that extent. The zinc concentrates will be treated by electrolytic method at Debari, about 6 miles from Udaipur with the production of about 18,000 tonnes of zinc metal and 9,000 tonnes of lead metal, 28,000 tonnes of sulphuric acid and 70 tonnes cadmium metal and 2,83,000 ounces of silver, in the first stage.

The second stage of the development proposes to raise the capacity of zinc smelting to about 50,000 tonnes. Based on the by-product sulphuric acid it is planned to manufacture super-phosphate (fertilizer) by reacting the sulphuric acid with the imported rock phosphate. The lead concentrates at present are being smelted near Tundoo, Katrasgarh, in Bihar.

(b) Copper: There are scores of places where old workings for copper mineral exist in the State. One of the last known and most important amongst them has been the Khetri-Singhana area, where millions of tonnes of slag are lying as a result of smelting carried out by the ancients. At the instance of the State Government intensive geological survey and exploratory drilling and mining programme has been undertaken here by the Geological survey and the Bureau of Mines. As a result of the work carried out by them and subsequent detailed work done by the National Mineral Development Corporation existance of a deposit carrying nearly 52 million tonnes of copper of 1 per cent copper content has been proved here; the probable reserve are in the neighbourhood of 60 million tonnes of like grade. Adjoining areas are still under exploration. Encouraging data has also been presented in the Kalihan Section, near Khetri township. Under the Third Five Year Plan a project has been established here by the National Mineral Development Corporation which have been granted mining rights through a mining lease by the State Government. The present plan consists of underground mining of about 6·7 thousand tonnes of ore per day with milling and smelting facilities. It is planned to produce 21,000 tonnes of copper metal annually, besides some precious metals viz. gold, silver, etc. Some aspects of the project are still under study, particularly the use of the pyrrhotite available in large quantity in the tailings for the manufacture of sulphuric acid and use of the latter in fertilizer manufacture and other chemical industries.

Systematic surveys of the copper ore carried out near Khahe Dariba in Alwar district, showed a small deposit. Further prospecting is currently underwa, near Babai, Dhanaute, Partapgarh, Bairah, etc. Preliminary investigations have been carried out near Delwara, and Kerovli in Udaipur district some years ago by the State Department of Mines & Geology. Further work has now been entrusted to the Geological Survey of India. Copper occurrence have also been indicated near Chainpura in Bhilwara district.

For metallic minerals, geophysical surveys over the various known tracts would be useful, and once the anomalies have been established the selected areas could be investigated in detail.

(c) Ferrous minerals: Amongst the ferrous group minerals occurrence of iron ore and manganese ore have been located at several places in the State, but the reserves found cannot compare with the huge deposit in the states of Madhya Pradesh, Orissa and Bihar.

At present twenty-three mining leases for iron ore are under operation, mostly in the district of Udaipur. A maximum output of 1,23,400 tonnes of iron ore was obtained in 1955-56. However, it has since fallen to a low of 67,000 tonnes in 1963. As it is all mined for the export market, the grade usually attained in between 62 to 66 per cent Fe. In sorting out the high grade ore there is a consequential rejection of almost as much quantity if not more of lower grade material. Systematic surveys for iron ore have been carried out by the State's Mines Department at the following places:

1) Neemla
2) Nathara ki pal
3) Thug
4) Pansal
5) Loharia
6) Loharpura

The Nathara ki pal deposit in Udaipur district was prospected in detail and a reserve of about 11·36 million tonnes has been proved here. The average quality of the ore, however, should be reckoned between 48-52 per cent. An analysis of an average sample is given below:

Fe	52·95%
SiO_2	23·23%
Al_2O_3	1·35
Mn	0·36
CaO	0·49
MgO	0·16
S	0.016
P	0·031

The significant use of the deposit can be the establishment of a mineral based industry in the vicinity. The Government of India have licensed here a 1,00,000 tonnes capacity pig iron plant to a private firm. A project report for the plant prepared by Yugoslavian experts is now under examination. It is proposed to manufacture special grade pig iron.

(d) Manganese: Banswara district has particularly been endowed with low grade manganese deposit. Some brisk mining activity by shallow quarrying continued here during the period 1956 to 1962. With the fall in prices of the manganese ore in the international market and consequential slump in the trade, virtually most of the mines have been closed down. The future of these deposits would depend on the revival of the manganese ore demand. Efforts will have to be made to beneficiate the low grade ore and sell the concentrate. The deposit no doubt requires further proving, and the Government of India have been requested to include the same in their programme.

(e) Tungsten ore: Rajasthan possesses the only known tungsten ore deposit in the country, where both underground and eluvial mining has been done during 1939-44; the mining activity was closed after cessation of hostilities during the World War II.

The eluvial mining was again revived in the year 1950, but it had been suspended in 1954 due to restrictions imposed on export sale of this mineral. There is a proposal to restart eluvial mining and hand drassing in the near future. A detailed prospecting programme had been undertaken by the Indian Bureau of Mines during the last four years, and it is expected that the same would shortly be completed. This deposit carries wolframite mineral and is comparatively a small one.

III, INDUSTRIAL AND NON-METALLIC MINERALS

Amongst the industrial and non-metallic minerals Rajasthan enjoys possibly as good a position as it does in respect of some metallic minerals. Besides soapstone, gypsum, mica, garnet, dolomite, limestone, are also being exploited in the State.

(a) Gypsum: Rajasthan produced a million tonnes of gypsum in 1963 which formed more than 90 per cent of the country's annual production. A large number of occurrences are located in the districts of Nagaur, Barmer and Bikaner besides some in Jaisalmer and Ganganagar districts. Most of these surface occurrence carry bedded gypsum under a small cover of overburden. Crystalline gypsum is also found in Bikaner district, though largely amorphous variety is available. Some selenite occurrences, small in size, have been located in some depressions near Lunkaransar, Thob. Typical analyses of gypsum of mostly crystalline, amorphous varieties and for selenite are given below:

Gypsum				*Selenite*	
Crystalline		Amorphous			
$CaSO_4$	73·60%	CaO	31·85	CaO	30·28%
$CaCO_3$	0·66	MgO	0·29%	MgO	0·18%
$MgCO_3$	0·79%	Fe_2O_3	0·32%	Fe_2O_3	0·74%
SiO_2	0·22%	Al_2O_3	0·90	Al_2O_3	—
Al_2O_3	0·087%	SO_3	43·24%	SO_3	46·00
Fe_2O_3	0·10%	SiO_2	1·84%	SO_2	1·85%
		CO_2	2·12%	SiO_2	1·16%
Combined water	19·20%	Combined water	19·40%	Combined water	19·69
Gypsum equivalent 97·08%		Gypsum equivalent 92%			

A gypsum occurrence was indicated in a tube well near Nagaur as early as 1944. Investigations in this area undertaken at the instance of the State Government by the Geological Survey of India, have since conclusively proved nearly 800 million tonnes reserve of good quality gypsum. Underground mining will have to be adopted to win the same.

About 75 per cent of gypsum production from Rajasthan finds its use in the manufacture of ammonium sulphate fertilizer and rest is consumed by cement, plaster industries. Prolific deposits of Rajasthan can easily support more fertilizer industries as well as building plasters, tiles, wallboard manufacturing industries. Considering the shortages for sulphuric acid in the country, use of gypsum as a raw material for the manufacture of the same can be considered. Its use, however, in plaster, wallboard industry will provide useful building materials which country demands today for construction of low cost housing.

While these industries are being planned, simultaneous experiments on the beneficiation of gypsum would be desirable so that some of the surface deposits which carry low grade (between 60-70 per cent $CaSO_4.2H_2O$) could be harnessed to provide high purity product.

(b) Soapstone: Almost the same importance which Rajasthan enjoys for its gypsum deposits, is claimed by talc, soapstone also. The annual production has reached 1,15,000 tonnes mark and represents nearly 75 per cent of the country's total production. The deposits are mainly located in the districts of Jaipur, Udaipur and Bhilwara. Nearly 200 prospecting licenses and mining leases exist at present for this mineral which is mostly produced by surface quarrying. Two distinct types of occurrence, one associated with the dolomite rock formation and the other associated with ultrabasics have been noted.

Much interest in the development of soapstone by private enterprisers has been seen. The mineral is easily minable, and after grinding, can fetch fair return on the investments. A number of pulverising plants have been established mainly at Jaipur, Udaipur, Neem-Ka-thana, Hindaun (Sri Mahaveerji), Alwar, etc. besides the existing ones at Bhilwara and Dausa. The deposits are scattered and not assessed with regard to their extent or quality. Systematic prospecting is required to estimate the reserves, shape and size of the mineral bodies. The present rate of production can be sustained for several years to come.

(c) Garnet: There were no mineral concessions for garnet, abrasive or gem variety, till about 1955, though some occurrences were known in tehsils of Sarwar and Toda-Raisingh. Good demand for this mineral has, however, generated during the last 4-5 years and there are 15 mining leases, though small ones, exist for this mineral today. The production is small and mining requires urgent proper planning and lay out. Processing arrangement for garnet should be made, so that it is easier for the industry to adopt the mineral for production of the abrasives, emery paper, etc. A percentage of this mineral is used as a semi-precious gem and cut for this purpose.

(d) Clays, Quartz and Felspar: Some deposits for clays are now being worked under a few licenses in Bikaner, Jaipur, Sawai Madhopur and Bhilwara districts. Large primary clay deposits are not known and almost all the available deposits are of secondary clays which on washing yield a good base for the pottery and ceramic wares. There is a great need in carrying out systematic tests for washing and firing of these clays. With regard to felspar and quartz, a number of occurrences are being worked in the districts of Ajmer, Bhilwara, Alwar and Jaipur. The annual production recorded below indicates an increasing trend:

	Clay	*Quartz* (in tonnes)	*Felspar*
1950	1,300	4,100	5,700
1963	7,147	9,220	12,463

These deposits are located in Barmer, Bikaner and Jaisalmer districts. Analyses of some typical samples are given below:

Bentonite		*Fuller's earth*	
SiO_2	52·76%	SiO_2	53·12%
Al_2O_3	23·36%	Al_2O_3	21·80%
Fe_2O_3	6.61%	Fe_2O_3	2·53%
CaO	0·99%	CaO	1·90%
MgO	4·96%	MgO	2.30%
K_2O/Na_2O	3·73%	K_2O/Na_2O	3·73%
L.O.I.	12·32%	L.O.I.	18·60%

The tests conducted for fuller's earth activation have been successful. During investigation a product has been obtained which has following qualities:

(i) Colour reduction in Oil — 70·5 per cent.

(ii) Compares well at par with the imported British fullment tested and Tensil Optimum earths.

The annual production for these minerals in the year 1963 has been as follows:

Bentonite	5,018 tonnes
Fuller's earth	8,981 tonnes

There is a great need for carrying out systematic research and experiments in the use of these minerals. It is known that some activated earths are still being imported in the country which could be replaced by the local product.

(f) Mica: Rajasthan enjoys the second position as a producer for mica amongst the States of the Indian Union, the first being Bihar and the third Andhra pradesh. The annual production in 1963 was 6,820 tonnes of crude mica. Most of the mica deposits are located in the districts of Bhilwara, Ajmer and Tonk. The pegmatites are worked mostly by underground mining methods, and the life of the deposits is usually small. The industry usually suffers from the vicissitudes of the foreign market. The recent efforts made by the Government of India to ban sales on consignment basis and to fix floor prices for certain grades, has helped in stabilising the conditions of the industry. It is felt that development could be accentuated if efforts were made to process different grades of mica by cutting and dressing and establishing direct export trade. The present pattern is that practically all the output is shifted to trade centres in Bihar, where it is dressed and shipped to foreign countries. In this process the Rajasthan producer does not get the best advantage from the exploitation of this mineral.

(g) Limestone: Aravalli, Raiols, Ajabgarh and Vindhyan geological formations have been contributing quality limestone in different parts of the State. The cement plants, one at Sawai Madhopur, and another at Lakheri, are already working for the last several years. One new cement plant is now under erection on the basis of the reserves of limestone proved near Chittorgarh by the State Department of Mines and Geology. Systematic surveys have indicated occurrences of cement grade limestone near Abu road. Preliminary indications are also available with regard to good quality limestone near Beawar in Ajmer district and near Bundi in Bundi district. Limestone exposed near Sojat and Gotan show some high quality bands, interspersed with dolomitic and siliceous ones. Sruvey is in progress to assess reserves in this area. An earlier survey conducted by the Department also indicated fairly large reserves of good grade limestone near Darra Ramganjmandi in Kota district.

Lime making industry is well established at Gotan, Sojat, Bilara Mundwa, Maonda, Rajgarh, Abu Road, etc.

The annual production in 1958 and 1963 for cement and lime manufacturing is recorded below:

	For cement (in thousand tonnes)	*For lime*
1958	1,124·3	118·6
1963	1,735·5	560·3

Limestone, as dimensional and flooring stones, is also being quarried in Kota and Chittorgarh districts and the annual production in Kota district in 1963 was 189,963 tonnes, and in Chittorgarh district 12,000 tonnes.

There are good possibilities of locating some more deposits of limestone, though they may require selective mining for supply to cement industry. It will be necessary to revise the convention regarding depths to which a deposit is usually worked. Modern open-pit mining machinery would permit depth-quarrying along with removal of overburden within economic limits. The heavy shortages which the country faces for cement and also for the flux grade limestone requires acceleration in the pace of systematic prospecting. Quality deposits, however, should be conserved and used for industrial purposes.

Survey by the Department of Mines for locating limestone reserve are currently being undertaken near Kotputli, Darauli, Sojat, etc. Preliminary survey which is being followed by detailed geological mapping and drilling investigations has indicated nearly 200 million tonnes of cement grade limestone reserve near Darauli (about 2 miles north of Dabok Aerodrome, Udaipur).

(h) Dolomite: The dolomites are found at a few places only; mostly high magnesia limestones have been worked as dolomite in Alwar, Ajmer and Jhunjhunu districts. They are used in preparing chips and powder for the building trade, and probably same of this dolomite production has also found its way in lime making.

(i) Calcite: This mineral chiefly occurs as veins in Jhunjhunu, Sirohi and Pali districts. The output as high as 5,351 tonnes has been recorded in the year 1963 as against 225 tonnes in 1955.

(j) Barytes: The Alwar district where small barytes deposits had been known for a long time, had contributed only a small production of 12 tonnes in 1955. There has been a systematic growth in the output of this mineral and the figures from 1960 to 1963 recorded below show that there is a revival of barytes production.

	(in thousand tonnes)
1960	1·3
1961	1·2
1962	2·0
1963	5·6

This production is obtained from seven lease holders. At present most of these deposits are almost burrowed with large unsupported inclines and pits. It is necessary that proper underground mining methods is adopted.

(k) Glass Sand: For the last three decades or so, Rajasthan has been a supplier of various qualities of glass-sand to glass factories located in U.P., Punjab, Maharashtra, etc. The increasing trend in glass-sand production is evinced by the following figures:

	(In thousand tonnes)
1960	23·3
1961	20·1
1962	31·3
1963	34·0

The quality of glass-sand as quarried is good. However, for large plants, engaged in the manufacture of quality product, it would be necessary to ensure "Alumina" constituent to the barest minimum. Uniformity could be achieved by careful sampling and planning at the mining stage. Washing methods will have to be adopted so that the end product is of high uniform standard. The reserves of the deposits need assessment. This simple beneficiation would lend greater confidence to the industry in the mineral raw material supplies.

(l) Fluorspar: A small pegmatitic occurrence of fluorspar was located near Chowkri in the Sikar district by the State Mines Department as early as 1944. The most noteworthy find has, however, been in the Dungarpur district near Mando-ki-Pal in 1956. It has since been thoroughly investigated and an economically workable deposit carrying about 1·25 million tonnes reserve has been proved with an average CaF_2 content of 17-19 per cent. The development of this deposit as a commercial undertaking is one of the schemes under the State's Third Five Year Plan.

A feasibility report on the deposit has been prepared by a Canadian Firm of consultants and shortly detailed project report and design for the mill would be prepared. It is considered that a 300 tonnes per day mining and milling activity would be possible, allowing production of 5,135 tonnes of acid grade, 9,510 tonnes of metallurgical grade concentrate annually. Not very far from this area, another fluorsper bearing zone has been discovered near Salumber; the same is now under investigation. Geological reconnaissances has indicated fluorsper bearing area near Asind in Bhilwara district and at Chappoli in Jhunjhunu district. In all these places investigations for proving reserves are in progress.

(m) Other minerals: Low grade graphite, kyanite, emerald, beryl, lepidolite and vermiculite have also been won at some places in very small quantities.

Asbestos of the tremolitic variety has been mined chiefly in Udaipur, Ajmer and Pali districts. A private firm is prospecting under a license in Dungarpur district for chrysolite asbestos. The production during the last four years has been as follows:

	(in thousand tonnes)
1960	1·3
1961	1·4
1962	1·4
1963	2·2

(n) Building stones: Amongst the building stones Rajasthan occupies a very important position in the country, both for quality as well as quantity, the chief ones amongst them being the marbles, sandstones, limestones, quartzite — The red sandstone with which the historic Red Fort of Delhi and the palaces of Fatehpur Sikri have been built, have its source in quarries located in Dholpur, Bharatpur, Bavana, Hindaun, Karauli and Kotah areas of Rajasthan. Wide spread quarrying, though mostly by manual methods, is carried out with conventional hand drilling and gunpowder. Faces of the quarry are developed to produce dimensional stones; here the traditional skill of the workman comes into play in preparing stone beams, slabs, flooring, etc. The transport by bullock cart has, however, been replaced in a great measure by trucks.

The name of Makrana has become a synonym for marble in the country. Various shades of the white pink, black, striped (Zebra variety), green, are quarried in Rajasthan.

Though most of the production comes from Makrana, many new areas have been developed for quarrying during the last few years, such as Bhainsalana and Bishala in Jaipur district; Kae, Hiri and Jhankri in Alwar district; Bar, Bhandia, Hadri, etc. in Pali district, Marthala in Sirohi, and Daulatpura, Kanwalai, Kaimpura, Khak, etc. in Ajmer district.

The demand for marble is increasing and it will be important that this industry fully gears up all the resources and adopts modern quarrying method which is able to produce large blocks of marble and simultaneously cutting and polishing technique is also improved.

CONCLUSION

The mineral resources of the State thus provide a large variety and have great potentiality for the establishment of mineral based industries. It is important, however, that their exploitation is systematic and properly supported by a continuous prospecting programme so that new sources are discovered and proved. For some minerals it is felt that prospecting by modern beneficiation methods at the mine head and preparation of standard and quality product will be necessary. It will create more confidence in the industry for the supply of raw material, and in the long run would guarantee better returns on the investment. The progress in the mining industry is shown in the following table.

Mineral Concessions in Rajasthan

Sl. No.	*Year*	*Major minerals*			*Minor minerals*		
		C.A.	*M.L.*	*P.L.*	*M.L.*	R.C.C.	*R.C. R.L.*
1	1955-56	541	237	239	240	135	—
2	1960-61	685	501	253	924	569	4,407
3	1963-64	388	607	182	1081	672	7,050

BYPRODUCT RECOVERY FROM SALINE LAKES AND ALKALINE SOILS[1]

by

K. Seshadri & D. S. Datar

Number of saline lakes and soils containing efflorescenses as *Reh*, *Khari*, *Kallar* and *User* which are local names for alkaline soils, exist throughout the arid and semi-arid areas of Rajasthan, Uttar Pradesh, and North Bihar (Jain, 1961). Sodium chloride, sodium carbonate, and sodium sulphate are the three main products that can be obtained from these lakes and soils. Sodium sulphate is in great demand for paper and glass industries. It is estimated that about 0·8 to 1·0 lakh tonnes of sodium sulphate will be required during the fourth five year plan period as against 45,000 tons being produced per annum at present.

Sambhar lake (26°55′ : 75°11′) situated at a distance of about 36 miles from Jaipur and covering an area of 90 square miles, Didwana (27°23′: 74°35′), covering an area of 4 square miles and Panchbadra (25°50′: 72°10′) are the important inland salt lakes in Rajasthan where common salt is produced. From the waste bittern, Sambhar source alone can yield 15,000 tonnes of sodium sulphate and 8,000 tonnes of sodium carbonate or together 25,000 tonnes of sodium sulphate from 250,000 tonnes of liquid bittern rejected annually at the Sambhar lake. The Didwana and Panchbadra sources can yield 18,000 to 20,000 tonnes of sodium sulphate per annum. The alkaline soils from North Bihar and Uttar Pradesh can yield 16,000 tonnes of sodium sulphate from 26,000 tonnes of Khari salt produced per annum. Hence, these sources alone, if fully exploited can yield about 70,000 tonnes of sodium sulphate per annum which can meet our industrial demand.

Appropriate phase rule data relating to each source has been studied and applied to recover sodium sulphate (Seshadri & Labo, 1957). The phase rule data at lower temperatures have revealed that sodium sulphate in pure state can be separated by chilling to 0°C and in the case of Khari salt, magnesium sulphate can be converted into sodium sulphate at lower temperatures and separated along with sodium sulphate (Seshadri & Vyas, 1962). The details of the processes are described below.

SODIUM SULPHATE FROM SAMBHAR AND DIDWANA BITTERN

Sambhar lake bittern, after harvesting common salt, measures 29° Be and contains NaCl 19·5 to 21·1, Na_2SO_4 6·3 to 7·5, Na_2CO_3 2·8 to 3·2, $NaHCO_3$ 0·8 to 0·9 per cent and on drying up leaves a solid containing Na_2SO_4 30·1, NaCl 66·0 and Na_2CO_3 2·0 per cent. The bitterns possess an intense red colour and emit a nasty smell due to the presence of algae. The recovery of the constituents from such a solution has been found difficult unless the algae is destroyed. An average dosage of 0·5 to 1·0 g of available chlorine per litre of brine and bittern respectively has been found to be effective in bleaching and destroying the algae (Seshadri & Buch, 1958) thereby, rendering the solution easy for processing. The process consists of the following steps: (1) elimination of algae from liquid bittern by chlorine treatment; (2) adjustment of composition of the solution and chilling it to 0°C; (3) separation of $Na_2SO_4.10H_2O$ by centrifuging; (4) dehydration and purification of sodium sulphate by melting; (5) recovery of sodium chloride by solar evaporation of desulphated liquor until the liquid reaches 10 per cent sodium carbonate strength; (6) carbonation of the desalted liquor for the recovery of sodium carbonate as bicarbonate. The overall recovery of sodium sulphate is 90 per cent.

Instead of recovering sodium carbonate by carbonation, it is found advantageous and economical to convert the sodium carbonate into sodium sulphate by reacting with gypsum (Seshadri & Vyas, 1960). By this treatment, concentration of sodium sulphate has been raised in the original bittern from 8 to 13 per cent. On chilling the enriched bittern to 0°C, higher yields of sodium sulphate are obtained, representing about 60 per cent higher recovery over that obtained with untreated bittern. This new process has been successfully worked out on a pilot plant scale and 250 kg of anhydrous sodium sulphate have been produced daily during trial runs at the Institute.

Based on the pilot plant studies in this Institute, it is estimated (Seshadri & Vyas, 1960, revised to the present market price of 1967) that a plant to produce 20 tonnes of sodium sulphate will need an investment of Rs 21 lakhs and the cost of production works out to be Rs 200/- per tonne of sodium sulphate against ex-factory price of Rs 300/- per tonne (present market price is Rs 800/-). The plant will also yield 6000 tonnes of high grade sodium chloride per year as byproduct. The return on the total investment is estimated as 33 per cent.

At Sambhar, a crust is found deposited in the bottom of the crystallizing pans when the subsoil

1. Contribution from Central Salt and Marine Chemicals Research Institute, Bhavnagar.

brines are used. This is scrapped off at the end of each season. This is known as pan crust and is comparatvely rich in sodium sulphate (45 to 62 per cent) and free from algae. It is estimated that about 1000 tonnes of this material is available per annum. Three methods (Seshadri & Buch, 1959) based on the solubility data have been worked out: (1) chilling process whereby 90 per cent of sodium sulphate from the crust is recovered; (2) precipitation method by saturating the solution with sodium chloride whereby 65-75 per cent is recovered as anhydrous sodium sulphate; (3) leaching and digesting the upgraded material has yielded 75 to 80 per cent sodium sulphate from the crust. Hindusthan Salts Ltd is contemplating to put up a plant shortly at Sambhar.

Didwana brine is richer in sodium sulphate than Sambhar brine. When it reaches 24°Be, the brine contains Na_2SO_4 6·7, NaCl 16·4 and Na_2CO_3 4·7 per cent while Sambhar brine corresponding to same density; Na_2SO_4 3·7, NaCl 22·0 and $Na_2CO_3$1·7 per cent. Saturation of sodium sulphate at Deedwana reaches earlier than at Sambhar and during crystallization of sodium chloride at Deedwana, sodium sulphate separates out along with sodium chloride rendering it impure.

By natural cooling during the winter months, sodium sulphate separates partially as decahydrate and deposits in the pan bed. By introducing the pre-condenser before feeding to the salt pans, it is possible to recover commercial quality sodium sulphate (Pandya & Maharishi, 1964). Alternativelly 80 per cent of the sodium sulphate present in the brine can be recovered by adopting chilling process. This helps in the recovery of pure sodium chloride by natural solar evaporation.

SODIUM SULPHATE FROM KHARI SALT

Khari salt (C.S.I.R. Pub. 1948) is efflorescence soil rich in sodium sulphate. The chemicals in the soil appear to come up to the surface of the earth from below by capillary action (Wadia, 1953) and are deposited at the surface by rapid solar evaporation. The main constituents of Khari salt are sodium sulphate and magnesium sulphate either as Vanthoffite. ($3Na_2SO_4.MgSO_4$) or astrakanite ($Na_2SO_4.MgSO_4$-$4H_2O$). The Khari salt of northern Bihar obtained from soils by lixiviation and by solar evaporation contains a considerable percentage of sodium chloride where as Patna Khari salt produced by lixiviation of the soil and evaporation by artificial heat has very little sodium chloride and is considered as good grade Khari.

Khari salt of North Bihar contains principally double sulphates of sodium and magnesium as vanthoffite ($3Na_2SO_4$, $MgSO_4$) and astrakanite ($Na_2SO_4.MgSO_4$ $4H_2O$). Three methods (Seshadri & Vyas, 1962) based on the solubility data have been worked out for the recovery of the constituents from Khari salt which contains 70 per cent Na_2SO_4 in high grade and 40 per cent in low grade salt. The leaching method is found suitable and economical for vanthoffite Khari and not for astrakanite Khari samples. The process consists of (1) leaching out the powdered Khari salt with a calculated quantity of water to remove magnesium sulphate and sodium chloride (1·75 kg Khari with 1 litre of water) leaving behind a residue rich in sodium sulphate 90 per cent, 2·7 per cent $MgSO_4$, 0·7 per cent NaCl. The yield was 76 per cent of the total sodium sulphate in Khari salt. The above upgraded salt (1·16 kg) is dissolved in 2·2 litres and the mud is removed by settling. Sodium sulphate decahydrate is crystallized out in shallow crystallizing pans in the open. The temperature fall during nights lowers the temperature sufficiently to enable considerable quantities of sodium sulphate to separate out.

Precipitation and chilling methods are applicable to astrakanite Khari. In one method both sodium sulphate and magnesium sulphate are recovered separately by chilling to 0°C for Na_2SO_4 and evaporating the mother liquor and chilling to obtain magnesium sulphate. In another method, all the sulphate present in the astrakanite Khari is recovered as sodium sulphate by converting magnesium sulphate into sodium sulphate at -5°C. One kg of vanthoffite Khari will yield 723 gm of sodium sulphate whereas one kg of astrakanite Khari will yield 640 gm of sodium sulphate or 428 gm of sodium sulphate and 471 gm of epsom salt. It has been found that precipitation by salting and chilling to recover all the sulphate as sodium sulphate is the best procedure for astrakanite Khari.

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SALT INDUSTRY IN RAJASTHAN[1]

by

G. C. Jain, N. N. Sharma, R. L. Datta & D. S. Datar

Sambhar Lake, the biggest inland source of salt of India, is situated in Rajasthan. Besides this, the other main sources of salt in the state are situated at Didwana and Pachbhadra. Sambhar Lake, when full, covers an area of 90 square miles with depth varying between 12 to 36 inches only, and is situated amidst the Aravalli ranges almost bisecting the state of Rajasthan. Didwana is 40 miles north-west, and Pachbhadra is 150 miles south-west of Sambhar Lake. Brines available at the three sources vary considerably as seen from Table 1 (Salt Export Committee Report, 1950).

Table 1: Composition of brines from Sambhar Lake, Didwana and Pachbhadra, and of brine from sea (Per cent on dry basis)

	Sambhar	*Didwana*	*Pachbhadra*	*sea brine*
Sodium chloride	87·30	77·19	85·66	77·76
Sodium sulphate	8·65	20·65	—	—
Sodium carbonate	3·87	0·60	—	—
Sodium bicarbonate	—	1·56	—	—
Calcium carbonate	—	—	—	0·35
Calcium sulphate	—	—	2·97	3·60
Magnesium sulphate	—	—	9·44	4·74
Magnesium chloride	—	—	1·93	10·88
Potassium chloride	—	—	—	2·46
Magnesium bromide	—	—	—	0·22
Undetermined	0·18	—	—	—

An examination of Table 1, shows that the constituents of brines at Sambhar and Didwana are common, although their percentages vary, whereas the constituents of brine at Pachbhadra and of sea brine are more similar, in comparison. Brines at Sambhar Lake and at Didwana are characterized by the presence of sodium sulphate, sodium carbonate, and also of bicarbonate, and by the absence of calcium carbonate and sulphate, of chloride and sulphate and bromide of magnesium, and of potassium chloride. These facts raised questions and consequently also controversies as to the origin of these sources. For instance, according to the Marine Origin theory (Agrawal, 1951), the western desert of Rajasthan was originally a part of the sea, which, while receeding, left impregnated strata of rocks, etc. at and near the lakes. The salinity was subsequently brought up the lakes by percolation and also streamed in by the flowing rivers. Sambhar Lake is fed by rain and a few rivers namely, Rupnagar, Mandha, Kharian and Khandel. Salt spring theory suggests that Sambhar Lake derives its salt from the subterranean saline springs, which are hidden in the settled bed of the lake. According to some, rock salt deposits exist below the bed of the lake, which brings up the salinity by rain water and water from the rivers flowing into the lakes. G. N. Saxena and T. R. Seshadri (1956) believe that salt is washed into the lakes at Rajasthan by the percolating water from the rock salt deposits of Punjab.

Windborne theory (Holland and Christie, 1909) assumed the carrying capacity of the wind for fine grain salt from the Runn of Kutch to Rajasthan. N. N. Godbole (1951) attributed the origin of salt to the pockets of saline deposits left behind by the regressing ancient (Tethy's) sea. Subsequent chemical transformation resulted in the presence of sulphate and carbonate of sodium at Sambhar and Didwana.

The source of salts in any particular region cannot be isolated from its geological history. Consequently, in the case of Sambhar Lake and other sources of Rajasthan, the ultimate source of salt cannot be considered entirely in isolation from the rest of the adjoining territories. More recently, the views (Sapre; Datta & Datar, 1964) expressed, consider Sambhar Lake as an area of internal drainage in a semi arid zone deriving its salinity from the desiccation and concentration of the drainage water from the adjoining area and basic igneous rocks. Weathering of the basic rocks may result in alkali carbonate, which by absorption of carbon dioxide and chemical reaction cause formation of bicarbonates. The presence of alkali carbonate is not likely to allow any calcium or magnesium salts to remain in solution. Potassium ion being highly exchangeable and hence removable by clay, results in the absence of potassium chloride in brines of the lakes at Rajasthan. Nevertheless, at least certain of the contensions require verification by direct experiments.

The silt deposits at the lakes, which are increasing, though slowly (estimated depth of 20 meters at the centre to about 4 meters at the sides of the lakes, Malhotra, 1964), may assume importance by way of reduction in oozing out of the brine to the surface

1. Contribution from Central Salt & Marine Chemicals Research Institute, Bhavnagar.

of the lake. These deposits already cause trouble to pumping operation.

The rate of natural evaporation of brine is particularly important in the winning of salt, because upon its optimum value depends the quality and quantity of salt from the lake brines. Factors upon which the rate of evaporation depend are incident solar radiation, ambient temperature, wind velocity and humidity. Extremes of any of these factors are detrimental to the quality and quantity of salt. Although data for incident solar energy in the lake regions of Rajasthan is not available, ambient temperature during summer months is reported (Malhotra, 1964) to be 42-45°C, wind is reported to be strong with average humidity in summer months as low as 27 per cent or so, resulting in an average evaporation of 44 in. Average rainfall in this region is of the order of 15 in. per annum. No control can, however, be exercised over these factors. Nevertheless such factors are, generally, favourable for the production of salt from the sources of Rajasthan. Apart from these factors which are, generally, favourable, the nearness of the consuming centre brings down the cost of transport. Being far away from coastal lines, the centres of salt production do not run the risk of being washed away by high tidal sea water. In the light of the above climatic conditions and geographical situation, it is worthwhile to examine the presently employed method of winning salt from these sources in order to be able to suggest improvements by making better use of the favourable circumstances, and control or avoid unfavourable ones, and also create new favourable conditions.

(1) Sambhar Lake Salt Source: Gypsum free brine at 2°Be′ of the lake is pumped into the main reservoir during September-November, which, when attains 4°Be′ or so, is branched into reservoirs situated at and near the Main lines, Deodani, New Kyar, Gudha Jhapog and Nawa, which are to prevent deposition of sodium sulphate crystals at subsequent operations on account of rapid evaporation and low temperatures recorded during winter nights. Dilute brine of 18-20°Be′ is added to keep the density of brine in the crystallizer to as near as possible to 25°Be′. The ratio of reservoir cum-condenser to crystallizer is varying from $\frac{0{\cdot}8}{1{\cdot}0}$ to $\frac{2}{1}$. Multiple irrigation system with single crop for winning salt is taken resort to. Brine obtained from percolation canals are mixed with lake brine in order to increase production of salt. Sub-terranean brine is processed in pans, though separately (on account of higher sodium sulphate), to obtain white crystalline salt of about 98 per cent purity. Bittern is not processed for the recovery of valuable sodium sulphate.

(2) Didwana Salt Source: As it will be noticed from Table 1, the percentage of sodium sulphate, a valuable chemical, is as high as 20·65, recovery of which presented problems of its own. Tail brine, after recovery of sodium sulphate, can be processed in the conventional way for manufacture of common salt. Extreme condition of low temperature of the locality during winter months may be utilized for sodium sulphate recovery.

(3) Pachbhadra Salt Source: Processing of brine of the locality is more of an art even now, which consists in digging the pits through which percolates brine in the underground surface. Over the surfaces of certain types of local shrubs, crystallizes the common salt which is subsequently brought over to the surface level and transported to storage yard.

A brief description of the methods of winning salt at the three centres of Rajasthan brings out pertinent facts which are wide open for improvements scientifically and otherwise.

Rainfall is essential for producing brine and bring it to the surface, but higher rainfall, may bring problems solution of which will lie in the layout of the salt work with due regard to the ratio of reservoir-cum-condenser to crystallizer. The value of existing ratio is not likely to be tenable under the condition of heavy rain. Prevention of loss of brine by percolation from crystallizers and other components of the layout by physical and physico-chemical methods will go a long way in increasing production of salt. Stabilization of the crystallizers and other components by puddling with addition of sand, gravel or mixture of gypsum and clay or asphalt, sand and clay is a likely step toward this direction. Certainly, maintenance of the percolation canals in trim condition and getting the lake area rid of the slush are important, but equally important is the prevention of the growth of algae and its removal if and when grown. Wherever, physical methods of removal fail, treatment with algicids like chlorine has been suggested (Rao, 1964). As has been indicated, subterranean brine is the source of Pan salt. Also the bitterns contain good amount of sodium sulphate and common salt. It is possible to win common salt from these and purity to obtain good quality of salt, and also recover sodium sulphate, if an integrated plant comprising washery and recovery unit are set up. It is known, such a scheme (Malhotra, 1964) is under consideration at Sambhar Lake. It is quite interesting to observe that in such a major salt producing centre like Sambhar, only two operations are mechanized, namely, pumping of brine from the lake to the main reservoir, and transportation of salt to the main stores. Evidently, as in any other salt works of sea brine, there is ample scope for mechanization of the various operations. It is also emphasized, such mechanization has to be very gradual to prevent socio-economic problems of the labourers being precipitated. In addition the two, stated above, the operations which may, by gradual stages, be mechanized, comprise puddling and rolling of crystallizer beds for soil stabilization, harvesting of salt by semi-automatic or mechanized units, drying in moving drying beds, conveying with elevators, automatic packaging, transportation. Attention is also required to be paid to the existing and developed services, namely, air lift pump, pneumatic conveyor, hydrocyclones in washing, etc.

Rajasthan, in general, and the centres of salt production there in particular, face the problem of water shortage due to which attainment of even the existing capacity of production of salt is hampered to a considerable extent. Towards the solution of such a problem attempt should be directed to: (1) conservation, as far as, possible of the natural sources of water, e.g. rain water; (2) processing of waste water for further use; (3) desalination of the brackish water of Rajasthan. Brackish water usually contains total dissolved solids (Deutch, 1962) varying between 1000-10,000 ppm. Techniques of desalination are known which require to be developed at different centres of salt production at Rajasthan. Techniques based on electrodialysis, and ion-exchange methods are known to be suitable for brackish water, but in the absence of good supply of power, these techniques may face difficulties. With constant supply of thermal power, and of course, nuclear power, which is likely to be in Rajasthan during the next five year plan, difficulties about shortage of power, not only for these techniques for which the cost of power alone may be as high as 50 per cent, but also other difficulties in relation to conservation of water, processing of waste water and mechanization of salt farms are likely to be solved. Nevertheless, it is thought desirable to attempt to develop the solar still technique in areas of Rajasthan, at least, to supplement the immediate need of water. Conditions which are considered favourable for such development in Rajasthan are abundance of incident solar radiation, cheap labour and availability of the materials of construction. Cost of maintenance of a plant for such a technique is very low. However, such a plant may perhaps be run also on a co-operative basis. It is estimated tentatively that the cost of construction of a solar still (with the brackish water available nearby) for producing 500 gallons of water per day, is about Rs 80,000, and the recurring expenses are low or practically insignificant.

One of the objectives of mechanization of salt works is certainly reducing human sufferings. Salt industry, generally, and particularly the salt works at Rajasthan has problems of labour. Although a cheap essential commodity, action of salt on human hands and feet which come in contact during manual operation is not very desirable. Such a situation is accentuated by the extremes of the climatic conditions in places like Rajasthan. Shortage of water and of transport have added to these difficulties. Seasonal nature of salt manufacture is also an important aspect requiring serious consideration. Development of washery units, and by-product recovery plants, manufacture and fabrication of equipments and of mechanized units for salt works may lead to solution of problems of labour arising out of the seasonal nature of the salt industry. Such ideas should, at the initial stages, be initiated in existing state sponsored organizations as in Sambhar Lake, Didwana and Pachbhadra.

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GEOGRAPHY OF DESERT

SOME GEOGRAPHIC FEATURES OF THE RAJASTHAN DESERT[1]

by

AMAL KUMAR SEN[2]

INTRODUCTION

RAJASTHAN desert extends between latitudes 24°35′N to 30°10′N and longitudes 69°30′E to 76°E. This includes the districts of Ganganagar, Bikaner, Churu, Jhunjhunu, Nagaur, Jodhpur, Barmer, Jaisalmer, Western Sikar, a small portion of western Jaipur and northern Ajmer, western Pali and the major portion of Jalore district excluding the S.E. strip. From the point of view of aridity the entire region receives less than 500 mm of annual rainfall. Based upon Koppen's (1931) index, the annual rainfall being less than $T+14$ the area is classed as arid region. Gorezynski's (1945) aridity factor K× (Latd. factor) ×(Range of temp.)×(Precipitation ratio) and Gaussen's (1959) Xerothermic index, work out to 30 and 300 (x_5) respectively, which are also indices of true arid climates. This also coincides mostly with the boundary drawn on Thornthwaite's (1943) precipitation evaporation ratio $11{\cdot}5\times\left(\frac{p}{T-10}\right)\frac{10}{9}$.

The 500 mm isohyet, therefore, has been selected as the basis for demarcation of arid zone in Rajasthan which occupies an area of about 1,81,062 square kilometres.

NATURE OF RAJASTHAN DESERT

Pithawalla (1952) concluded that Rajasthan desert is not a true desert. This conclusion is mainly based on Sir Aurel Stein's (1939) assumption that there is no real climatic change taking place and of Huntington (1907) that large areas in the continent of Asia have dried up by some causes like the diminution of glaciers in the Himalayas, the diversion of a branch or branches of perennial rivers cut off etc. But this desert, which is essentially a part of the great Indian desert, being located on the western margin of the land mass along the tropics (20° to 30°) coincides with the desert belt of the globe.

The tropical and sub-tropical deserts of the globe have come to exist due to climatic oscillations which took place after the retreat of the last phase of glaciation during the Pleistocene (Krishnan, 1952). It is a fact that Rajasthan continued to be moist till perhaps sub-recent times due to the lowering of temperature due to Ice Age and presence of the foredeep. It was later on when the Himalayas became a prominent feature in the north and the monsoon conditions established in India that the desertic conditions were accentuated. This dated back to 1,000 B.C. This is thus a consequence of the natural phenomena as it is associated in case of the origin of the major deserts of the globe.

The physiography of the Rajasthan desert possesses true desertic features. The Luni, which had its origin before the rise of the Himalayas, is the only river of the desert which has an outlet into the sea. All the other rivers are misfit, as they are lost in the desert lands or in the detritus brought by them during the period of short 'cloud burst' or die out soon due to alluvial suffocation. Their courses are short and they are essentially internal in character, having their independent basins and base levels to which they are lowering themselves. With such characteristics of desert streams, the landscape in a number of cases depicts this as the true arid zone. Sen (1962) has traced the progress of an arid cycle in sculpturing the land form in Siwana area of western Rajasthan. In Siwana and adjacent area, the topography is marked by steep sided residual mountains and hills on an extensive and very nearly level plain. The residual hills are very high to be monadnocks on a peneplane surface. The steep sides and abrupt transitions are the consequence of the process of geological weathering. The steep gradient persists to the bareness of every slope. This cannot be explained due to normal cycle. With a constant slope of the hill sides, it appears that nearly the level extensive plain is due to back wearing of the mountains rather than their wearing down. The back wearing has caused the 'slope retreat' of the hills which has resulted in the replacement of the hills by gently sloping piedmont formed progressively at the base of the back-worn slopes, diversified by isolated residual hills. The landscape has thus a characteristic resemblance with "inselberg" type — a topography essentially produced by mechanical weathering and wind erosion — an index of a true desert.

Along the hills of Siwana, Jalor, Barmer and Jodhpur, the mushroom form of the rock masses, hollows and caves being formed by intermittent attacks of wind driven sand; the highly weathered

1. Contribution from Central Arid Zone Research Institute, Jodhpur
2. Cartographer at the Institute.

and disintegrated rocks deposited at the lower reach of the drainage lines, consisting of flutting, channelling and breakways formed by localized wind actions are often marked. These topographic features are identical of the true desert topography of the globe.

Identical to all other dry deserts, the parts of Rajasthan desert consist of hills in Barmer, Jodhpur and Jaisalmer. Like the mountains of Kalahari, Nevada, Sahara and the middle east everywhere bare rock strike outs. Everywhere these are roughly pitted by wind action. At the base of the hills the wet weather torrents deposit their loads. Finally they merge into the sandy plains. Often the sand is heaped into dunes. Like other deserts, the lowest part of the desert plain contains either a 'salt lake' or 'dry lake' or 'playa'. The Pachbhadra salt lake, the ranns of Pokran, Thob and Sanwarla are good examples of dry salt lake and typical 'playas', particularly the last two ranns, in an arid landscape in the Central Luni River Basin and the adjacent areas.

The characteristics of the vegetation are also similar to other hot desert areas of the World. This consists of grasses and other small herbaceous species, which sprout quickly after the infrequent rains, remain green only for a few weeks, and then quickly wither and disappear. Like the other deserts, the plants are small in number but the number of species is large. Shanti Sarup (1952) has reported 500 species in the Indian desert. Like other deserts — two types of plants have been distinguished by Shanti Sarup (1952), namely, (1) those which depend upon the rain like *Aerva tomentosa, Euphorbia hirta, Cleome viscosa*, etc. and (2) those which depend upon sub-terranian water like *Calotropis procera, Tecomella undulata, Calligonum polygonoides* and *Salvadora persica*.

There are also historical and archaeological evidences to show that the Rajasthan desert is a true desert. The existence of the desert in ancient times has been referred even in the *Mahabharata*. It may be assumed then that in the early centuries A.D. when the *Mahabharata* was written, the desert was already in existence. From the archaeological evidence Prof. Sankalia (1952) concluded that a couple of centuries before the Christian era western Rajasthan was known as '*Maru desa*' or '*Sthala*' from which the name 'Marwad' has been derived. Similar conclusion has been arrived at by Ghose (1952) based on evidence collected from the Saraswati River Valley. These suggest that owing to several causes political, cultural, migration, trade and commerce, in spite of the desert conditions, Jodhpur was populated by foreign and Indian traders from the 5th and 6th century onwards. Almost in the desert and now sparsely inhabited, the Bikaner, Suratgarh, Anupgarh areas, could support during the protohistoric period (C. 3000-500 B.C.) a riverine civilization on the ancient Saraswati. Like the Sahara and Egypt, the Rajasthan desert might also possibly yield data of the Palaeolithic and later Stone Age cultures, if properly investigated.

From the human geographical or the anthropogeographical points of view also the Rajasthan desert possesses characteristics of a true desert. From earliest historical period, since the disappearance of the Harappa culture the people of this region became nomadic or semi-nomadic in character. The villages within the desert are not marked by any signs of fixed habitations. Their permanency depends on the supply of water in wells which in the heart of the desert is often brackish. As soon as the water becomes undrinkable, the village is deserted for a better site (Singh, 1952). Like the nomads or semi-nomads of the principal deserts of the globe, the wealth of the Raikas, Banjaras and other nomadic or semi-nomadic tribes of the Rajasthan desert are animals. In the true desert districts, Barmer has a density of 23 per sq. km, Jaisalmer, Bikaner, Jodhpur 39 persons per sq. km. In Ramgarh and Sam tehsils of Jaisalmer district the density of population is very low i.e. 1·30 and 1·36 persons per sq. km. The figures are comparable with that of Arabia where the population is less than 2 million, excluding the oasis of Yeman and Oman. Western Rajasthan including the oasis supports nearly 7 million people but the true desert belt of Jaisalmer, Bikaner, Barmer and Churu has a population of only 1,893,657 persons. The density is, however, more than Sahara or Australian deserts, the reasons for which lies not in less arid conditions but being patronized by the mediaeval rulers and kings even during the British period.

CAUSE OF THE ORIGIN OF THE DESERT

As already stated Rajasthan desert owes its origin due to the climatic oscillations which took place after the last phase of glaciation during the Pleistocene and caused the shifting and rearrangements of the wind belts and air masses of the globe resulting in the formation of middle and low latitude deserts (Krishnan, 1952). There are no evidences to show the uneconomic exploitation of resources and large scale deforestation during the end of Harappa culture and Saraswati Valley civilizations, which are often mentioned as the causes of the origin of this desert. It is probable that increased aridity might have caused the shifting and desiccation of the rivers that made the desert gradually uninhabitable. Other factors which contributed to the formation of the desert in Rajasthan are: (1) The tract is located on the leeward side of the Aravallis and, therefore, the precipitation is small; (2) It is located on the trade wind belt where air is moving equatorward causing warm and increased capacity to hold moisture which causes high evapo-transpiration loss resulting in aridity; (3) Internal location; cut off from the sea by the Aravallis and, therefore, the area has reduced precipitation; (4) Dry N.W. winds during winter months low in this tract. It is the centre of lowest pressure and high temperature during summer months; (5) It is also the centre of an enormous cyclonic system and its location is the hydrodynamic consequence of barrier presented to air flow by mountain system and high temperature (Banerji, 1952); and (6) Rise of the Himalayas and lowering of the Aravallis have changed the course of moisture bearing winds.

Banerji (1952) has stated that an " analysis of rainfall data of Rajasthan and adjoining areas for nearly 100 years show a tendency to decreasing rainfall in Rajasthan and towards the north and north-west ". This is, of course, not peculiar to Rajasthan desert but also of Kalahari, Asia and North America as elaborated by Banerji (1952) from Huntington and Schwarz's work. This increased aridity is partly due to over exploitation of resources like cutting down of the trees for timber, overgrazing etc., but mainly due to the rise of the Himalayas and lowering of the Aravallis in recent geological time which must have affected the temperature and rainfall distribution.

CHARACTERISTICS OF GEOGRAPHIC REGIONS OF THE DESERT

The Rajasthan desert lies in the N.E. to S.W. direction along the western flank of the Aravallis. From the geographic and the climatic point of view the Rajasthan desert can be divided into two broad regions, viz. (1) the hot or dry desert, receiving less than 300 mm of annual rainfall and (2) the steppe desert, the region receiving 300 to 500 mm of annual rainfall.

THE HOT OR DRY DESERT

This includes the districts of Jaisalmer, Bikaner, western Churu, Nagaur, S.W. Jalor and the greater parts of Jodhpur, Barmer and Ganganagar. From the Rann of Kutch in the south it extends northwards where the S.W. monsoon is not much felt. According to Heron (1938) the region was peneplaned during the Pleistocene or sub-Recent time. The relief increases from 50 m in the south to 350 m in the east, and 100 m in the west and south-west to 300 m in the east and north-east. Sand dunes, internal drainage and saline depressions are the reckoning features of the landscape. Along the western tract the concentration of the sand dune is highest, where 60 to 100 per cent of the land is covered by sandy hills. In the west the sand dunes are oriented in E.N.E.-W.S.W. direction. They are at right angles to the direction of S.W. monsoon winds. Later, aeolian agencies produced longitudinal valleys with intervening ridges left between them. The sand dunes form parallel ridges —the intervening valleys are often cultivated. Towards the east, the sand dunes are longitudinal, irregular with transverse ridges lying across them. Orientation is N-S and height never exceeds 100 m.

Salt content of the soil is generally high and towards the west the tract becomes sterile and desolate. Soil in the region is loose and sandy (Sen, 1961). In the rocky deserts, the soils have developed mature profiles on rhyolites or granites or sandstones at a lower depth. Soils are structureless and permeability is high. Cultivation is limited by climatic and root zone limitations.

In the dune country the soils depict no profile development. They are very deep and sandy. Sandy layers are often separated by *kankar* layers depicting wind deposition cycle. Soils have rapid drainage. Cultivation is limited due to low water table and climatic limitations. The analysis of a typical soil profile examined at Gadra Road nursery is given in Table 1.

In the depression of the salt lakes or ranns the soils are heavy. Cultivation is not possible due to impeded drainage and high degree of salinity in the basin. The following is the chemical analysis of a profile of a rann, on the way to Rann of Kutch from Sanchore. Below 8 cm the formation of a salt pan is evident.

TABLE 2: Characteristics of soil profile of a rann

Depth in cm	*$CaCO_3$*	*Organic carbon %*	*Moisture*	*pH*	*T.D.S. in p.p.m.*
0-8	1·176	0·329	11·25	7·8	22784·00
8-28	0·472	0·329	8·5	8·0	25600·00
28-51	3·84	0·165	8·5	8·3	14400·00
51+	8·66	0·165	10·95	8·4	11360·00

TABLE 1: Characteristics of soil profile at Gadra Road

Depth in cm	*pH*	*Coarse sand %*	*Fine sand %*	*Silt %*	*Clay %*	*$CaCO_3$*	*Organic carbon %*	*Water holding capacity*	*Moisture equivalent*
0-15	8·55	17·90	71·00	4·32	5·40	3·53	—	26·46	5·099
15-36	8·75	20·20	68·00	6·57	3·85	2·47	0·416	30·21	5·099
36-51	8·60	22·00	66·00	5·70	4·80	2·75	0·416	29·52	5·144
51-89	8·65	15·95	72·40	3·87	4·20	3·32	0·0312	29·02	5·301
89-124	8·65	18·55	68·70	3·67	4·57	4·74	0·0208	28·97	5·457
124-147	8·65	4·70	3·92	69·03	19·20	7·212	0·0416	29·71	5·876

In such a terrain diversified economic activities are not expected and human adaptation depends mostly on the local physical conditions and settlements are mostly controlled by the nearness of water table. Villages are in general scattered and in the west they are often 32 km apart. In favourable localities concentration of population is high having compact villages with an agglomerated pattern. Temporary villages of the semi-nomadic tribes are common in Jaisalmer, Barmer and Bikaner. During the adverse seasons people leave the villages and return during cultivation season or favourable period of the year. With the development of the means of communications, there is a tendency to concentrate along the roadsides, and roadside settlements are gradually springing up.

Agriculture is the main occupation, although the cultivated land is limited to less than 30 per cent of the total area. *Bajra* is the chief crop cultivated occupying more than 90 per cent of the total cultivated land. In Ganganagar, where canal irrigation is available to 16 per cent of the area, wheat occupies 38 per cent and *bajra* 39 per cent. Well is the chief source of water supply. In the whole area only one per cent of the total land is irrigated.

STEPPE DESERT

This belt lies along the western flank of the Aravallis in a N.E.-S.W. direction. The western and northern section is more sandy and dry and gradually merges in the sandy tract of the hot desert. This is clearly evident in Siwana tehsil.

The relief rises from 155 m in the west to 245 m in the east up to 460 m in the Aravallis. Heron's (1938) Pleistocene or sub-Recent peneplane is well evident in Pali and Jalor districts. Below the sand dunes of the lowest part of the peneplane lie the hills of Malani rhyolites and Jalor granites (La Touche, 1902). The isolated granite and rhyolitic hills on a nearly level surface of Siwana are analogous to the inselberg topography.

The sand dunes increase towards the west and north-east. In general, 20 to 40 per cent of the area is covered by sand dunes which are mostly of transverse type and fixed.

The Luni, ephemeral river, is the most important river system of the tract. Even in the Luni basin, internal drainage is common in Siwana and Jalor areas. Elsewhere internal drainage having local base levels, salt lakes are common. Water table increases towards the west reaching a depth of 243 m. In this part concentration of salt at a lower depth is also common.

On the true steppe, the soils are well drained and moderately shallow. Top soil is depositional in character. The sub-soil layers are impregnated with calcareous concretions which increase with depth. Cultivation is restricted due to climatic and root zone limitations. The analysis of a typical soil profile at Pali is given in Table 3.

In the hills and foothills areas the soil is very shallow, loose, structureless and highly eroded. The dune soils have the same characteristics as that of the hot desert.

On the Luni flood plain, the soils are light, structureless and deposited on *kankar* layers at a depth of 70 cm (Table 4).

On the rocky uplands of Bhinmal, Jalor and Pali the soil is well drained, moderately shallow and highly permeable. Below 25 cm lies the zone of *kankar* accumulation. Cultivation is restricted due to climatic and root zone limitations. The chemical analysis of a soil profile at Ramseen in the Jalor district is given in Table 5.

TABLE 3: Characteristics of soil profile at Pali

Depth in cm	*pH*	*Coarse sand %*	*Fine sand %*	*Silt %*	*Clay %*	*$CaCO_3$ %*	*Organic carbon %*	*Water holding capacity*	*Moisture equivalent*
0-15	8·15	35·50	25·57	14·75	20·05	0·607	0·305	28·80	124·00
15-38	8·35	24·84	20·20	16·78	29·45	7·282	0·436	47·99	15·820
38-61	8·40	24·25	14·25	10·65	19·95	26·82	0·366	48·55	16·310
61-91	8·25	No	Soil cover only concretions			29·60	—	—	—

TABLE 4: Characteristics of soil profile at Narta (Flood plain)

Depth in cm	*Coarse sand %*	*Fine sand %*	*Silt %*	*Clay %*	*$CaCO_3$ %*	*Organic carbon %*	*Moisture equivalent*	*pH*
0-30	46·8	44·9	1·1	6·80	0·68	0·137	2·60	8·7
30-61	42·0	48·2	3·6	0·72	0·72	0·46	3·05	8·7

TABLE 5: Characteristic of Ramseen soil profile

Depth in cm	*Coarse sand %*	*Fine sand %*	*Silt %*	*Clay %*	$CaCO_3$ %	*Organic carbon %*	*Moisture equivalent*	*pH*
0-8	50·5	28·4	4·9	12·7	1·50	0·2190	8·85	8·50
8-25	45·0	23·9	6·5	19·2	4·50	0·2562	12·10	8·55
25-56	39·4	9·8	7·2	21·6	21·10	0·3928	16·00	8·40
56-102+	40·1	8·5	10·6	17·4	23·54	0·3568	17·00	8·50

In all the 4 different soils, described above, *bajra* is the main crop produced. In Pali and Ajmer *Jowar* is also raised. Small scale irrigation, but often locally, is practised. On the whole 1 to 10 per cent of the land is irrigated and 50 per cent of the total land is cultivated.

Settlements, here too, are controlled by water table parallel to drainage lines, the villages are compact and largely concentrated road side linear villages are also common in Pali and Ajmer. The villages are better settled than the hot desert. The nomadic or semi-nomadic population is small.

CREEP OF THE DESERT

There is not enough data yet to say definitely if the desert is encroaching towards the east or north-east. From a comparison between the present S.O.I. topographical sheets and those prepared earlier

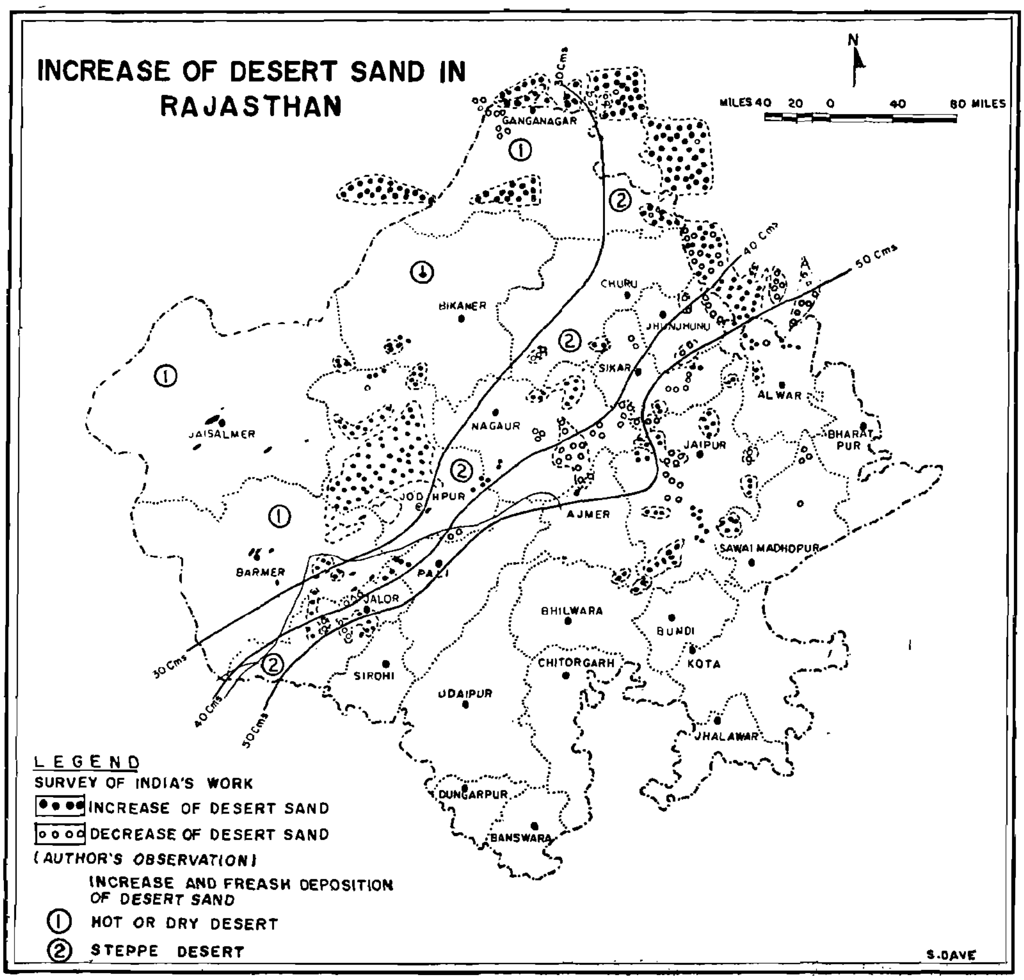

Fig. 1

about 60 to 70 years ago, Singh (1952) concluded that some spreading of the desert to the N.E. has taken place as it is evident in the S.O.I. sheets 44 K, 44 O and 53 C.

Studies conducted at this Institute clearly show that there is an increase of sand during the recent years in Rajasthan desert. A hill towards the N.E. of Barmer town (S.O.I. sheet 40 O) which has been reported in the S.O.I. map to be free of sand cover 30 years earlier, is now almost buried. Huge sand dunes are piling up against the hills. Fresh depositions and increase of desert sands are also evident in the Dhanpura hills, south of Jalor town, Mewa Nagar (all in S.O.I. sheet 45 C), and along the Jodhpur-Sheo road in 45 B. A sandy tract with small immature dunes towards the west of Jodhpur town (S.O.I. toposheets 45 F and 45 B) is also a recent addition of the topography as these high sand hummocks are not shown in corresponding S.O.I. sheets. The S.O.I. sheets published after 1935-36 show the location of dunes round about Mitha and Kharia ranns, near Jaisalmer town (40 I and 40 J) which were not shown in the sheets published earlier in 1926. These have also been confirmed in the field. Similar observations were also revealed towards the S.E. of Pokaran in 40 N. The accompanying map shows the areas where the desert sand has increased or decreased recently.

The observations reveal that: (1) fresh deposition is still going on; (2) the general trend of the increase is from S.W. to N.E.; (3) the creep of the desert is strong towards the west; i.e. in the hot desert than the steppe desert; (4) a number of breaks towards the N.E. along the Aravallis provide the exit for the wind blown sand towards the east.

SUMMARY

Geographically the Rajasthan desert is a true desert. Its geographical characteristics, appearance and origin are comparable to identical phases in other hot deserts of the globe. This desert can be divided into two geographic regions, namely, hot desert and steppe desert, each of which has distinct geographical characteristics. The creep of the desert is strong in the hot desert. Evidence from the S.O.I. toposheets and field observations confirm that increase of desert sand and fresh deposition is still going on more in the hot desert than in the steppe desert. Although with the lack of quantitative data, it cannot be definitely ascertained whether the desert is spreading or not, but the tendency of the increase of sand from the S.W. to N.E. is quite evident.

ACKNOWLEDGEMENT

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DISCUSSION

S. Pels: On what evidence is the geological age of Recent ascribed to the tectonic movements?

A. K. Sen: The sub-Recent peneplane is observed at about 1000 ft. on the west of the Aravalli range which tectonically forms the backbone of a great dome. The sand dunes of Rajasthan are accumulated on this peneplane. The isolated granitic hills of the Pali area are typical monadnocks on this peneplane surface. Two curves-hypographic and hypographoid-prepared also indicate a facet or erosional surface at this summit. The effect of the upheaval is evident in the faults of Jaisalmer and Palana, play of north South pressure in Kutch, rise, fall and change of the river beds and even the drying up of some of the rivers. The Rajputana shield is itself a zone of earthquake.

MAPPING OF ARID LANDS OF INDIA BY NATIONAL ATLAS ORGANIZATION[1]

by

S. P. CHATTERJEE[2]

THEMATIC MAPS

THE thematic maps of the arid and semi-arid lands of India are being brought out by the National Atlas Organization at the scale of one to one million. Three sets of such maps, depicting physical features, population distribution and transport network connecting places of tourist and other interest have either been printed or are in proofing stage. Each set comprises 3 plates designated as Delhi, Rajkot and Jaipur plates. Two other sets of maps at the same scale depicting land use and administrative units are under preparation. There will be another five sets at the scale of one to two million, depicting hydrology and pedology of this region together with neighbouring areas. The climatic and other features of this region will be shown on all India maps, drawn at smaller scales.

Study of plates reveal that these arid and semi-arid regions of India extend for 640 km from north-west to south-east with an average width of 300 km from west to east, covering over 175,000 sq km. It has a well-defined boundary on the east marked by the Aravalli range. More than one-half of the surface rises between 150 and 300 m. The eastern part of the region bordering the Aravalli range is designated as Rajasthan *Bagar*, which is less arid, less sandy and clothed with steppe vegetation unlike the desert proper which is named here as the *Marusthali*, that is, a region of moving sands and deficient rainfall.

MARUSTHALI

The Marusthali, which is young tropical desert with all its characteristic features, covers more than 100,000 sq km in India and extends to Pakistan in the west where sands, driven by the wind, are piled up in heaps and ridges or spread out in sheets, obliterating the pre-desert fluvial topography. The Pakistan portion of the desert is bordered on the west by the Nara river, once an active distributary of the Indus, and is styled as the 'little desert' (the 'Thar') in contrast to the 'great desert' on the Indian side (the 'Thal'), indicating that the desiccation of this area started from the east. The influence of the S.W. monsoonal wind is apparent in the orientation of sand dunes in 'Thar Parkar'. Long narrow sand ridges of seif type run parallel in a north-east-south-west direction, enclosing in between them dune lakes, styled as *dhands*. The Great Indian Desert falls into two broad sections: Jaisalmer desert in the north and Mallani desert in the south. Rocky plains, isolated flat-topped hills and vast sand hills diversify the topography of both the deserts. In the former, however, there is not a single water course which can flow all the way across it, the entire area being an interior drainage basin. But in the latter, the Luni and its tributary Sukri maintain their courses, though at times they are nothing but detached pools of salt water. Another difference lies in the fact that sand dunes appear to be moving all the time in the Jaisalmer desert, though slowly, about 5 m per year, whereas they appear to be more or less fixed in the Mallani desert. A detailed study of the northern Jaisalmer desert would reveal that around Jaisalmer town occurs a sandstone plain, chattani thal, intersected by dry short river valleys, dhrians, and covered with shattered rock chips. Immediately to the north of the sandstone plain occur a number of playa lakes, ranns, with centripetal drainage. Another rocky plain with rugged border lies near Pokran composed of boulders of Gondwana age. Small knolls of granite, undercut and polished by aeolian erosion are very characteristic. Stony surface is, however, overlain by moving sands in a greater part of Jaisalmer desert, and at least two distinctive types of landscape are met with: (i) the *tibba* land to the west and south of Jaisalmer town, and (ii) the *toba* land lying north of the town. The former consists of a complex system of sand dunes or *tibbas*. Longitudinal *tibbas* (seifs) predominate in this part, on which occasionally develop transverse *tibbas* of barchan type; and flat-floored depressions or pats occur sandwiched between two longitudinal tibbas. It is these parts that provide sites for verdant oases; their length and width appear to be very much restricted in areas of rapidly moving sands. The Mallani desert has one typical stony surface near Barmer surrounded by more or less fixed sand dunes of barchan type. Near Chohtan there are granite knolls, sculptured characteristically

1. Contribution from National Atlas Organization, Calcutta.
2. Director of the Organization.

by the wind. The Luni with its tributary Sukri has a wide flood plain strewn with conglomerates and built up a delta when the river was more active in the past.

The thals are sand covered plains, which are the most distinguishing feature. These are in places separated by relatively sand free plains like that of the Bap upland, or fringed by rocky eminences, locally called *bhakars*, such as Osian *bhakar*. In the Nok thal the sand dunes are of seif type, though here transverse to the direction of the prevailing wind. The seif chains are 16 to 32 km long, and attain basins (blowouts), the latter providing sites for rural settlements. The settlement pattern depends primarily on the width of the blowouts and the height and length of the barchans. The dispersed type of settlement near Bhimarlai is due to the presence of wide sand-free basins and short barchans which rise to the maximum height of 100 m above the ground level. Barmer stands on the eastern edge of a pediplain, carved out of Jurassic sandstone hills, and dotted with residual hills of bornhardt type. This town of about 20,000 population is the largest commercial centre in this part of Rajasthan, served by a railway and important arterial roads. To the east of the Luni, sand dunes seldom shift their position and have given rise to undulating surface which is clothed with fairly dense vegetation and dotted with no less than 250 settlements. The density of population is the highest in this part of the desert, being 24 per sq km.

The northern Jaisalmer desert is more desolate and is covered practically everywhere by shifting sand dunes, locally known as dhrians. West of Shahgarh the dhrians run in chains and are of very complex type. It is, however, only in the 'blowouts' of this desert that man could get some foothold. The number of such settlements of precarious existence also do not exceed 100. Their largest number is to be found in the Jaisalmer pediplain, the dry beds and banks of which could more easily be tapped for groundwater, and wherever the water supply is more or less assured settlements could spring up. To the north of Jaisalmer a number of playa lakes, designated as ranns occur in basins more or less rimmed by low scarps. These lakes though fed by centripetal drainage, remain dry for the greater part of the year, but their importance is mainly due to the fact that they yield salts. A number of settlements including Sri Mohangarh, the largest village with a population of over a thousand owe their existence to the salt deposits in these ranns.

Marwar arid plains and the *Marusthali* of Bikaner are regions of deficient rainfall, internal drainage and sand ridges. But the population map shows that man has succeeded in establishing himself even in the remoter parts of the region despite unfavourable environments. For example, Bap, Nokh, Bikampur, Girasar and many other settlements have sprung up and wells have been dug to a depth of 50 m or more even in the most difficult part of the desert to the north-east of Phalodi where rainfall is less than 250 m per year and chains of crescentic sand dunes cover up the ground to a height of over 30 m. Phalodi is a flourishing market town in this part of the desert, and its palaces and fine buildings with carved sandstone fronts around the fort and a vast reservoir of water indicate that man can even prosper in a desert environment by his ingenuity and indomitable courage. Rainfall somewhat increases eastwards, and nearer the Aravallis it ranges per year between 500 mm in the north and 650 mm in the south.

TABLE 1: Normal July temperature and dew point of Jodhpur and Bombay

Level	*Temperature* °A		*Dew point* °A		*Dew point Depression* °A	
	Jodhpur	*Bombay*	*Jodhpur*	*Bombay*	*Jodhpur*	*Bombay*
Surface	304·5	300·3	295	298	9	2
850 mb	296	291	291	290	5	1
700 mb	286	284	279	279	7	5
600 mb	278	278	271	274	7	4
500 mb	270	271	264	268	6	3
400 mb	261	261				
300 mb	248	248				
200 mb	227	227				
150 mb	215	213				
100 mb	209	206				

At 600 mb level Jodhpur and Bombay have the same temperature. At lower levels, Jodhpur temperature is progressively higher than that of Bombay. Between 600 mb and 200 mb levels, temperatures are almost the same level to level. Above 200 mb level once again Jodhpur temperature becomes higher than that of Bombay. The dew point depression over Jodhpur in the lower levels is more than that of Bombay showing that air over Jodhpur is drier.

During the southwest monsoon season, a low pressure area — the seasonal low — lies over Northwest India and parts of West Pakistan. The 25 cm annual isohyetal and the sea level monthly mean isobar (997 mb in July or 999 mb in August) run generally parallel. Although a low pressure area exists over the region still dry weather prevails. A low pressure area is considered favourable for the occurrence of weather. The absence of weather in this case is, therefore, a feature of considerable meteorological interest. To get an idea how rain producing processes are inhibited over this region, a study was made of the convergence/divergence of the air flow over here. Convergence/divergence was calculated for the month of July using the mean monthly upper wind data of stations in northwest India and adjoining parts. The resultant wind vector of July of the concerned level was resolved into zonal (u) and meridional (v) components. From isopleths of these the derivatives (du/dx and dv/dy) were calculated, and the convergence/divergence ($du/dx+dv/dy$) calculated. This was done for levels 0·6, 0·9, 2·1, 4·5, 6·0 and 9·0 km a.s.l. heights of 30 to 35 m. Their crest lines are sharp and serrated and have a collapsing front, which encloses tiny fragments of cultivated patches in their hollows, trending parallel to the sand ridges, and provide sites for temporary habitations, locally called *dhanis*. The entire area is dotted with lined and unlined wells indicated on the maps by little circles in blue, which contain brackish water. Within the Nok thal occur several flattish plains with a thin veneer of sand, which support open scrub and grass. Charanwala village stands on one such sand free plain, surrounded by sand dunes, and dotted with wells of brackish water. Near Bikampur dry shallow depressions of playa type trend northwest-southeast. Sand thins out towards east, and at Girjasar isolated, crescent shaped sand dunes prevail. The Bap upland is a typical desert peneplain, littered with a mosaic of pebbles, representing the coarse products of rock disintegration, the finer ones being winnowed away by wind outside the region. The coarser products are heaped up to a height of about 50 m forming stony wastes. The stony surface has also been scooped out by wind forming rock tanks, locally called *talao* or *sar*, which contain water during rains, making it possible for growing crops in the neighbourhood. The patches of green fields, open scrub and scattered trees are found interspersed with sterile stony flats in this region. The Bap upland faces on the east a shallow dry salt lake, locally designated rann, which gets flooded from July to September every year. There are working salt pans within this basin. To the east of the Bap upland thal three other thals where sand has become thinner resulting in the formation of parabolic sand dunes and sand levee, that is, flat topped parallel ridges without the collapsible fronts. The presence of disused canals in South Bikaner thal indicates that this area was much more agriculturally productive in the past.

RAJASTHAN BAGAR

To the west of the Aravalli range lies the steppe country of Rajasthan which covers above 75,000 sq km. The Luni divides it into two parts. To the north of the river sand dunes persist, though they appear to be undulating whale backs of sand, that is, of dead or non-mobile type in contrast to the living and mobile sand dunes of *Marusthali*. Hence this region of sand dunes has been designated as thali, a subdued form of thal. South Churu thali is full of such sand levees which can be best seen from the railway station of Panhara. Here short discontinuous sand levees strike northeast-southwest on a plateau, enclosing in between them little playas. The dispersed type of fairly dense settlements in this area indicates that the isolated sand hills do not much interfere with the normal agricultural pursuits of the local farmers. Moreover, wells are much shallower. Near this village a water-bearing layer occurs a little below the surface. Farther east in Shekhawati, sand thins out still further, and because of its nearness to the Aravalli range it receives water courses flowing down the western flank of the range. This is the rohi country with its green fields and prosperous villages. To the south of the Shekhawati rohi lie two large elongated playa lakes with high concentration of salts — Didwana and Sambhar, the former producing about half a million tonnes of salt per annum and the latter producing more than a million tonnes of salt. Two other smaller playa lakes near Khatu and Kuchaman also deserve mention. The Luni, the only river that traverses the whole of the Indian desert, has its upper reaches in *bagar* country. It rises in the Aravalli range near Ajmer and flows westwards, receiving most of its tributaries including the Sukri on its left bank, and its water becomes brackish on leaving Balotra. The southern half of the Rajasthan *bagar* forms a vast bolson, rimmed by flat-topped hills of sandstones and limestones of Vindhyan age in the north, called *bhakars* near Jodhpur, and granitic and rhyolitic hills on the south. These hills have been breached by the Luni and the Sukri-Jawai at both the eastern and western ends. The water gap carved on limestones between Kalu and Bilara indicates that the Luni has been superposed on its present topography. The upper slopes of the bolson especially in the north represent a predominant surface built on sandstones on which stands Jodhpur town, and lower down aggradational slopes of the type of *bajada* are met with especially on the left bank of the river. Residual low hills or inselbergs rise above the floor of the bolson near Pali, Chanod and Siwana. Mention may be made of a piedmont plain lying at the foot of the Aravalli and watered by innumerable short streams coming down the western flank of the range. This is the fertile Godwar Plain of Western Rajasthan.

POPULATION MAP

The plates depicting the population reveal the typical features of the distribution of population. The human settlements run either along short dry valleys (*wadis*) or located on pediplain and shallow basins near some deep well. There are a number of villages on the flood plains of the Luni, the only desert river that enters into the sea in years of normal rainfall.

It appears from the plates that the southern part of the *Marusthali* with Barmer as its nodal centre is not as sparsely populated as the northern part of Jaisalmer town as its focal point. The road that extends from Gadra Road Station to Phalsund may be taken as the dividing line between the northern Jaisalmer desert and the southern Barmer desert. The northern desert is characterized by the seif or longitudinal type of sand dunes, and the sand hills of the southern desert are of barchan or transverse type. In the Barmer region the barchans rise from 50 to 100 m above the ground level and hence they cannot be easily shifted by the wind. This accounts for its higher density of population, that is, 17 per sq km in contrast to 2 per sq km in Jaisalmer desert. The railway line that runs from Barmer to Bhimarlai and farther east traverses a number of such barchans interspersed with shallow and another favourable factor is the presence of a piedmont plain built up by innumerable short streams coming down from the hills. This accounts for the greater concentration of population in the foot-hill zone, especially in a triangular area bounded on the north and south by the Luni and Jawai-Sukri rivers respectively. There are several towns including Pali in this fertile agricultural pursuits. The Luni is the only river, which flowing through this part of Rajasthan can ultimately reach the sea, and several hundred of villages lying on either side of it, can have their water-supply either from the bed of the river or from shallow wells sunk in its flood-plains. Settlements have also sprung up around salt lakes and marble quarries. Didwana in the northeast and Pachpadra in the west are typical examples of salt lake towns; and Makrana is a well-known centre of marble quarries. Jodhpur, the largest town, occupies a central position on a rocky surface around a large ancient fort, about one-half of its population being dependent on service and professions for their livelihood. Isolated rocky hills, bare and unpopulated, are the conspicuous features of the landscape to the south of the Luni at the base of which are a number of villages receiving their water supply from hill streams during heavy downpours; and on the top of one such hill stands Abu (1,200 m) the only hill station in Rajasthan.

In the north are the deserts of Bikaner and *bagar* country of the Gang Canal area. Bikaner, one of the largest cities of the *Marusthali* is situated in a large and fertile thali. West of Bikaner in the Birisalpur thal there are vast stretches of sand dunes with deep water table accounting for very low density of population, not even one person per sq km. But up in the northern part of the desert area in Ganganagar district has already been reclaimed and brought under irrigation. Large number of new settlements have sprung up here amidst irrigated fields. A still larger part will be brought under plough when the Rajasthan Canal Scheme is completed which will turn this *bagar* area into one of the most fertile tracts of India.

TRANSPORT AND TOURISM MAP

The various plates reveal the salient features of the transport network. There are two national highways which run along or near its northern and western boundaries, but no national highway actually traverses the region. In fact the density of roads is proportional to the population density, and the nature of road somewhat reflects the physical features. It is true that Jaisalmer and Barmer are nodal towns, but roads radiating out from these towns westwards are mere foot-tracks and unmetalled roads. The towns in the eastern part of the regions, Bikaner and Jodhpur are better examples of nodal towns being served both by roads and railways. Except for Jaisalmer all other towns are served by railways. But the only railway that traverses the entire region from east to west lies in the south, running for some distance along the Middle Luni Valley. The Luni does not carry enough water to be of any use as a waterway. All the towns within the area that have some tourist importance have been located on map. The typical examples of such cities and towns are Ganganagar, Bikaner, Jodhpur, Jaisalmer, Barmer and Balotra. Sri Kolyatji has an ancient temple.

DISCUSSION

N. D. Rege : Is there any scheme for producing maps depicting crops grown, temperature, rainfall, etc., in graphical and pictorial forms ?

S. P. Chatterji : The National Book Trust is taking this up.

CLIMATIC FACTORS

SOME CLIMATOLOGICAL AND SYNOPTIC FEATURES OF THE ARID ZONES OF WEST RAJASTHAN

by

R. K. Datta & C. J. George

INTRODUCTION

The extreme western districts of Rajasthan are the arid zones of India. This forms the eastern edge of the extensive arid zones of the south-west Asia. Over this region of West Rajasthan, the annual rainfall is of the order of about 30 cm and 89 per cent of this rain falls during the south-west monsoon season. The number of rainy days is hardly 10 to 15 in a year; a station getting almost as much rain in a day as the average annual total rainfall is not uncommon. Thus almost the whole year round dry weather prevails over the region. From the available evaporimeter records, it is seen that there is a mean annual deficit here of the order of 300 cm due to evaporation. This deficit is a very vital factor to be taken into account in any development plan for the area. Climographs of Jodhpur and Jaipur representing the arid and semi-arid zones of India and that of Bombay representing the humid zones of India are shown in Fig. 1. The horizontal extent of the diagram is indicative of continental climate while the vertical extent that of monsoon climate. These diagrams bring out, in comparison, the special climatological features of the arid zones of India.

This paper consists of two parts; the first part, discussing some climatological features which are responsible for making the region arid and the second part the synoptic developments that lead to wet spells. On these wet spells depend to a large extent most of the agricultural, hydrological and other human activities in this region requiring water resources.

TEMPERATURE AND HUMIDITY

Normal temperature and dew point, based on evening ascents of Jodhpur and Bombay for July, a typical south-west monsoon month, are given in Table 1.

At 600 mb level Jodhpur and Bombay have the same temperature. At lower levels, Jodhpur temperature is progressively higher than that of Bombay. Between 600 mb and 200 mb levels, temperatures are almost the same level to level. Above 200 mb level once again Jodhpur temperature becomes higher than that of Bombay. The dew point depression over Jodhpur in the lower levels is more than that of Bombay showing that air over Jodhpur is drier.

Table 1: Normal July temperature and dew point

Level	*Temperature* °A		*Dew point* °A		*Dew point depression* °A	
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During the south-west monsoon season, a low pressure area — the seasonal low — lies over north-west India and parts of West Pakistan. The 25 cm annual isohyetal and the sea level monthly mean isobar (997 mb in July or 999 mb in August) run generally parallel. Although a low pressure area exists over the region still dry weather prevails. A low pressure area is considered favourable for the occurrence of weather. The absence of weather in this case is therefore a feature of considerable meteorological interest. To get an idea how rain producing processes are inhibited over this region, a study was made of the vergence field. Vergence was calculated for the month of July using the mean monthly upper wind data of stations in north-west India and adjoining parts. The resultant wind vector of July of the concerned level was resolved into zonal (u) and meridional (v) components. From isopleths of these the derivatives du/dx and dv/dy were calculated and the vergence $(du/dx + dv/dy)$ calculated. This was done for levels 0·6 km, 0·9 km, 2·1 km, 4·5 km, 6·0 km and 9·0 km a.s.l. Of these values at 0·6 km, 2·1 km, 4·5 km and 6 km a.s.l. are shown in Fig. 2. The data available are very limited and hence the values obtained may be taken to represent only the order of magnitude of the vergence. In the lower levels, it is seen that divergence generally prevails over

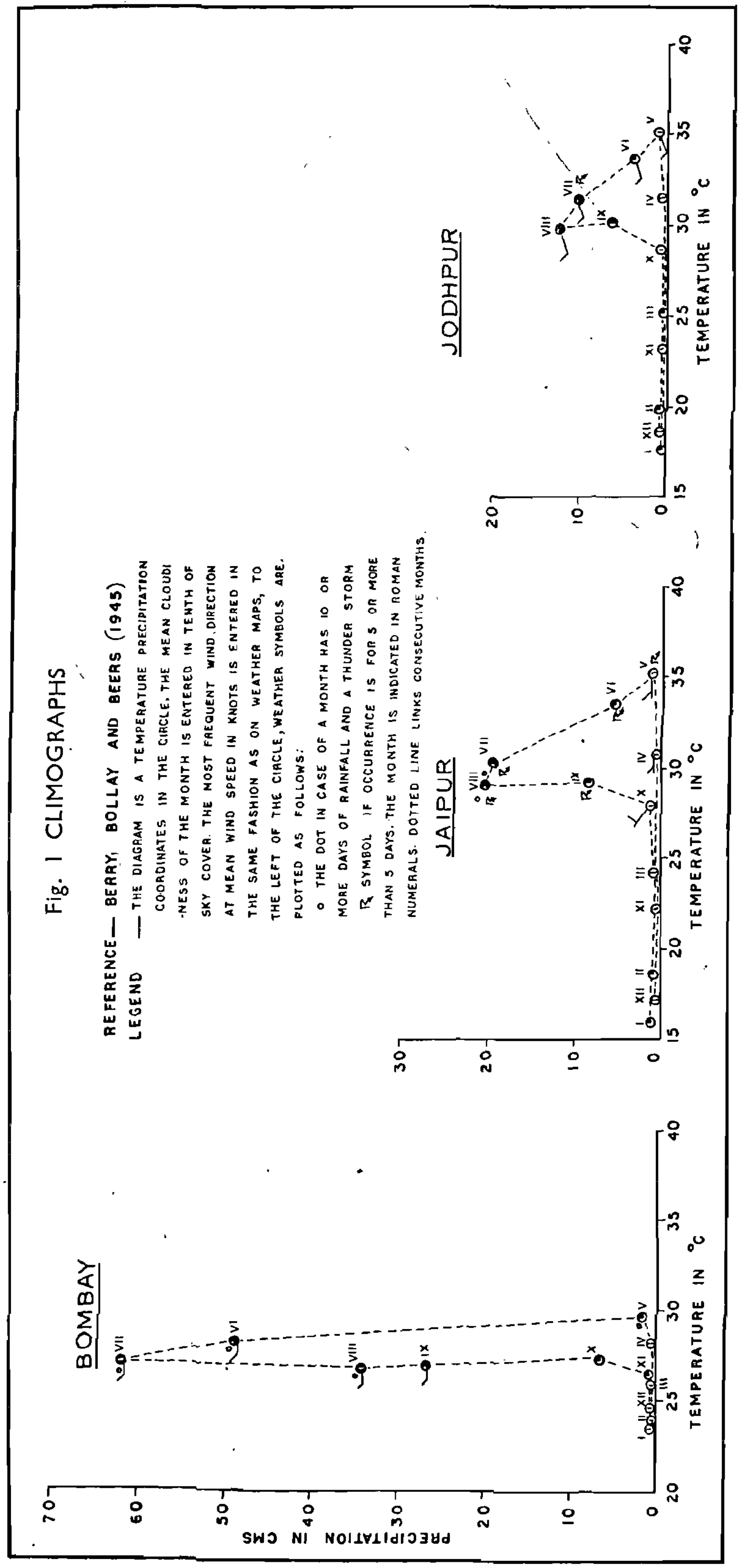


Fig. 1 CLIMOGRAPHS
REFERENCE— BERRY, BOLLAY AND BEERS (1945)
LEGEND — THE DIAGRAM IS A TEMPERATURE PRECIPITATION COORDINATES IN THE CIRCLE. THE MEAN CLOUDI-NESS OF THE MONTH IS ENTERED IN TENTH OF SKY COVER. THE MOST FREQUENT WIND DIRECTION AT MEAN WIND SPEED IN KNOTS IS ENTERED IN THE SAME FASHION AS ON WEATHER MAPS, TO THE LEFT OF THE CIRCLE, WEATHER SYMBOLS ARE PLOTTED AS FOLLOWS:
o THE DOT IN CASE OF A MONTH HAS 10 OR MORE DAYS OF RAINFALL AND A THUNDER STORM
R SYMBOL IF OCCURRENCE IS FOR 5 OR MORE THAN 5 DAYS. THE MONTH IS INDICATED IN ROMAN NUMERALS. DOTTED LINE LINKS CONSECUTIVE MONTHS.
BOMBAY
JAIPUR
JODHPUR
PRECIPITATION IN CMS
TEMPERATURE IN °C

FIG. 1

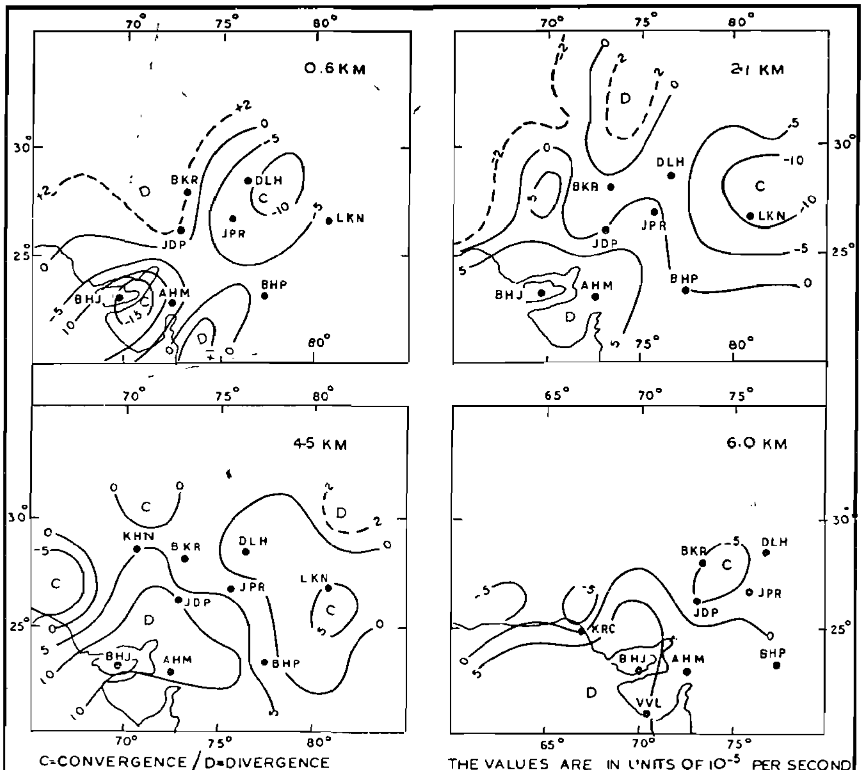


FIG. 2. NORMAL DIVERGENCE/CONVERGENCE FIELD IN THE MONTH OF JULY.

the western districts of Rajasthan while centres of convergence lie to its southwest and or north-west.

With a view to study the variation of vergence over Rajasthan, its values were calculated for two representative stations namely Jaipur (East Rajasthan) and Jodhpur (West Rajasthan). The values for the different levels shown in Fig. 3, bring out the following features:

(i) There is convergence over Jaipur and divergence over Jodhpur at the lowest level considered (0·6 km).

(ii) Convergence over Jaipur decreases with height and becomes zero at 2 km.

(iii) Divergence over Jodhpur decreases with height and becomes zero at 0·8 km. Above this height there is some convergence, which however decreases with height and becomes zero at 2 km.

(iv) Between 2 km and 5·7 km divergence exists both over Jodhpur and Jaipur. Divergence over Jodhpur is comparatively more prominent.

(v) Level of non-divergence over both the stations is at about 5·7 km.

The low level convergence over Jaipur indicates the prevalence of ascending air in the lower levels over the region, which is a situation favourable for weather to occur. Over Jodhpur, on the other hand, divergence predominates indicating that subsidence of air is taking place over this region and thus is unfavourable for weather to occur. This essential difference in the vergence pattern seems to be the main reason why the western districts of Rajasthan get less rainfall compared to the eastern districts. Subsidence over West Rajasthan also results in the air over the region becoming drier and warmer. The higher temperatures and larger dew point depression observed over Jodhpur (referred to in para 2) thus get accounted for.

SYNOPTIC DEVELOPMENTS

The synoptic charts for the periods when significant wet spells occurred over West Rajasthan during the monsoon seasons of 1961-63 were examined. Monsoon depressions/low pressure areas seemed to be the major synoptic development that

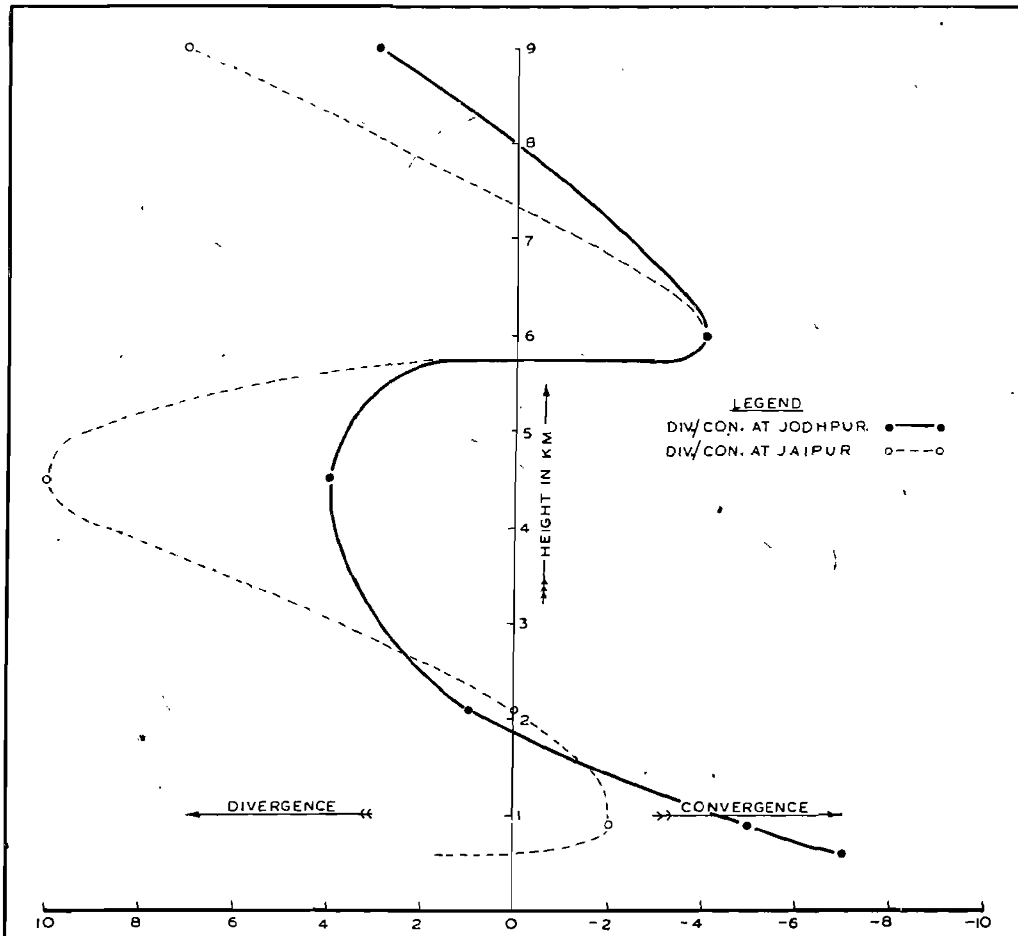


FIG.3 NORMAL CONVERGENCE/DIVERGENCE AT JODHPUR AND JAIPUR IN THE MONTH OF JULY

caused wet spells. These depressions or low pressure areas from the Bay of Bengal moving in a westerly to north-westerly track are seen causing rainfall over West Rajasthan from the time their centres are located near about 26°N and west of 77°E. The monsoon depressions or the low pressure areas associated with upper air cyclonic circulation which affected West Rajasthan, can be classified as follows: (i) those that moved across West Rajasthan; (ii) those that recurved east of Jodhpur, and (iii) those that weakened out just before reaching West Rajasthan.

From the point of causing rainfall over West Rajasthan the first type is the most effective.

FREQUENCY OF DEPRESSIONS MOVING ACROSS WEST RAJASTHAN

The India Meteorological Department publication (1964) gives the tracks of depressions for the period 1891-1960. During this 70 years period, in the month of June there were only two depressions which moved across West Rajasthan. In July there were 10 such depressions. It is of interest to note that in some decades in July there were as many as 4 such depressions which moved across West Rajasthan while in others there were none as indicated below:

1891-1900	4 depressions
1901-1910	Nil
1911-1920	Nil
1921-1930	4 depressions
1931-1940	Nil
1941-1950	2 depressions
1951-1960	Nil

In August and September there were 4 and 8 such depressions respectively. Thus in all there were 24 depressions that moved over the West

Rajasthan in the monsoon season during the period of 70 years. Out of these, 14 depressions moved across West Rajasthan following the normal west to north-westerly track. The remaining 10 depressions, mostly in the month of September, recurved and then moved over West Rajasthan, a typical track of this type observed in the year 1909 is shown in Fig. 4. Broadly speaking, in the latter case after recurvature the system moved fast as is also seen from the track (Fig. 4) and thus affected the area only for a very short period.

During the period mentioned above, there was only one depression from the Arabian Sea that moved across West Rajasthan. This was in September 1947.

DEPRESSION OF SEPTEMBER 1961

During the week ending 13th September 1961, rainfall over West Rajasthan was 688 per cent above normal. Details of the synoptic development that caused this wet-spell over West Rajasthan are discussed below.

A low pressure area formed on 5th September 1961 over the head of Bay of Bengal and adjoining land areas. This concentrated into a deep depression by next day with centre near Kharagpur. Moving in a general west-north-westerly direction the deep depression lay between Pendra and Umaria on 8th and east-south-east of Ajmer on 11th. The track of the depression is shown in Fig. 4. This depression followed a track different from the normal in its later stage. A similar track was also observed in September 1958, shown in Fig. 4.

The sea level isobars of 00 GMT on 11th September, 1961 when the depression lay over Rajasthan are shown in Fig. 5. The cyclonic circulation associated with this pressure system was well-marked and extended upto 500 mb. The vergence field computed in the manner detailed in para 3 for the level 1·5 and 3·0 km a.s.l. at 00 GMT on 11th September, 1961 is shown in Fig. 6. The change in the lower levels from the normal field is very striking. The normal low level divergence observed over Jodhpur has been replaced by marked-convergence.

In the upper level (200 mb), the flow over the depression was anticyclonic. Thus the air converging in the lower levels in the field of the depression ascended, and in the higher levels diverged out in the anticyclonic flow. The low level convergence was thus realized, resulting in the appreciably above normal rainfall over the region.

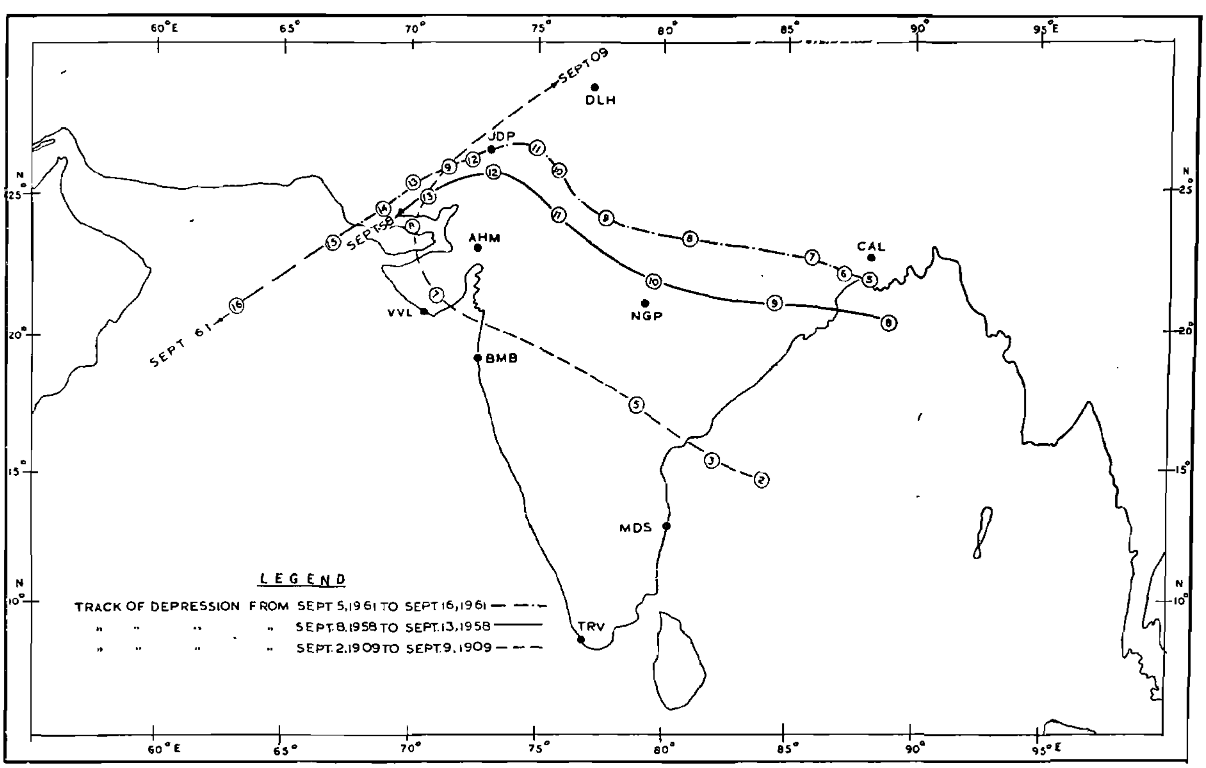


FIG.4 TRACKS OF DEPRESSION

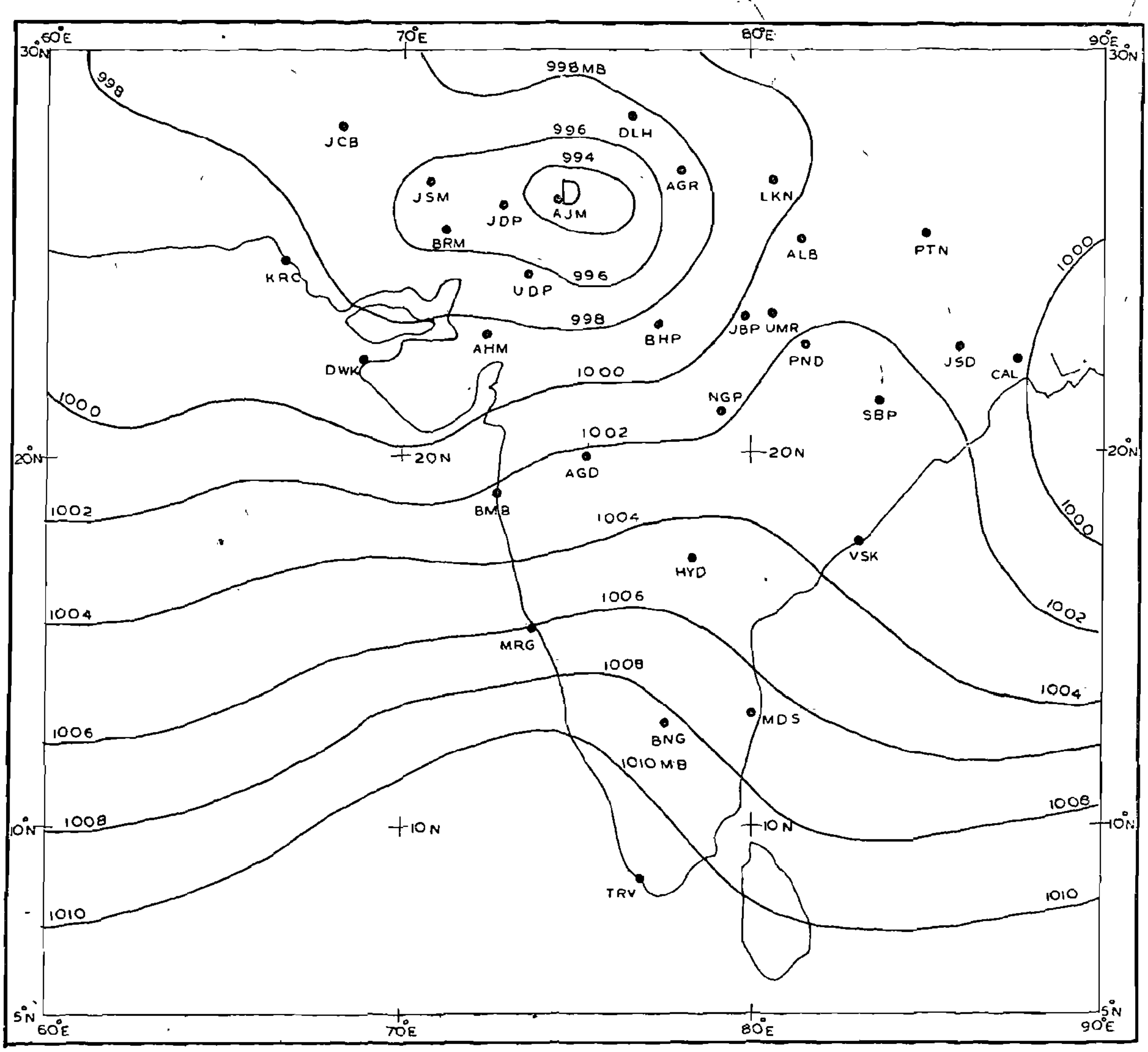
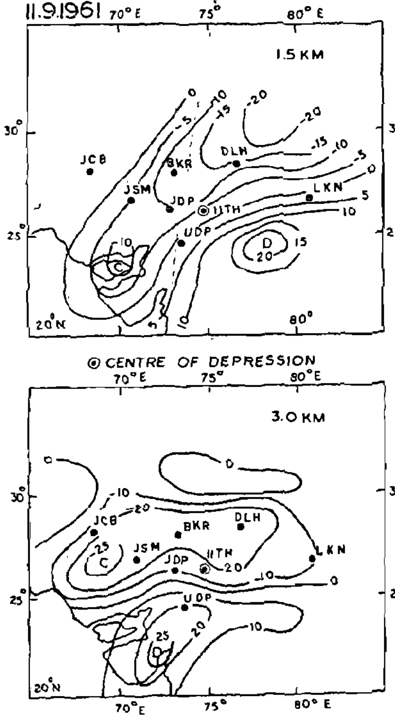


FIG.5. SEA LEVEL ISOBARS OF 00 GMT ON 11.9.1961

FIG.6. DIVERGENCE/CONVERGENCE FIELD AT 00 GMT ON 11.9.1961



C=CONVERGENCE D=DIVERGENCE
THE VALUES ARE IN THE UNITS OF 10^{-5} PER SECOND

CONCLUSION

In the south-west monsoon season, normally divergence prevails over West Rajasthan in the lower levels of the troposphere. As a consequence, there is general subsidence of air over the region resulting in warmer and drier air, and absence of precipitation in spite of the seasonal sea level low pressure area over and near the region. When monsoon depressions affect the region, the normal low level tropospheric divergence gets replaced by intense convergence. This, under favourable upper tropospheric flow, causes significant rainfall to occur over West Rajasthan.

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DISCUSSION

S. P. Chatterji : What have the depressions to do with the wet spells ?

P. Jagannathan : The significant wet spells over Rajasthan are usually associated with monsoon depressions and low pressure areas.

A NEW CLIMATIC INDEX AND ITS APPLICATION TO SUB-CLASSIFICATION OF ARID ZONES[1]

by

N. C. Majumdar

Classification of climates into various climatic types has long engaged the attention of climatologists, but little success seems to have been achieved so far in formulating a general scheme which would meet the requirements of all concerned. Apart from the agricultural meteorologist, we have the bio-climatologist the clothing scientist, the logistic planner, the designer of service equipment, the military planner, the nutrition chemist, the industrialist, and so on, who are all interested in climatic classification, though for different reasons. Study of climates in relation to deterioration of material has also assumed a role of major importance. Generalization is made extremely difficult by such a wide diversity of the requirements which, however, do overlap over a considerable area, and it is in this area that we can hope for a fair measure of success.

Since the early efforts of Koppen, a large number of formulae have been proposed from time to time by various investigators (Dzerdzeevskii, 1958) to characterize the climatic features of regions all over the world in a more or less quantitative manner. The approach has been essentially in relation to plant and forest ecology. Thornthwaite's system of classification (1948) based on a critical study of the moisture balance of the soil in relation to various meteorological parameters, is generally regarded as the most rational approach. He introduced the term " Potential Evapo-transpiration " (P.E.) defined (Subrahmanyam, 1956) as the total amount of water that would evaporate and transpire if it were always available for full use. His simplified expression for the computation of P.E. requires a knowledge of mean monthly temperature and precipitation together with the latitude of the place. For the purpose of classification of climatic types, he evolved an empirical formula defining a " moisture index " I_m as the dimensionless ratio

$$\frac{100\,s-60\,d}{n}$$

where s = surplus moisture in soil in the humid season; d = lack of moisture in the dry season; and n = necessary quantity of moisture for the plant, and is taken to be equal to the P.E.

Computational procedure involved in the evaluation of I_m is rather elaborate, which some what restricts its practical usefulness. Several other limitations are:

(i) The climatic scale in terms of I_m is not linear, being highly compressed for the arid type (I_m -60 to -40), and progressively spreading out towards the humid type (I_m 20 to 100). No upper limit has been prescribed for the perhumid type, which may very well approach 1000, as in the case of Cherrapunji. Thus I_m for the entire dry climates from the dry subhumid to the arid types, lies in the range 0 to -50 as compared to the range 0 to about 1000 for the entire moist climates varying from the moist subhumid to the perhumid types.

(ii) The index does not appear to reflect the proper radiation balance and the prevailing atmospheric humidity and wind, all of which have important effects on the potential evapotranspiration. It is well known that, for the same latitude, insolation and radiation exchange with the surroundings are relatively high in desert areas as well as at high altitudes. The expression for P.E. may require suitable modification in these respects.

In the light of the foregoing considerations, climatological study of arid zones in terms of Thornthwaite's " moisture index " presents obvious difficulties. It is important not only to be able to define the boundaries of arid zones with reasonable precision, but also to grade them in terms of relative degrees of aridity. The climatic scale with I_m, having low sensitivity in the arid zone, is not suitable for the purpose. It was therefore considered worthwhile to attempt a fresh approach to the problem from a general standpoint and not exclusively from the point of view of the agricultural meteorologist.

A NEW CLIMATIC INDEX

Studies undertaken at the Defence Laboratory, Jodhpur resulted in the development of a new climatic index, which we propose to name as the

1. Contribution from Meteorology & Climatology, Defence Laboratory, Jodhpur.

"DLJ Dryness Index" and designate as I_d. The main object of the work has been to achieve linearity of the climatic scale, equally sensitive to all climatic types. The details of the development have been presented in an earlier paper (Thronthwaite, 1948), but the method will be briefly outlined here for ready reference and to enable other workers in the field to follow the line of reasoning.

Although a satisfactory scheme of climatic classification should reflect the combined effect of the major climatic elements, it is hardly feasible to incorporate these elements individually in any formula meant for practical use. But nature has provided us with a simple and reliable composite climatic factor in the form of the "diurnal range of temperatures" which seems to combine the effects of the major climatic parameters in a reasonably satisfactory manner. Typical arid regions are characterized by a large diurnal range of temperatures. The humidity is low, and radiation exchange with the surroundings is high. This, together with clear sky and bare ground almost without vegetation, result in high insolation during day time followed by rapid cooling during night. At the other extreme, the climatic elements of highly humid regions are invariably opposite to those prevailing in the deserts, resulting in a relatively small diurnal range of temperatures. A strong negative correlation (Majumdar and Sharma 1964) has been found to exist between the annual average of the diurnal range of temperatures (D) and the average annual precipitation (R), with respect to 150 non-coastal stations in India and neighbourhood. Coastal stations, in the presence of vast surfaces of water, naturally tend to have a high humidity and hence a low diurnal range even in the absence of rains. It thus appears that the diurnal range of temperatures, regarded as a composite climatic factor, is comparable in importance to the single element of precipitation, and it should therefore be possible to express the overall climatic feature of any place in a fairly quantitative manner, in terms of two simple parameters D and R.

The proposed climatic index, I_d, was developed on the basis of the following assumptions:

(1) I_d is in the nature of a dryness index, in contrast with Thornthwaite's moisture index, I_m so that I_d is positive for all dry climates and negative for all moist climates, its value increasing algebraically with increasing dryness.

(2) Change in I_d is proportional to the fractional changes in D and R, and not to their actual changes.

(3) D and R are equally important in their control over I_d.

The second assumption is obvious on physical grounds and ensures linearity of the climatic scale, while the third assumption follows as a first approximation from the foregoing discussion.

The first two assumption can be mathematically expressed in the differential form

$$\partial I_d = a.\frac{\partial D}{D} - b.\frac{\partial R}{R} \qquad \dots (1)$$

the zero value of I_d corresponding to transition from moist to dry climate. a and b are positive constants, the negative sign with b implying that dryness increases with decreasing precipitation.

According to the third assumption $a = b$, whence equation (1) becomes

$$\partial I_d = a\left(\frac{\partial D}{D} - \frac{\partial R}{R}\right)$$

Integration leads to

$$I_d = a \log D/R + k \qquad \dots (2)$$

Now let D_0/R_0 be the value of the ratio D/R when $I_d = 0$. Then we must have

$$0 = a \log D_0/R_0 + k \qquad \dots (3)$$

From equations (2) and (3) we obtain

$$I_d = a \log\left(\frac{D/R}{D_0/R_0}\right) \qquad \dots (4)$$

Equation (4) defines the *DLJ* Dryness Index, I_d, as proportional to the logarithm of the dimensionless ratio

$$\frac{D/R}{D_0/R_0}$$

The constant a is also dimensionless, and its value depends only on the arbitrary choice of the size of the unit of I_d. Constancy of the ratio implies constancy of the climatic index.

In our proposed scheme of classification as indicated in Table 1, we have followed the terminology of Thornthwaite (1948), but extended its scope to enable sub-classification of arid and perhumid climates.

TABLE 1: Tentative scheme for classification of climates in terms of DLJ Dryness index, I_d

Climatic type		*Range of I_d*
	Extreme	+71 to +90
Arid	Moderate	+51 to +70
	Mild	+31 to +50
Semi-arid		+11 to +30
	Dry	0 to 10
Sub-humid	Moist	−1 to −10
Humid		−11 to −30
Per-humid	Moderate	−31 to −50
	Extreme	−51 to −70

Constants of Eq. (4) were evaluated on the basis of the generally accepted boundary between semi-arid and arid zones in western India, and also that between the sub-humid and humid zones near the West Bengal-East Pakistan border. The equation in its final form is

$$I_d = 56 \log_{10} \frac{120D}{R} \quad \dots (5)$$

in which D and R are expressed in °C and mm respectively. With the help of this equation, a simple nomogram as presented in Fig. 1, has been prepared for quick evaluation of I_d, thereby avoiding tedious computational work.

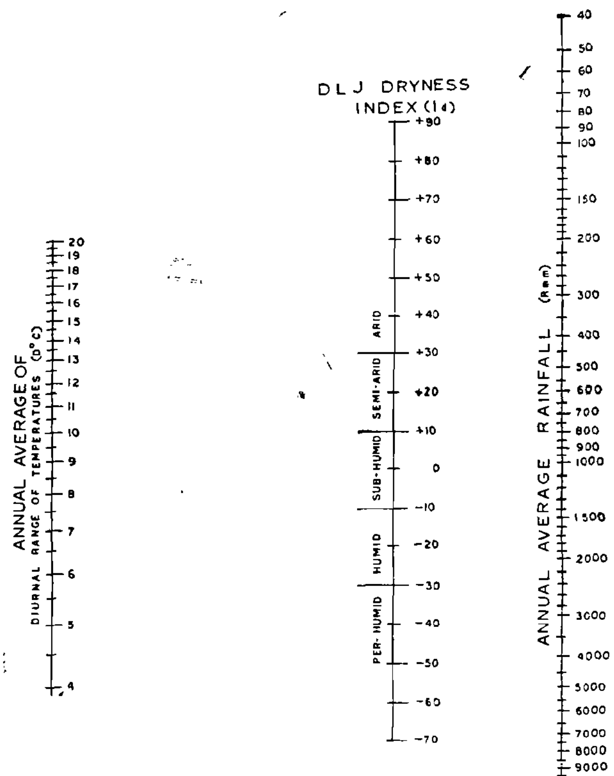

FIG. 1 NOMOGRAM FOR EVALUATION OF CLIMATIC INDEX IN RELATION TO CLIMATIC TYPES

182 stations in India and neighbourhood have been classified according to the proposed scheme with the help of the nomogram, and a climatic map prepared (Majumdar and Sharma, 1964).

The promising features of the new climatic index are: (i) reasonable linearity of the climatic scale, (ii) adequate sensitivity of the climatic scale in the arid zone, to enable its sub-classification, (iii) a fair representation of the combined effect of the major climatic elements, and (iv) simplicity of the method of evaluation.

Comparison between I_d and I_m. Subrahmanyam (1956) presented the I_m values of 30 stations, computed according to the method of Thornthwaite. The I_d values for the same stations have been computed with the help of the nomogram in Fig. 1 and graphically compared against the corresponding I_m values in Fig. 2. The figure clearly demonstrates the non-linearity of the moisture index scale. Considering that the two climatic indices are based on entirely different approaches, the figure indicates a reasonably good correlation between them, except for the four high-altitude stations, which require a closer study. Possible reasons for such discrepancy have been discussed earlier, which lend support to the contention that the effect of altitude has not been taken into account in Thornthwaite's classification.

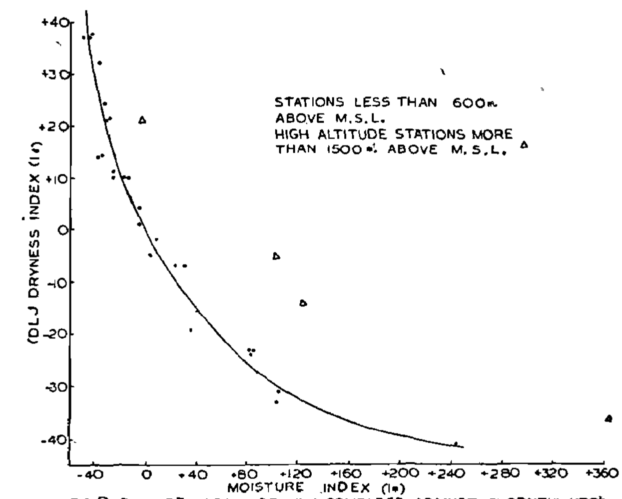

FIG. 2 DLJ DRYNESS INDEX (I_d) COMPARED AGAINST THORNTHWAITE'S MOISTURE INDEX (I_m) WITH RESPECT TO 30 STATIONS IN INDIA AND NEIGHBOURHOOD.

Arid zones of India and neighbourhood — The DLJ Dryness index, I_d, has been used to sub-classify 44 stations in arid regions of India and neighbourhood. The results are presented in Table 2.

It will be seen from Table 2 that among the stations studied, Leh in Ladakh ($I_d = 72$) is the only station in India which is on the border line between extreme aridity and moderate aridity. The rest of the Indian stations are only mildly arid, Sriganganagar heading the list with $I_d = 49$. Agricultural wealth of the region might be entirely due to canal irrigation.

Almost whole of West Pakistan is moderately arid, Jacobabad being a border line case ($I_d = 73$). Nokkundi and Dalbandin in Baluchistan, and Zahidan and Seistan in Iran are extremely arid. The results demonstrate a rapid increase in aridity from Western Rajasthan, across West Pakistan towards further west. It may be worthwhile to undertake a more detailed study of the arid regions in terms of the new climatic index I_d.

TABLE 2: Sub-classification of 44 stations in arid regions of India and neighbourhood, in terms of I_d

Sl. No.	*Station*	I_d	*Climatic type*	*Sl. No.*	*Station*	I_d	*Climatic type*
1	Nokkundi	86	Arid (Extreme)	23	Dera Ismail Khan	49	Arid (Mild)
2	Seistan	84	,,	24	Sriganangar	49	,,
3	Zahidan	82	,,	25	Meshed	48	,,
4	Dalbandin	76	,,	26	Montgomery	47	,,
5	Jacobabad	73	,,	27	Badin	46	,,
6	Leh	72	,,	28	Muscat	45	,,
7	Sukkur	70	Arid (Moderate)	29	Ormara	44	,,
8	Ispahan	67	,,	30	Wana	44	,,
9	Panjgur	66	,,	31	Fort Sandeman	44	,,
10	Sibi	65	,,	32	Bannu	43	,,
11	Bahawalpur	62	,,	33	Kargil	43	,,
12	Kalat	61	,,	34	Lyallpur	42	,,
13	Shar Jah	61	,,	35	Kabul	41	,,
14	Khanpur	60	,,	36	Barmer	40	,,
15	Gilgit	56	,,	37	Bikaner	40	,,
16	Charbar	56	,,	38	Jodhpur	37	,,
17	Multan	54	,,	39	Peshawar	37	,,
18	Hyderabad (Sind)	53	,,	40	Miranshah	36	,,
19	Chaman	50	Arid (mild)	41	Khushab	36	,,
20	Quetta	50	,,	42	Bhuj	36	,,
21	Jask	50	,,	43	Hissar	34	,,
22	Pasni	50	,,	44	Lahore	32	,,

CONCLUSIONS

The present study is exploratory in nature, and as such is neither exhaustive nor conclusive. Its principal object has been to demonstrate how it is possible to achieve linearity of the climatic scale as, for example, in a thermometer for which a change of one degree always means the same thing whatever may be the range under consideration. The DLJ Dryness Index, as the new climatic index has been named, offers ample scope for further improvement and refinement, such as by taking seasonal variations into consideration on the basis of monthly data. This index together with a knowledge of ambient temperature may give a more complete picture of the climatic conditions, such as for Jacobabad and Leh, both having the same degree of aridity.

In conclusion, it may be emphasized again that the "diurnal range of ambient temperatures" as a composite climatic factor, deserves further critical study for a more complete assessment of its merits.

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DISCUSSION

P. Jagannathan: Several climatic classifications have been proposed. Most of them are empirical. How far does the author's method achieve the purpose ?

N. C. Majumdar: The scale of aridity has proved more uniform as against Thornthwaite's aridity index. Nomograms have been derived with which the index can be computed easily.

ENERGY FROM THE SUN IN RAJASTHAN[1]

by

P. JAGANNATHAN & H. R. GANESHAN

INTRODUCTION

SUN is the ultimate source of all energy on the Earth. Estimates of solar radiation received at the earth's surface have practical applications in the field of applied climatology and hydrology. Such estimates have immediate utility in the energy balance method for estimating heat and vapour transport at Snow, Water, Soil or Plant surfaces. Actual records of solar radiation are extremely scanty. It is only from about 1957 that regular observations of solar radiation were started at a few stations in India. In Rajasthan solar radiation observations were started at Jodhpur in March 1960.

Estimates of solar radiation income has naturally to take recourse to other considerations. It has along been known that a relation exists between the radiation received at the earth's surface and the duration of sunshine. The earth receives heat energy not only from the direct sun beams but also from the short wave radiation scattered by the air and the constituents of the atmosphere. This diffused radiation is a significant fraction of the total radiation received. Angstrom (1928) has estimated from observations at Stockholm that with overcast skies, the incoming short wave radiation is on the average a quarter of that received on a cloudless day. His empirical formula for the total incoming short wave radiation is

$$Q = Q_o\left(0{\cdot}235 + 0{\cdot}765\frac{n}{N}\right) \qquad \ldots (1)$$

where Q is the total actual short wave radiation,
Q_o is the total radiation on a clear day,
n is the actual duration of sunshine,
N is the possible duration of sunshine.

Russell *et al.* (1954) present an empirical graphical method of converting observed values of sunshine as percentage of possible hours into estimates of insolation.

The position regarding data of sunshine is neither very satisfactory. Observations of duration of sunshine with sunshine recorders are not available except for a few stations even in the whole of India and barely two from Rajasthan. Only Jodhpur and Jaipur are having the instruments. Thus for estimating solar radiation with a fair degree of accuracy some reliable estimates of sunshine became a necessary prerequisite.

ESTIMATION OF SUNSHINE — THEORETICAL CONSIDERATIONS

The approximate estimation of the average daily duration of sunshine can be made from an idea of the amount of clouding responsible for cutting off the sunshine. We assume that the conditions along the path of the sun are random samples valid for the entire visible sky. If the fraction of the arc length of the sun's path that is caused by clouds is C, the length of the rest of the path is $1-C$. If H is the duration from sunrise to sunset, the number of hours of realizable sunshine is

$$S = H(1-C) \qquad \ldots (2)$$

If N is the fraction of the sky covered, we assume that expectation $E(C) = N$ so that (2) reduces for expectation of S

$$E(S) = H(1-N) \qquad \ldots (3)$$

In reality the above hypothesis is not applicable for individual days but for an average day within a period of at least a month. Conrad & Pollak (1950) have shown that the monthly values derived on the above hypothesis differ by less than 10 per cent of the actual.

It may be mentioned that in practice an unknown fraction of the cloud is too thin to obstruct the sun. Further the sun at low elevation is too weak to make a record. If h is the fraction of the duration between the sunrise and sunset during which the sun is within say 5° of the horizon, the loss can be expressed as ϵh. Thus the estimate of S from (1) above can be improved by putting

$$S = H(1-C)(1+\delta C)(1-\epsilon h)$$

Since S and ϵ are small, to a first degree of approximation we have,

$$S = H(1-C)(1+\delta C-\epsilon h) \qquad \ldots (4)$$

If actual values of S and C are available, δ and ϵ can be obtained by the method of least squares. Thus a fairly reliable estimate, though approximate of the average duration of sunshine can be made from the mean values of clouding.

1. Contribution from Meteorological Office, Poona 5.

SOURCE OF DATA

Observations of cloudiness are available for all the climatological stations in India which number about 300. In the 'Climatic Tables of Observatories in India'— India Meteorological Department (1953) average amounts of all clouds and low clouds in tenths of sky covered are given month by month for the two principal hours viz. 0830 and 1730 hours I.S.T. These are average amount of 'all cloud' have been utilized in the first instance for the estimation of the average daily duration of sunshine. For all the stations the possible duration of sunshine H during the twelve months have been calculated as well as the mean cloud amount. As fraction of sky $N = (N^1 + N^{11})/20$ where N^1 and N^{11} are the average amounts in tenths of sky of all clouds at 0800 and 1700 hrs I.S.T. The duration of sunshine is calculated from equation (3).

ESTIMATION OF ANOMALIES

It may be stated that the duration of sunshine thus calculated will be subjected to another source of error further to those already mentioned in section 2·1 in as much as the mean cloud amount is determined from the 2 observations viz. at 0800 and 1700 hours I.S.T. only. If N is greater than the mean of the day time clouding the duration of sunshine will be underestimated; while if N is less than the mean the duration will be over-estimated.

To determine the extent of the error introduced on account of the various sources of errors, the values calculated by the above formula in respect of the stations for which sunshine records are available in I.M.D. India Weather Review, Annual Summaries are compared with the actual mean sunshine recorded and the anomalies $\epsilon = (S$ actual-S calculated) are charted out for all the twelve months. Isoanomals are drawn and anomalies for the rest of the stations picked out from these charts and applied to the values calculated. The corrected values of S is given by the formula

$$S^1 = H(1-N)+\epsilon \qquad \dots (5)$$

have been utilized in the foregoing analysis. The monthly duration of sunshine in respect of the Rajasthan stations* are given in Table 1.

SUNSHINE OVER RAJASTHAN

Barmer and Bikaner have the largest duration of sunshine of about $9\frac{1}{2}$ hr on the average in the year and Kotah the least with 7·8 hr. During the year April and May and in some places June are the sunniest. The sunshine is least during the height of Monsoon with Mount Abu having barely $2\frac{1}{2}$ hr in the day each in July and August. Even during the height of the monsoon Ganganagar and Bikaner enjoy nearly 9 hr of sunshine. Ganganagar has the least sunshine of the year in January with 7 hr in the day. The lower sunshine during the winter season December to February at this station is due to passage of western disturbances which cause considerable clouding in the North Western parts of the country.

SEASONAL VARIATION OF SUNSHINE

The seasonal variation of sunshine can be adequately represented by the first two terms of the Fourier series starting with the fundamental period of 12 months.

$$S_t = \bar{S} + \alpha_1 \sin\left(\frac{2\pi}{p}t + \varphi_1\right) + \alpha_2 t \sin\left(\frac{2\pi}{p}t + \varphi_2\right) \qquad \dots (6)$$

where S is the mean annual sunshine, α_1, α_2 are the annual and semiannual amplitudes, φ_1 and φ_2 are the phase angles of the two oscillations, P the period viz. 12 months. Table II gives the parameters representing the seasonal variation. The two harmonic terms account for nearly 90 per cent of the annual variation.

* The authors have prepared as described above monthly charts of sunshine for the whole of India, Pakistan, Burmah and Ceylon. The full paper dealing with entire data will be published elsewhere.

TABLE 1: Mean daily duration of sunshine in Rajasthan

Station	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
Barmer	9·0	9·5	10·0	11·5	11·0	10·4	6·8	6·8	9·7	10·0	9·8	8·9	9·5
Bikaner	8·3	9·3	9·4	11·4	9·6	9·3	8·0	8·8	10·0	9·8	9·5	8·6	9·4
Ganganagar	6·9	8·9	9·3	9·8	10·0	10·1	9·0	9·3	9·7	9·7	9·2	7·9	8·8
Jaipur	8·6	9·1	9·7	9·9	10·1	7·7	4·6	4·7	7·4	10·1	9·9	9·0	8·4
Ajmer	8·5	10·2	8·9	9·8	8·9	8·2	4·8	5·1	8·2	9·6	9·2	8·5	8·3
Mount Abu	9·4	9·6	10·0	10·8	11·0	7·5	2·5	2·8	6·8	9·8	10·5	9·0	8·3
Jodhpur	8·7	9·5	9·0	10·0	9·2	9·7	6·7	5·9	8·5	9·8	9·9	9·0	8·1
Kotah	8·7	9·1	8·9	9·5	8·9	6·6	4·5	4·4	7·2	9·0	8·9	7·4	7·8

TABLE 2: Parameters representing seasonal variation of sunshine

Station	Annual oscillation				Half yearly oscillation		
	S	α_1	ϕ_1	Date of maximum	α_2	ϕ_2	Date* of maximum
Barmer	9·5	0·94	29°39′	15 March	1·48	250°46′	24 April
Bikaner	9·4	0·36	10°16′	5 April	0·98	280°09′	10 April
Ganganagar	8·8	0·86	74°47′	1 Feb.	0·77	270°00′	16 April
Jaipur	8·9	1·77	70°36′	4 Feb.	1·88	243°34′	28 April
Ajmer	8·3	1·54	70°43′	4 Feb.	1·32	261°45′	19 April
Mount Abu	8·3	2·82	66°04′	9 Feb.	2·57	240°22′	30 April
Jodhpur	8·1	0·93	66°56′	8 Feb.	1·18	233°04′	4 May
Kotah	7·8	1·76	68°13′	7 Feb.	1·45	261°50′	20 April

*The second maximum occurs 6 months later.

It is seen that the half-yearly wave is as prominent as the annual wave. The annual wave has an amplitude of $1\frac{1}{2}$ to 2 hr in East Rajasthan with Mount Abu having as much as 2·8 hr, while West Rajasthan has less than one hour. The maximum in the oscillation occurs early in February except in the arid sector where it is delayed to the middle of March or early April. The half-yearly amplitude is $1\frac{1}{2}$ to 2 hr practically over the whole area except in the extreme Northwest where it is less than 1 hour; the maximum in the oscillation occurs towards late April or early May and late October or early November.

ESTIMATION OF SOLAR RADIATION

The amount of solar radiation reaching unit area of any part of the earth's surface at any time depends upon (i) the sun's capacity to radiate, (ii) the transparency of the earth's atmosphere and (iii) the angle of incidence which is determined by the latitude of the place, the time of the year and the time of the day. No simple formula will summarize these effects. In the absence of the atmosphere, the total energy delivered per unit area on the earth's surface in the course of the day is

$$Q' = \int_{(SR)}^{(SS)} S \cos \theta \frac{r_m^2}{r^2} dt = \frac{24}{\pi} \frac{r_m^2}{r^2} S \sin \varphi \sin d (H\text{-}\tan H) \qquad \dots (7)$$

where

r_m — means distance of the Sun from earth
r — distance of Sun from earth
S — Solar constant
H — Hour angle between sunrise and sunset $= -\tan \varphi \tan \delta$
φ — latitude
δ — solar declination

Because of the presence of the atmosphere, the depletion of the energy in the solar beam is greater at high latitudes, where due to large zenith angle, its path through the atmosphere is longest. For this reason the region of maximum insolation, which in the absence of the atmosphere would be located near the Poles in summer, is shifted to about 30° latitude.

The monthly values of solar radiation for Jodhpur was calculated using Angstrom's relationship (1928), the values of n were taken from Table 1. N the possible hours of sunshine have been calculated for the appropriate latitude of Jodhpur. Smithsonian Meteorological Tables, List (1951) provides tables for daily direct radiation reaching the ground with various atmospheric transmission coefficients for some specific dates of the year. The values of Q_0 for the middle of the different months have been interpolated from this table for the different values of the transmission coefficient $a = 0{\cdot}6$, $0{\cdot}7$, $0{\cdot}8$ and $0{\cdot}9$. Then diffuse sky radiation reaching the horizontal surface has been computed as indicated by list as $\frac{1}{2}(0{\cdot}91Q - Q_0)$. The calculated values of Q^* — the total radiation which is the sum of direct and sky radiations along with the mean daily total short wave radiation recorded with the Moll-Gorczynski Solarimeter in use at Jodhpur during the period March 1960 to September 1963 are given in Table 3. It will be seen that the values calculated on the basis of $a = 0{\cdot}9$ fairly agree with those actually observed and hence an atmospheric transmission coefficient of 0·9 appears to be appropriate for Jodhpur for the whole of the year. Using this value $a = 0{\cdot}9$, the total inclining radiation for all stations have been calculated and given in Table 4.

SEASONAL AND SPATIAL DISTRIBUTION OF SOLAR ENERGY

While considering distribution of solar radiation during four seasons i.e.

(i) December-February   Winter Season

*The calculated values are given only for a = 0·8 and 0·9.

TABLE 3: Mean daily total short-wave radiation received at Jodhpur and those calculated for different atmospheric transmission coefficients

	Gm Cals. per square centimeter											
	Jan.	*Feb.*	*Mar.*	*Apl.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
Actual (1960-1964)	411	479	557	630	653	620	499	475	511	505	430	381
Calculated a = 0·8	357	441	494	573	586	606	501	461	504	477	400	341
a = 0·9	396	483	535	624	621	650	619	492	545	523	447	389
Actual-calculated for a = 0·9	−14	4	−22	−6	−32	30	120	17	34	18	17	8

TABLE 4: Total short-wave radiation (Sun+Sky) received at the surface gm Cal cm^{-2} day^{-1} Rajasthan

Station	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
Barmer	395	482	583	698	690	656	494	484	580	513	448	380	533
Bikaner	353	480	545	683	622	612	549	569	583	497	415	348	521
Ganganagar	296	432	528	596	634	635	600	593	557	478	388	307	504
Jaipur	360	445	555	610	641	544	394	393	469	510	429	354	475
Ajmer	377	508	537	618	591	557	403	407	516	496	429	361	483
Mount Abu	411	487	588	669	687	532	298	306	454	513	473	382	483
Jodhpur	384	482	543	629	610	625	488	449	532	509	455	384	507
Kotah	390	474	537	606	589	489	390	384	475	482	421	335	464

(ii) March-June	Hot Weather Season
(iii) July-September	Southwest Monsoon Season
(iv) October and November	Postmonsoon Season

It is seen that the intensity of radiation is least in the winter season and highest in the hot weather season. The figures bring out clearly the areas of high and low intensities, the manner and gradient of variation over the area in the different seasons.

ENERGY AVAILABLE IN RAJASTHAN

The total solar energy available during the different seasons over the whole area of Rajasthan has been calculated by weighting the mean intensity between two isopleths with the planimetric area comprised within and integrating for the whole area of Rajasthan comprising of $3,41,712 \times 10^{10}$ sq. cm. The energy available over the whole of Rajasthan in Kilowatt hours are given in Table 5.

TABLE 5: Solar energy in Rajasthan—Seasonwise

Season	*Intensity per day Gm.Cal Cm^{-2} day^{-1}*	*Total energy Billion Kw-hours*
December-February	394	3,380
March-June	601	6,989
July-September	472	4,139
October-November	462	2,686
Annual	—	17,194

It may be seen that the solar radiant energy available in Rajasthan is equivalent of about **17,194** billion kW hours.

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DISCUSSION

M. L. Khanna : How far the estimated values of solar radiation tally with these given by Dr. Ramdas, in his paper in "Wind and Solar Energy". Dr. Yellot's solar radiation recorder is available in the market and could be used as a secondary standard. How many stations in India are at present making measurements of actual solar radiation ?

N. C. Majumdar : How far fixed hour observations during the day could be regarded as random samples with respect to cloudiness ?

V. P. Subrahmanyam : The use of an H-type thermistor borometer, which is not only satisfactory but even very cheap for recording intensity and duration of solar radiation for radiation surveys in and around Rajasthan is suggested.

P. Jagannathan : Dr. Ramdas estimated solar radiation from 22 stations in the whole of India for which sunshine data were available using Angstrom's empirical formula, while the authors have utilized besides all the available sunshine data, data of cloudiness recorded at over 250 stations in India. As such the maps of seasonal radiation presented are much more realistic. The observations of solar radiation are at present being recorded at about a dozen stations in the whole of India.

WET SPELLS IN RAJASTHAN[1]

by

P. JAGANNATHAN & V. K. RAGHAVENDRA

INTRODUCTION

ARIDITY signifies deficiency of moisture to support vegetation. Arid lands are characterized as much by the variability of climate as by the lack of water.

On the average West Rajasthan receives about 30 cm of rain in the year and East Rajasthan about 70 cm of which 90 per cent falls during the monsoon season. The number of rainy days in the year is less than 5 at some stations in Jaisalmer district increasing to 25 towards the Aravalli hills and thence to over 45 in East Rajasthan. In 1917 the monsoon rainfall of West Rajasthan was 119 per cent above normal and the very next year the same area received barely 22 per cent of the normal rainfall. Several stations in Rajasthan have recorded on a number of occasions very heavy rainfalls. Instances are on record when nearly 50 cm of rain has fallen in a single day. In 1944 there have been as many as 90 instances of over 12·5 cm of rainfall in a day at some station or other in Rajasthan during July and August. Jaipur has once recorded as much as 5 cm in a single hour and Jodhpur 4 cm. These show clearly that the total rainfall is made up of a few heavy falls. Heavy and very heavy rainfalls are generally associated with the movement of depressions and once rains start in association with depressions, very often they continue for a few days.

Every year is more or less exceptional. In arid and semi-arid regions, where the rainfall is scanty and highly unreliable, proper utilization of the available water is most important. The highly variable character of the little precipitation that falls poses further problems to the agriculturist and the irrigation engineer. An idea of the probability of length of wet spells of different duration during the growing season of agricultural crops are most important for agricultural operations.

FREQUENCY OF WET SPELLS

In the foregoing we shall study the characteristics of wet spells at four representative stations, Jaisalmer and Bikaner representing the arid western region and Jaipur and Kotah the semi-arid eastern region. Here we shall treat a day as 'wet-day' if there has been at least 0·3 mm of rainfall. It may be mentioned that spells considered here are continuity of wet days and not continuous rain during the entire spell.

Table 1 gives the frequency of wet spells of 1, 2, 3, etc. days duration during the monsoon season June to September based on the data for the 50 years 1901-1950. In Jaisalmer the longest wet spell was of 6 days duration while in Jaipur on one occasion rainfall has been experienced on 18 continuous days. It may be seen that in West Rajasthan 90 per cent of the total wet spells have duration upto 3 days while in East Rajasthan wet spells upto 3 days account for 75 per cent only, while another 15 per cent are of longer duration between 4 and 6 days.

The probability of a wet day p the probability that a wet day follows a wet day p_1 and the

TABLE 1: Frequency of wet spells during the period 1901-1950

Length of spells in days	*Stations*			
	Jaisalmer	*Bikaner*	*Kotah*	*Jaipur*
1	246	359	312	359
2	82	132	161	155
3	34	48	112	94
4	9	32	73	72
5	9	10	35	35
6	4	5	24	30
7		2	14	27
8		2	11	10
9		0	6	8
10		0	6	7
11		1	6	7
12			7	1
13			3	3
14			2	4
15			2	0
16			0	0
17			1	2
18				1
Total no. of spells	484	591	775	815
Total wet days	617	1016	2145	2241
Probability of a wet day (p)	0·1011	0·1665	0·3516	0·3674
Probability of a wet day following a wet day (p_1)	0·3776	0·4183	0·6357	0·6363
Probability of a wet day following 2 wet days (p_2)	0·4077	0·4541	0·6620	0·6802

1. Contribution from Meteorological Department, Poona 5.

probability that a wet day follows 2 wet days p_2 are also given in the table.

STUDY OF PERSISTENCY

If the rainfall has occurred purely by chance we can easily calculate the frequencies of runs of different duration of wet days. If p is the probability that a day was a 'wet day' and $(q = 1-p)$ the complementary probability that the day was not a 'wet day', the frequency f_r of an r wet-day spell during N monsoons each of length m days is given by

$$f_r = N[2p^r q + q^2 p^r(m-r-1)]$$

In the above we have assumed that the probability of a wet day remains same and not affected by the fact that the previous day was wet or not. However, if there is some persistence and if p_1 is the probability of a wet day following a wet day and this probability remains constant after the second day, frequency f_r of wet-spell runs of 2 days, 3 days etc., are given by

$$p_1 f_1,\ p_1^2 f_1 \text{ etc.}$$

where f_1 is the frequency of 1 day spells. Similarly we can calculate the frequencies when persistence of greater orders exist. In Table 2 are shown the actual frequencies of wet spell during the 50 years period along with the frequencies calculated on the hypothesis of (i) chance occurrences, (ii) 1 day persistence, (iii) 2 day persistence.

It is seen that the frequencies calculated on the basis of chance occurrence are in very wide variance with the actuals, indicating thereby that the occurrence of rain on any day is not random but is guided by the fact that the previous day was wet or not. The frequencies calculated on the basis of the probability a wet day following a wet day, and a wet day following two wet days agree better with the actual frequencies. The x^2 for testing the goodness of fit is also given below the table. It is seen that the x^2 in respect of p_1 and p_2 are not significant for the West Rajasthan stations showing that the fit are good. However, in East Rajasthan the fit in respect of p_2 appears to be good as seen from the low insignificant value of x^2 while the fit in respect of p_1 is not good.

Frequencies calculated on the basis of (1) p_1 constant and (2) p_2 constant show that there is a tendency for persistence upto 2 days at least in West Rajasthan and at least 3 days in East Rajasthan.

p_1 the probability that a wet day follows a wet day is greater than p the probability of a wet day, indicating that once rain has occurred the chance of the next day being wet is more than for chance occurrence. Similarly, p_2 the probability of a wet day following 2 wet days is also greater than p, and also p_1 even though in the later case the difference is not considerable.

CALCULATION OF PROBABILITY OF SPELLS OF DIFFERENT DURATION

If we plot the frequency f_r of spells against the duration r, the length of spell, we get a curve which is a rapidly dying; the rapidity being more in the case of West Rajasthan stations and slightly less in the case of East Rajasthan stations. This shape suggests that the values can be represented by the successive terms of the series given by

$$f_r = \alpha \frac{x}{r} \qquad \dots (1)$$

where α and x are parameters representing the frequency distribution.

The parameters can be easily calculated as follows.

$$x = \Sigma r f_r / [\Sigma r f_r + \alpha] \qquad \dots (2)$$

and

$$\alpha = \Sigma f_r / \log_e (1-x) \qquad \dots (3)$$

For complete details of solving these equations the reader may refer Williams (1947).

It is easily seen that the parameter x is a function of the average number of days per wet spell.

Average No. of days per wet spell

$$= \frac{\Sigma r f_r}{\Sigma f_r} = \frac{x}{(1-x)(-\log_e \overline{1-x})} \qquad \dots (4)$$

The parameter α is a function of the total number of wet days as well as the number of wet spells.

These curves have been fitted to the total frequency of wet spells obtained during the period 1901-1950. The representative parameters for these four stations are given in Table 3.

The goodness of the fit was tested by the X^2 test. The X^2 was not significant at 5 per cent level of significance indicating that the fit is good. Therefore the distribution of the wet spells in any period is described satisfactorily by the 2 parameters of α and x. This model for the frequency distribution can be used to calculate the probability for any desired length of wet spell.

DEPENDENCE OF LENGTH OF SPELLS ON SUNSPOT CHARACTERISTICS

In this section we shall study whether the parameters of the frequency distribution of wet spell duration have any bearing on the solar activity. The parameters have been calculated.

(i) For the years in which sunspot numbers were maximum and for the years when the sunspot numbers were minimum and respective parameters compared.

(ii) For the years during which sunspot numbers were increasing and for the year when the sunspot numbers were decreasing and the respective parameters compared.

TABLE 2: Actual and calculated frequencies of wet spells on hypothesis of chance occurrence and with P_1 constant and P_2 constant

Length of spells in days	*Jaisalmer*				*Bikaner*				*Kotah*				*Jaipur*			
	Actual	*Calculated on hypothesis*			*Actual*	*Calculated on hypothesis*			*Actual*	*Calculated on hypothesis*			*Actual*	*Calculated on hypothesis*		
		Chance occur-rence (p)	P_1 *cons-tant*	P_2 *cons-tant*		*Chance occur-rence* (p)	P_1 *cons-tant*	P_2 *cons-tant*		*Chance occur-rence* (p)	P_1 *cons-tant*	P_2 *cons-tant*		*Chance occur-rence* (p)	P_1 *cons-tant*	P_2 *cons-tant*
1	246	499	(246)	(246)	359	548	(359)	(359)	312	910	(312)	(312)	359	905	(359)	(359)
2	82	50·4	92·8	(82)	132	90·7	150·2	(132)	161	320	199·3	(161)	155	332·6	228·4	(155)
3	34	5·1	35·0	33·7	48	15·0	62·8	63·6	112	112·5	127·3	106·0	94	122·2	145·3	105·4
4	9	0·5	13·2	13·8	32	25	26·3	30·6	73	39·5	81·3	70·6	72	44·9	92·5	71·7
5	9	0·05	5·0	5·7	10	0·4	11·0	14·7	35	13·9	51·9	46·7	35	16·5	58·9	48·8
6	4	0·005	1·9	2·3	5	0·1	4·6	7·1	24	4·9	33·1	30·9	30	6·1	37·5	33·2
7					2	0·01	1·9	3·4	14	1·7	21·1	20·5	27	2·2	23·9	22·6
8					2	<0·01	0·8	1·6	11	0·6	13·5	13·6	10	0·8	15·2	15·4
9					0	do	0·3	0·8	6	0·2	8·6	9·0	8	0·3	9·7	10·5
10					0	do	0·1	0·4	6	0·07	5·5	5·9	7	0·1	6·2	7·1
11					1	do	0·1	0·2	6	0·03	3·5	3·9	7	0·04	3·9	4·8
12									7	0·01	2·2	2·6	1	0·01	2·5	3·3
13									3	<0·01	1·4	1·7	3	<0·01	1·6	2·2
14									2	do	0·9	1·1	4	do	1·0	1·5
15									2	do	0·6	0·7	0	do	0·6	1·0
16									0	do	0·4	0·5	0	do	0·4	0·7
17									1	do	0·2	0·3	2	do	0·3	0·5
18													1	do	0·2	0·3
X^2			8·02	4·80			7·65	6·33			37·86*	17·39			64·36*	11·16
df			(4)	(3)			5	5			10	10			10	10

TABLE 3: Parameters α and x for wet spell frequencies

Station	α	x
Jaisalmer	491	0·56
Bikaner	649	0·61
Jaipur	547	0·80
Kotah	514	0·80

The following years data have been pooled for this purpose:

Sunspot Maximum: 1905, 06, 07, 17, 18, 19, 27, 28, 29, 37, 38, 39, 47, 48, 49 — 15 years

Sunspot Minimum : 1901, 02, 11, 12, 13, 22, 23, 24, 32, 33, 34, 42, 43, 44 — 14 years

Sunspot increasing: 1901-04, 13-16, 23-27, 33-36, 44-46 — 20 years

Sunspot decreasing: 1905-12, 17-22, 28-32, 37-43, 47-50 — 30 years

(A) Sunspot maxima versus Sunspot minima: The parameters are given in Table 4.

TABLE 4: Parameters for different stations

Station	*Parameter for average frequency per year*			
	Sunspot minimum		*Sunspot Maximum*	
	α	x	α	x
Jaisalmer	13·3	0·499	8·9	0·564
Bikaner	19·7	0·514	9·8	0·658
Kotah	12·1	0·790	10·5	0·798
Jaipur	10·5	0·795	10·8	0·795

The fit of the curve was tested by X^2 and found to be good. It is seen that in West Rajasthan the value of α during sunspot minimum is about twice the value for Sunspot maximum indicating that frequencies fall off more rapidly during Sunspot minimum than during Sunspot maximum. Further the x shows an increase from Sunspot minimum to Sunspot maximum in West Rajasthan indicating that here the average number of days per wet spells are small during Sunspot minimum than during Sunspot maximum.

The variation of the value of α and x calculated for the 4 stations during the two epochs has been tested by the 'analysis of variance' and the results given below.

TABLE 5: Analysis of variance

Source of variance	*Degrees of freedom*	*Sum of squares*	*Mean square*	*Variance ratio F*
Parameter α				
Stations	3	19·17	6·39	1·39
Sunspot No.	1	32·00	32·00	6·99*
Residual	7	32·05	4·58	—
TOTAL	11	83·22	7·57	—
Parameter x				
Stations	3	0·114128	0·038043	40·2**
Sunspot No.	1	0·005886	0·005886	6·2*
Residual	7	0·006626	0·009466	—
TOTAL	11	0·126640	0·011513	—

*Significant at 5% level. **Significant at 1% level also.

It is seen that the difference in α and x between the two epochs was significant at 5% level. Further the variation in x from station to station is significant at 1 per cent level indicating that this parameter depends considerably upon the location.

(B) Sunspots increasing versus Sunspots decreasing: The parameters are given in Table 6.

TABLE 6: The parameters for different stations

Station	*Parameters for the average frequency/year*			
	Sunspot increasing		*Sunspot decreasing*	
	α	x	α	x
Jaisalmer	9·8	0·556	9·8	0·559
Bikaner	15·1	0·575	11·0	0·652
Kotah	12·0	0·791	10·3	0·812
Jaipur	12·1	0·786	10·3	0·805

The fit of the curve was tested by X^2 and found to be good.

The analysis of variance was done for α and x separately and the results are given below in Table 7.

TABLE 7: Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance ratio F
Parameters α				
Stations	3	10·69	3·56	5·84*
Sunspot No.	1	7·22	7·22	11·83*
Residual	7	4·25	0·61	—
TOTAL	11	22·16	2·01	—
Parameter x				
Stations	3	0·093910	0·031303	61·4**
Sunspot No.	1	0·001800	0·001800	3·53
Residual	7	0·003570	0·000510	—
TOTAL	11	0·097280	0·008844	—

*Significant at 5% level. **Significant at 1% level also.

It is seen that the variation due to the epochs sunspot increasing or decreasing, is significant only in case of α while that due to the stations are significant in both parameters α and x.

The analysis brings out the important fact that the duration of wet spells in the arid and semi-arid regions of Rajasthan are related to sunspot characteristics.

ACKNOWLEDGEMENTS

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DISCUSSION

C. P. Bhimaya: In Rajasthan people say that wet years occur once in two years, 3 years, etc. The occurrence of such wet years is of importance for afforestation works as Central Arid Zone Research Institute has found that in all years of normal rainfall the seeding is as successful as transplanting and if the programme can be correlated to such years lot of success and saving can be achieved in afforestation.

P. Jagannathan: A discussion of the time interval between successive occurrences of specified rainfall anomalies — excess or deficiency — has been given in the paper. Besides, the wet spell characteristics associated with sunspot cycle have been given. A complete power spectrum analysis of the after time series would be necessary to indicate all the periodicities.

CLIMATIC ENVIRONMENT AND ITS FLUCTUATIONS IN RAJASTHAN[1]

by

P. JAGANNATHAN

CLIMATIC HISTORY OF RAJASTHAN

PLAEOCLLMATOLOGICAL studies have revealed that in the Pleistocene and geologically Subrecent times, the North Western parts of the Indian sub-continent was not arid. Archaeologists have found evidence that Baluchistan was relatively well wooded and was occupied by extensive human settlements down to about 4000 B.C. Mohenjo Daro excavation (Mackay, 1934) revealed existence of culverts constructed about 2750 B.C. to carry away storm water and that these sites were partially abandoned because of serious flooding by the Indus between 2750 B.C. Unakar (1933, 1934) found evidence in RG-VEDA of three types of climate, first a period of cool weather with uniform rains throughout the year and few thunderstorms, second a stormy period when winter depressions gave copious rains and finally a period of increasing drought. These possibly cover the period 5000 B.C. to 2000 B.C. However now we have here the most infertile region of India. Climatic conditions are also very severe and unfavourable for crop production. In the words of Blanford (1876) "it is neither barren nor uninhabited, it is covered with bushes and shrubs in general and in places small trees are found". Rajasthan occupies an area of 1,32,000 sq miles but is very much less populated than the rest of the country.

DELIMITATION OF THE ARID AND SEMI-ARID ZONES

Aridity signifies deficiency of moisture to support vegetation, due to the fact that water available on the soil and in the soil is less than the evaporation potential. Dry climates are those in which water deficiency exceeds water need, i.e. evaporation exceeds precipitation and no surplus water remains to maintain constant ground water level.

Koppen was the first to introduce the concept of precipitation effectiveness to express aridity-humidity boundaries. He defined the PE-index in terms of precipitation and temperature. For an area to be treated as desert (BW) the annual rainfall in cm should be less than $t + k$ where t is the annual mean temperature in °C and k takes the value 7 or 0 or 14 if the rainfall in uniform throughout the year, or if the summer is dry or if the winter is dry respectively. However, if the rainfall is more than these values but less than twice these, the area is to be treated as steppe or semi-desert (BS). Thornthwaite brought in the concept of precipitation effectiveness, seasonal concentration of precipitation and thermal efficiency. The combined loss of water through evaporation from the soil surfaces and transpiration from plants is called evapotranspiration. The monthly march of potential evapotranspiration is compared with the monthly march of precipitation to obtain a moisture index. If the potential evapotranspiration is greater than the moisture available, an index of aridity is worked out as the ratio between the water deficiency and water need. But if potential evapotranspiration is less than moisture available, an index of humidity is worked out as the ratio of water surplus to water need. Since water surplus and water deficiency occur at different seasons in most places both must enter into the moisture index. A water surplus in one season cannot prevent a deficiency in another, however, the moisture stored in the soil during the surplus season helps to relieve the deficiency of the subsequent drier season to a certain extent. In seasons of water deficiency, transpiration proceeds at a reduced rate. In the over all moisture index, the humidity index is given greater weight in the ratio 1 to 0·6 compared with aridity index. A moisture index of —40 separates the arid from semi-arid and an index of —20 separates semi-arid and dry sub-humid regions.

Several other schemes of climatic classifications have been proposed, most of them purely empirical but none of them satisfies all the requirements. The basic difficulty is inherent in the fact that there exist hardly any sharp boundaries between climatic zones except at the crest of mountains and at the coast lines and the various climatic regions fade into each other. Further the shifts of the general circulations from season to season and from year to year bring fixed localities on the surface of the earth sometimes into one and sometimes into another. Thus all dividing lines are essentially arbitrary.

Attempts have been made by several authors to delimit the climatic zones of India using one or other of the criteria above stated.

It is very difficult to say as to how Rajasthan became infertile during the last few millenia.

1. Contribution from Institute of Tropical Meteorology, Poona 5.

Whether the deterioration was due to climatic changes or due to human activities which could have initiated unproductivity through soil exhaustion or soil erosion, a proper appraisal of the climatic environment and the nature and extent of the climatic fluctuations if any, are absolutely essential for proper planning towards countering further deterioration taking place and for reclaiming as much as possible. A brief description of the relevant climatic features is given in the next section. As the insufficient and unreliable rainfall of the region are the most important features which contribute largely to the aridity, the variability of rainfall and the causes which contribute to the production of rainfall of the area are studied in the third section. In the last section the fluctuation of climate during the historical period is dealt with.

CLIMATIC FEATURES OF RAJASTHAN

The annual march of the different climatic characteristics have been represented diagramatically in Fig. 1. Bikaner and Jaisalmer represent the Thar Desert portion and Jaipur and Kotah the semi-arid East Rajasthan.

RAINFALL — On the average during the year East Rajasthan receives 70·41 cm of rainfall and West Rajasthan receives 31·14 cm. Of this about 90 per cent falls during the southwest monsoon season, and about 5 per cent during the cold weather period in association with western disturbances. Total rainfall is 10 cm or less on the extreme west in a small area of Jaisalmer district and gradually increases to over 100 cm at some stations in Kotah, Banswara and Jhalawar in southeast. The normal number of rainy days in the year is less than 5 days at some stations in Jaisalmer district increasing towards the Aravalli Hills to 25 and thence to over 45 days in Jhalawar District in East Rajasthan. The variability is highest in this region varying from 30 per cent in the south-west corner to over 70 per cent in the west in Jaisalmer district. The normal monthly rainfall in the West and East Rajasthan and the coefficient of variability (CV*) are given below:

	Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
A — West Rajasthan													
Mean (mm)	5·4	5·9	4·0	3·4	7·7	28·6	98·5	109·9	40·4	4·3	0·8	2·5	311·4
CV %	223	152	157	170	182	96	59	76	147	253	333	180	
B — East Rajasthan													
Mean (mm)	9·0	6·0	4·7	3·2	8·5	68·3	242·8	228·5	112·0	12·2	4·3	4·6	704·1
CV %	107	152	162	231	139	63	38	50	78	150	145	171	

These figures are based on the data for the period 1901-1950. The variabilities are very high during the non-monsoon months indicating the highly erratic nature of the rainfall during these months. Even during the monsoon months the variabilities are high. The least being

$CV^* = \frac{\sigma}{M} \times 100$, where $\sigma = \sum_{1}^{n} \frac{(r_s - M)}{M-1}$, r_s is the monthly rainfall in the study year, $M = \sum_{1}^{n} r_s$ is the mean rainfall and n number of years of rainfall records. In the month of July, 59 per cent in West Rajasthan and 38 per cent in East Rajasthan. Further discussions of the variability is made in section 3.

TEMPERATURE — Characteristic of the arid region, the annual range of temperature is highest being of the order of 20°C. The heat of summer is intense and scorching and West Rajasthan is the hottest, the mean maximum temperature rising to over 45°C in May, June. Occasionally temperatures of the order of 50°C have been recorded. Winter is very cold with mean temperature falling to nearly freezing point in January. Occasionally in association with western disturbances during the months December to March, many places in West Rajasthan experience temperature below freezing point resulting frost. The diurnal range of temperature from the early morning cold to the afternoon heat is on the average about 15-18°C. The characteristic seasonal variation of the mean temperature, the mean daily maximum and mean daily minimum temperatures, the mean monthly maximum and monthly minimum temperatures as well as the highest and lowest temperatures so far observed in the different months are represented by the station curves in Fig. 1.

HUMIDITY — The march of mean relative humidity during the seasons at 0830 IST in the morning and at 1730 IST in the afternoon are shown in Fig. 1. The Relative Humidity is highest in the day at about 5 A.M. and least about 2 to 3 P.M. about the same time as the minimum and maximum temperatures occur. This will be clear from the isopleths of temperature and relative humidity in

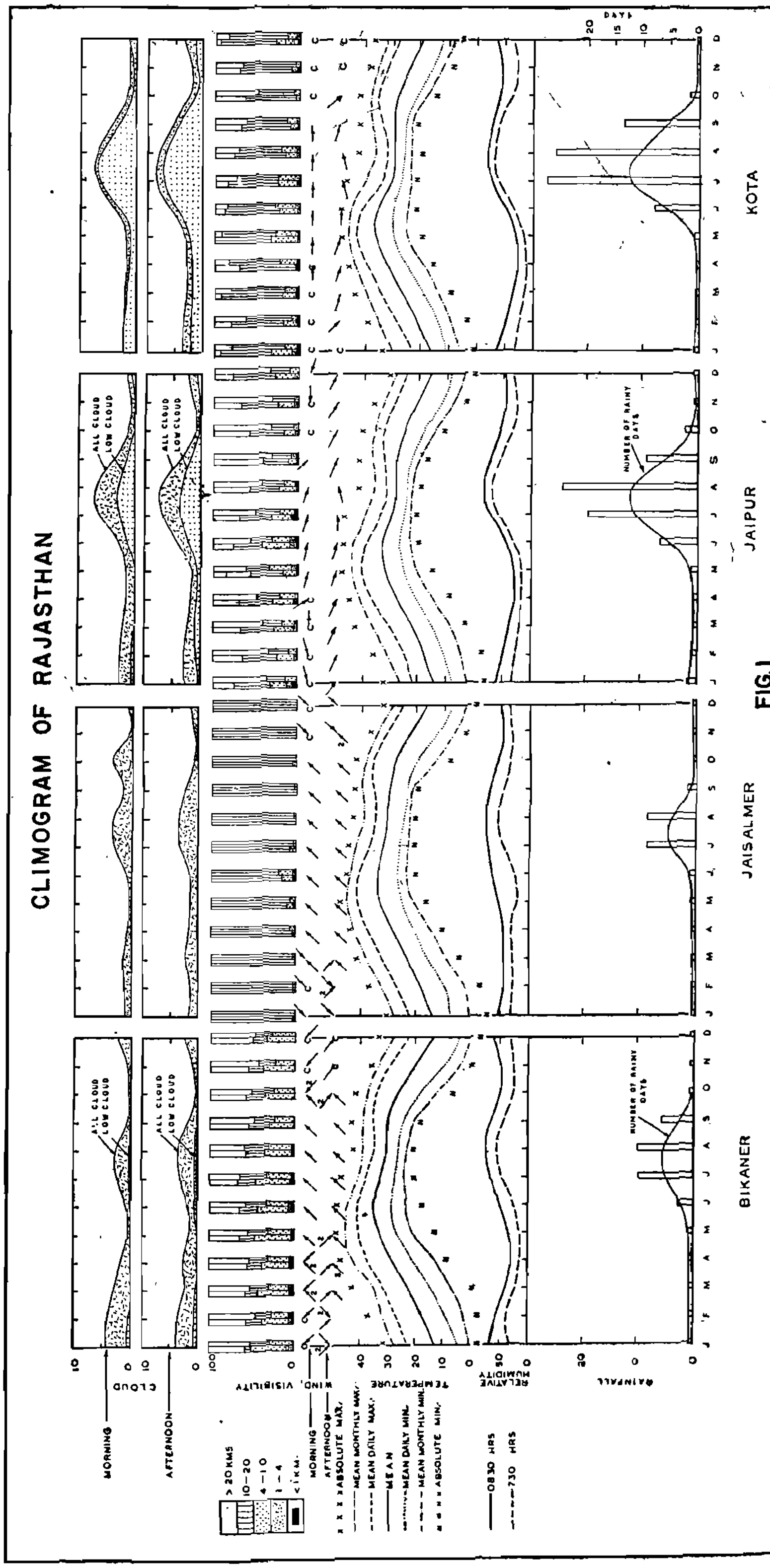
CLIMOGRAM OF RAJASTHAN
BIKANER
JAISALMER
JAIPUR
KOTA
MORNING
AFTERNOON
CLOUD
ALL CLOUD
LOW CLOUD
WIND, VISIBILITY
TEMPERATURE
RELATIVE HUMIDITY
RAINFALL
NUMBER OF RAINY DAYS
DAYS
ABSOLUTE MAX.
MEAN MONTHLY MAX.
MEAN DAILY MAX.
MEAN
MEAN DAILY MIN.
MEAN MONTHLY MIN.
ABSOLUTE MIN.
0830 HRS

FIG. I

respect of two stations Jodhpur and Jaipur given in Fig. 2. It will also be seen that the relative humidity is least during the hot weather season March to May and highest during the monsoon months July to September. In April the relative humidity is least. However, the actual moisture content of the atmosphere is least during the cold weather season and highest during the monsoon season.

WIND — The predominant wind directions month by month in the morning at about 0830 hr IST and in the afternoon 1730 hr IST in respect of the four stations Bikaner, Jaisalmer, Jaipur and Kotah are given in Fig. 1. Winds are strong southwesterly during the monsoon months over the western portions while over the east they are mainly westerly, but much lighter. During the rest of the year, over West Rajasthan, the winds come mainly from the SE in the mornings and NW in the afternoon. They are much weaker and calms are fairly frequent. Over the East Rajasthan winds are much lighter and generally come from WNW. Calms are very frequent. During the hot weather season the dry sand and dust particles on the parched and barren soil are raised by the strong and gusty winds particularly in the West Rajasthan. These dust raising winds carry the dust and heat eastwards to East Rajasthan and long distances beyond into the adjoining Uttar Pradesh.

VISIBILITY: In Rajasthan dust is raised by turbulent winds in the winter months and in the pre-monsoon months when the atmosphere is dry and soil surface loose. However, during the monsoon months when the atmosphere and the soil are more moist, the lifting of dust is considerably reduced. The presence of dust in the atmosphere affects the transparency and results in poor or bad visibility conditions. Such conditions are also likely when fog or moist-haze are present in the atmosphere. However, in these dry tracks the moisture in the atmosphere except occasionally when associated with western disturbances is so small that we can

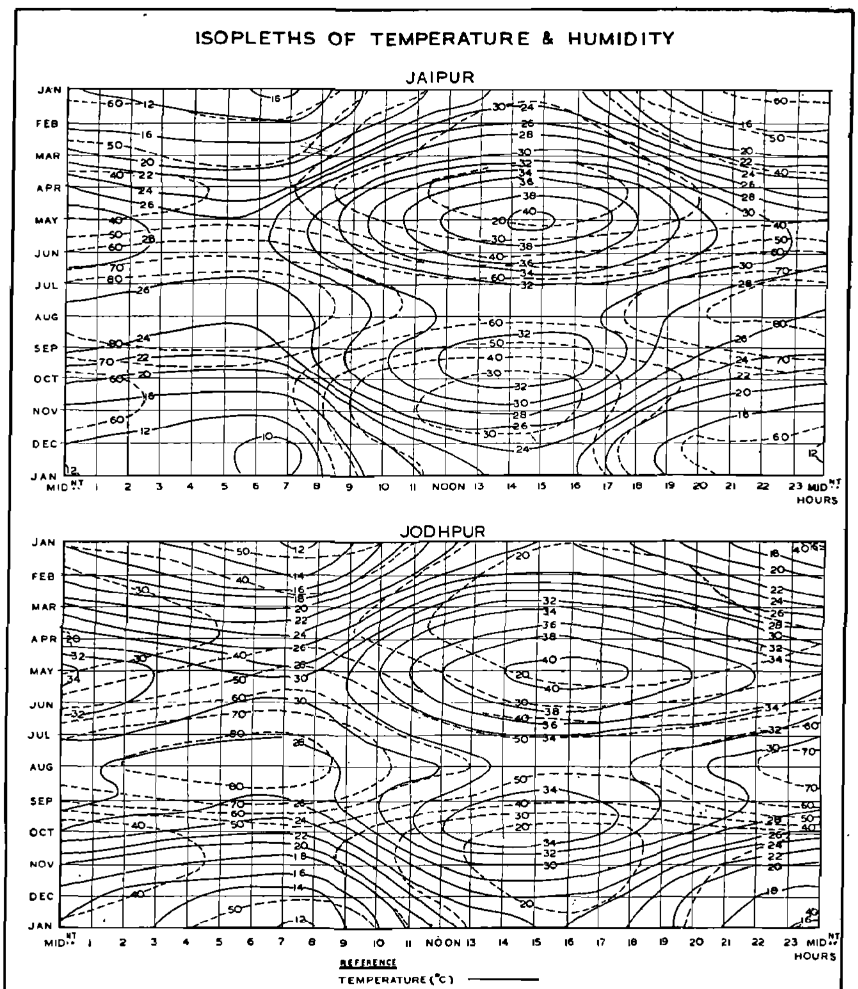

FIG. 2

ordinarily assume the atmospheric transparency as a measure of the amount of dust present. Sriganganagar and Bikaner have recorded 6 days and 4 days of fog respectively during the months December to February. Poor or bad visibility due to dust are most frequent in the extreme north being of the order of 10-20 in each of the months at Sriganganagar decreasing to less than 2 days in South and East. A quantitative estimate of the amount of dust suspended in the air can be had from frequency of poor visibility conditions. The frequency of visibility in the different ranges both in the morning and afternoon are shown in Fig. 1.

It is seen that dust in the air increases after February and poorest visibilities are experienced during the hot weather season April, May, June and to some extent in July when the dust raising winds and duststorms are most frequent. Sand or duststorms are most frequent in West Rajasthan but decrease very much towards the East. The rains associated with the southwest monsoon season precipitate the dust and by August or September the visibility improves considerably.

CLOUDING: The extent of the sky covered with low clouds and clouds of all types both in the morning and afternoon are shown in Fig. 1. These represent the mean over the months as a whole. The number of days when the sky was heavily covered to overcast (6 oktas or more), with all the clouds and low clouds separately are given in the table below. These indicate how frequently such cloudings occur. The occasions are very few during October-November and April-May. They are most frequent during the monsoon season over the Aravallis and East Rajasthan while over the arid tracks represented by Sriganganagar and Bikaner such heavy clouding occur on 4-8 days, low cloud frequency decreasing northwards.

UPPER AIR CONDITIONS: The mean upper air conditions over Rajasthan are represented fairly by Jodhpur. Fig. 3(a) shows the mean resultant winds (speed and direction) upto 16 km. These have been obtained by vectorially combining the winds on the different days. The speed of the resultant wind when compared with the mean wind speed calculated without taking regard of the directions gives a measure of the steadiness of the wind during the month. 100 per cent is absolutely steady and 0 per cent is completely variable. This steadiness percentage is shown by isolines in the same figure. Steady and strong westerly winds below above 3 km during November to May. While during the monsoon season winds upto 2 km are mainly Southwesterly, aloft they are very variable but predominantly northerly.

In Fig. 3(b) the temperature (Å) and humidity mixing ratio gm/km of dry air are indicated. The air upto 1 km is warmest during May-June. With the monsoon coming in by the end of June there is a quick drop in temperature. The maximum is delayed gradually as we go higher up and at 9-12 km. The maximum occurs in July-August. The air is coldest in the month of January.

There is a pronounced increase of moisture in the lower levels with the advant of the monsoon. It will be interesting to compare the values for Agra and Ahmedabad given by Ramanathan (1952). The moisture upto 5 km during the monsoon season is much larger over Agra while at Ahmedabad it is of about the same order with that over Jodhpur upto 3 km. This monsoon air over Agra and Ahmedabad is cooler than that over Jodhpur by 2-3°C while higher up Jodhpur is cooler in the month of July and almost 3 gm/kg lower in August than in Jodhpur.

Frequencies of days when sky was covered with 6 oktas or more of all clouds (N) and low clouds (N_L).

			I — 0830 hrs IST.						*II — 1730 hrs IST.*					
Station	*Hr*	*Clouds*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Ganganagar	I	N	11	11	8	4	1	3	5	2	2	1	1	5
		N_L	0	1	0	0	0	1	0	1	0	0	0	0
	II	N	11	8	6	6	2	5	7	8	3	1	2	7
		N_L	1	1	0	1	0	1	0	1	0	0	0	0
Bikaner	I	N	6	6	5	2	0	4	7	5	2	0	1	4
		N_L	3	4	2	0	0	2	3	4	1	0	0	2
	II	N	5	7	5	4	1	8	8	7	2	0	1	5
		N_L	2	3	2	2	0	4	3	6	2	0	0	2
Jodhpur	I	N	8	7	6	3	2	12	22	20	10	0	3	5
		N_L	1	3	1	2	1	2	15	14	6	0	1	0
	II	N	10	9	9	7	3	10	18	18	8	1	3	6
		N_L	2	2	3	3	1	4	7	8	5	0	0	0
Jaipur	I	N	6	6	5	2	0	8	17	14	5	1	2	3
		N_L	2	1	2	0	0	2	8	6	3	0	0	1
	II	N	8	7	6	3	3	9	21	21	7	1	3	6
		N_L	1	2	2	0	1	4	8	8	3	0	0	1
Kotah	I	N	10	8	7	4	3	15	27	22	10	2	4	6
		N_L	4	5	1	1	2	7	21	18	6	2	3	2
	II	N	10	9	7	6	6	16	25	24	13	4	5	7
		N_L	4	4	4	2	4	12	18	18	6	0	2	2

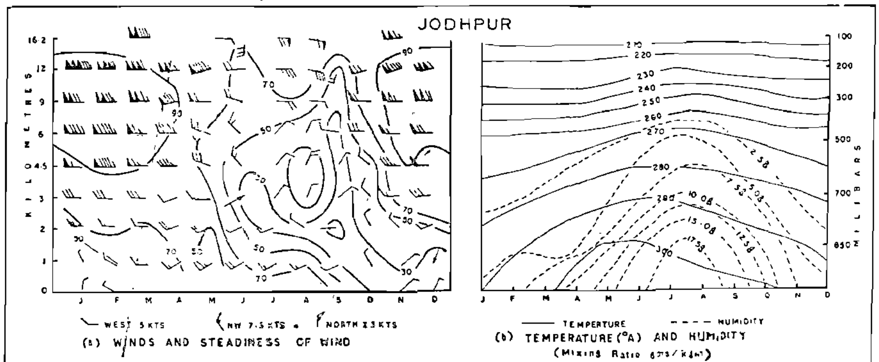

FIG. 3

During the monsoon season there is a permanent low pressure area over Sind and Baluchistan and this brings in moist air from North Arabian Sea as a Southwesterly stream over the South and East Rajasthan. This current is, however, very shallow and at levels above 2 km, it is dominated by the anti-cyclonic circulation bringing hot dry Northerly air over-running the moist Southwest monsoon current. When the monsoon air penetrates into the desert region, even the few clouds that exist in the easterly or southerly air are dissipated by the dry Northerly current and the atmosphere is continuously being desiccated. Thus even during the monsoon season when the rest of India experiences considerable rain, over Rajasthan, the skies are clearer with very little rain leading to intenser insolation, higher temperature and consequently greater evaporating power of the atmosphere which evaporates out even the little rain that falls.

EVAPORATION: Pramanik (1952) estimated the annual evaporation over the desert and semiarid regions in Rajasthan from small pools and surfaces to be of the order of 120″ and from large lakes to be of the order of 90″. Evaporating power during May and June is the highest and lowest in December, January. During June to September it is of the order of 25″.

Evaporation from soil surface is comparable to that for a free water surface only as long as the surface remains saturated with water. When the surface dries up the actual evaporation depends upon several factors like soil humidity, depth of water table etc. Ramdas (1952) has estimated that over West Rajasthan the entire rainfall is evaporated.

VARIABILITY OF RAINFALL

Figure 4 shows the progress of the monsoon rainfall over East and West Rajasthan year after year from 1875 to 1962. While some fluctuations are characteristic of all time series, some years stand out as phenomenal years when the rainfall was very much in defect and some years when the rainfall was very much in excess. This brings out the high variability of rainfall in these tracts.

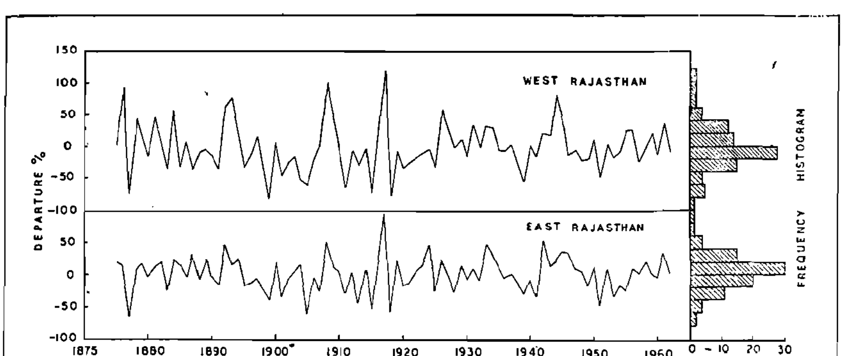

FIG. 4 RAINFALL OF RAJASTHAN 1875-1962

DDGC/2156.12:63

ABNORMAL MONSOONS: In the following years rainfall was in defect or excess by more than 50 per cent.

Rainfall in large defect

West Rajasthan		*East Rajasthan*	
1899	−83 per cent	1877	−66 per cent
1918	−78 ”		
1877	−75 ”	1905	−61 ”
1915	−74 ”		
1911	−66 ”	1918	−56 ”
1905	−60 ”		
1936	−56 ”	1915	−53 ”
1904	−51 ”		

Rainfall in large excess

West Rajasthan		*East Rajasthan*	
1917	+119 per cent	1917	+98 per cent
1908	+102 ”		
1876	+93 ”	1942	+63 ”
1944	+82 ”		
1893	+77 ”	1908	+54 ”
1892	+63 ”		
1926	+60 ”		
1884	+57 ”		

It may be seen that in 8 out of the 88 years, rainfall in West Rajasthan was more than 50 per cent in defect, the largest defect was 83 per cent in 1899. Another 8 years the rainfall was in large excess >50 per cent the largest excess was in 1917 when the rain was 119 per cent above normal. In East Rajasthan in 4 years the rainfall was in defect by more than 50 per cent, 3 years in excess by more than 50 per cent.

SPELLS OF EXCESSIVE AND DEFICIT MONSOONS: It will be interesting to examine the duration after which the rainfalls of certain specified defect or excess had occurred. The following table gives the frequencies of such durations:

Duration in years 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	*Total*	*Mean duration in years*
Defects > 20 per cent		
West Rajasthan		
6 7 3 3 1 2 . . 1 . . . 1 . . .	24	3·29 years
East Rajasthan		
1 6 2 2 . 1 1 . . 1 . 1 . . . 1	16	4·75 years
Excess > 20 per cent		
West Rajasthan		
7 4 3 1 . . 1 2 1 1 1	21	4·05 years
East Rajasthan		
4 5 4 . 1 1 1 3 1	20	3·85 years

The average duration in years between consecutive defects (or excesses) greater than 20 per cent are given in the last column. The significance of the largest spells was tested and found to be insignificant.

RANDOMNESS OF THE SEQUENCE OF MONSOON RAINFALL: To examine if the sequence in which such intervals occurred were random or followed any specific law, the sequence of the length of rains were examined for randomness by the method developed by Kendall and Wallice and Moore.

The number of turning points (p) and the phase length (d) and the numbers calculated on the basis of randomness are given below:

	P Act.	*P Cal.*	*SE*	*D = 1*		*D = 2*		*D > 3*		*X²*
				Act.	*Cal.*	*Act.*	*Cal.*	*Act.*	*Cal.*	
West Rajasthan										
Defect > 20%	15	14·6	1·99	8	9·0	5	3·8	1	1·2	0·51
Excess > 20%	15	12·7	1·85	12	9·0	2	3·8	0	1·2	3·05
East Rajasthan										
Defect > 20%	10	9·3	1·59	2	5·9	2	2·3	1	0·8	0·05
Excess > 20%	13	12	1·80	7	7·7	5	3·2	0	1·1	2·16

The variation from randomness is not significant.

NORMALITY OF THE DISTRIBUTION: The analysis in the previous two sub-section indicate that the sequenee of monsoon rainfalls have been random. The frequency histograms ot the departures of monsoon rainfall for East and West Rajasthan are also shown in Fig. 4. They generally conform to the normal law of error as confirmed by the Fisher's g statistics given below (Rao, 1958).

	g_1	$SE(g_1)$	g_2	$SE(g_2)$
East Rajasthan	+0·02	0·27	+0·16	0·27
West Rajasthan	+0·64	0·53	+0·90	0·50

The departure from the normal curve is not significant. However, there is a slight indication of positive skewness in West Rajasthan.

WEEKLY RAINFALL ABNORMALITIES: Govindswamy (1953) has prepared charts showing sequence of "dry" and "wet" weeks for the period 1908 to 1950. For this purpose a week is termed "dry" or "D" if the week's rainfall was less than 50 per cent of normal and a week is termed "wet" or "F" if the week's rainfall was more than 200 per cent of normal. The data for the following have been extracted from the MSS charts kindly given to me by the author.

The frequency distribution showing the number of years when West and East Rajasthan experienced 0, 1, 2, 3, etc. weeks of "F" or "D" during the monsoon season are given below:

No. of weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	13
1. *West Rajasthan*														
"F"	4	6	3	13	8	4	4	.	.	.	1	.	.	.
"D"	1	.	.	.	3	1	6	3	9	6	5	3	4	2
2. *East Rajasthan*														
"F"	3	4	13	8	7	4	1	2	1	.	.	.	.	.
"D"	1	.	1	4	5	5	6	7	7	5	2	.	.	.

It is seen that West Rajasthan had experienced heavy rainfall to the extent of more than twice normal for 3-4 weeks of monsoon season, in about 50 per cent of the years. While there have been 8-10 weeks of "D" (rainfall less than half normal) on about 50 per cent of the years. On over 20 per cent of the years such deficient rainfalls have occurred in more than 10 weeks of the season. In the two years 1918 and 1938 there have been as many as 13 weeks out of the 16 weeks of the season when rainfall was in defect by more than 50 per cent, while in 1917 there were 10 weeks when rainfall was in excess by 100 per cent.

Over East Rajasthan on 50 per cent of the years 2-3 weeks of "F" have occurred and there were 4 weeks of "F" in another 17 per cent of the years. However, 7-9 weeks of deficient rainfall "D" have occurred in about 50 per cent of the years and during the 43 years there have been no years with more than 10 weeks of deficient rain. In 1915 and 1918, East Rajasthan experienced as many as 10 weeks of very deficient rainfall (>50 per cent).

RELATIONSHIP WITH INCIDENCE OF DEPRESSIONS: An examination has been carried out to find the extent to which the monsoon depressions have been responsible for rain over this area and its neighbourhood.

The yearly frequencies of "D" and "F" during the monsoon season were correlated with the number of depressions. The CCs are given below:

A — CC between the number of weeks of "F" in the sub-divisions and the number of depressions which terminated in Punjab, Rajasthan, Gujarat, Sind and Baluchistan.

Sub-division	*C.C.*
Rajasthan East	+·28
Rajasthan West	+·67*
Sind	+·37*
Baluchistan	+·42*

B — CC between the number of "D" weeks in the sub-divisions and the number of depressions which terminated in Vidarbha, Madhya Pradesh and U.P.

Sub-division	*C.C.*
Punjab	+·19
Rajasthan East	+·26
Rajasthan West	+·12
Sind	+·25
Baluchistan	+·35

The Table A shows the high dependence of the rainfall of the arid sub-divisions Rajasthan West, Sind and Baluchistan on the passage of depressions during the monsoon season. Though none of the C.Cs in B are significant, the fact that all the 5 C.Cs show consistently positive values show that the early filling up of the depressions in the Central parts of the country have got an adverse effect on the rainfall of this area.

FACTORS CAUSING RAINFALL OVER RAJASTHAN: It is common experience that there is very little rain over most of Rajasthan even during the monsoon season unless some low or depression moves towards it from east or southeast. When a disturbance moves over to Rajasthan well distributed rain occurs over most of Rajasthan. However, there are occasions when some districts have experienced rain even in the absence of a depression, in association with the simple monsoon current from the Bay of Bengal or Arabian Sea and sometimes purely as local thunderstorms. An examination has been carried out to find the individual effects of the different operating factors in two contrasting years. Daily rainfalls over Rajasthan and Sind during June to September in the two contrasting years 1917 and 1918 when rainfall was very much in excess and very much in defect respectively, have been examined with reference to the daily weather charts. The daily rainfall in the different districts were marked out as due to one or other of the operating factors. The rainfall due to the different groups have been grouped separately.

An analysis of variance has been carried out to determine the variance accounted for by the different operating factors individually and the spatial variance. The individual variances have been tested in the usual manner. The following are the results of the analysis:

1917 *Sind:* + 114%, *West Rajasthan:* + 119%	1918 *Sind:* 81%, *West Rajasthan:* −78%

June

1917: Five districts viz., Karachi, Tharparkar, Jaisalmer, Jodhpur and Bikaner reported rain; there were 34 district — day cells in respect of all four factors.

Depressions	12 cells
Arabian sea current	11 ,,
Bay current	5 ,,
Other causes	6 ,,

	S.S.	D.F.	M.S.	F.
Districts	1·1650	4	0·2913	1·943
Factors	0·9898	3	0·3299	2·208
Error	3·8964	26	0·1499	
Total	6·0512	33		

Variance between districts was not significant but variance between factors was just significant. The number of items are, however, small to be treated as conclusive.

1918: Two districts Bikaner and Jodhpur reported some rain. There were 9 districts — day cells of which 8 were due to Arabian Sea current and 1 due to the Bay current. No analysis was attempted due to insufficient data.

July

1917: Six districts viz., Karachi, Upper Sind, Tharparkar, Jaisalmer, Jodhpur and Bikaner reported rain. There were 51 districts-day cells in all.

Arabian sea current	32 cells
Bay current	14 ,,
Depressions	5 ,,

	S.S.	D.F.	M.S.	F.
District	3·0494	5	0·6099	3·170
Factors	0·8685	2	0·4342	2·257
Efror	8·2716	43	0·1924	
Total	12·1895	50		

Variance between districts was significant i.e. the area is not homogeneous as regards rainfall during this month. The variance between factors was not significant i.e. all factors are equally operative in producing rainfall.

1918: Two districts Bikaner and Jodhpur reported rain. There were 8 districts day cells, all Arabian Sea current. No analysis was attempted.

August

1917: 10 districts Karachi, Hyderabad, Nawabshah, Larkhana, Sukkur, Upper Sind, Tharparkar, Jaisalmer, Jodhpur and Bikaner reported rain in 166 district-day cells.

Depressions	46 cells
Arabian sea current	86 ,,
Bay current	12 ,,
Other causes	22 ,,

	S.S.	D.F.	M.S.	F.
Districts	5·5240	9	0·6638	1·044
Factors	6·9360	3	2·3120	3·932
Error	89·9612	153	0·5880	
Total	102·4212	165		

Variation between districts is not significant, variation between factors is significant at 1 per cent level indicating differential response to the different factors.

1918: 7 districts Karachi, Hyderabad, Upper Sind, Tarparkar, Jodhpur and Bikaner reported rain. There were in all 34 districts day cells.

Depression	19 cells
Arabian sea current	13 ,,
Bay current	2 ,,

No analysis was made.

Contd.

1917	1918
Sind: +114% *West Rajasthan* +119%	*Sind:* 81% *West Rajasthan*: −78%

The rainfall contributed by the different factors are as follows:

Factor	Mean daily rainfall in inches	Total rainfall in inches
i) Depression	0·73*	33·55
ii) Arabian sea currents	0·26	22·16
iii) Bay currents	0·29	3·51
iv) Other causes	0·37	8·17

The significance of the difference between the values were tested by the t-test. The intensity of rainfall in the districts due to depressions is significantly high. However, if we consider the total rainfall-contributed by the different factors the difference between-depression and the Arabian sea current are not significant. Depressions account for only 50 per cent of the month's rainfall. The Arabian Sea currents follows closely accounting for 1/3 of the rainfall and the other 2 factors combined account for the balance of 1/6th of the rainfall.

September

10 districts (same as for August) reported rain with 131 district — day cells.

Depressions	69 cells
Arabian sea current	34 ,,
Bay current	24 ,,
Other causes	4 ,,

	S.S.	D.F.	M.S.	F.
Districts	9·9044	9	1·1005	
Factors	0·2913	3	0·0971	
Error	187·6049	118	1·5899	
Total	197·7999	130		

Variance between factors and that between districts are not significant.

5 districts Hyderabad, Sukkur, Tharparkar, Jodhpur and Bikaner reported rain in 21 district — day cells.

Arabian sea currents	12 cells
Western Disturbance	6 ,,
Depression	3 ,,

FLUCTUATIONS OF CLIMATE DURING INSTRUMENTAL PERIOD

Banerji (1952) characterized Rajasthan as a hot desert with high temperature, small rainfall and evaporation far exceeding rainfall leaving insufficient moisture to support vegetation. He observed that there has been a slight decrease of rainfall except on the Aravallis and a slight increase of temperature. Pramanik, Hariharan and Ghosh (1952) made a study of the meteorological conditions for 70 years. Their study did not suggest that there has been any appreciable accentuation of Rajasthan desert or any large scale extension of the desert conditions over the adjoining areas during the last 70-80 years. Pramanik and Jagannathan (1954) made a rigorous statistical study of trend by fitting orthogonal polynomials upto 5th degree in time for rainfall, temperature and pressure. They found that there was no general tendency for a systematic increase or decrease at any of the places examined but at some places there are some variations of an oscillatory character with a period of about 30-40 years. They observed an increasing linear trend in the annual rainfall in the case of Bellary in the semi-arid Deccan which was reflected in a similar trend in the southwest monsoon rainfall of the place while over Rajasthan and neighbourhood there was no significant trend in rainfall. This was also confirmed by Rao (1958).

Maximum temperature showed an increasing linear trend at Multan in Sind while at Aurangabad and Bellary in the Deccan the tendency was one of decrease. Minimum temperature over the Deccan, Saurashtra and Kutch and extreme northwest showed an increasing tendency. These findings suggest an increasing maritimity over the peninsular of India; while over the extreme northwest a suggestion of decrease of clouding or of increased solar radiation during the hot weather period and a slight increase of clouding during winter.

As regards atmospheric pressure, the polynomial analysis and moving averages revealed significant oscillatory tendency with a general decreasing tendency over the Indian theatre, the notable regions are Sind, Rajasthan, Uttar Pradesh, West Cost of India, North Andhra Pradesh, South Orissa and Assam. The winter pressures represented by

January confirmed the decreasing tendency over India with an increasing tendency over Burma and N.W.F.P. while the summer pressure represented by July showed the decreasing tendency over the country outside the South Peninsula and extreme north-west. These suggest a slight shift of the sub-tropical high pressure cell.

Fluctuation in the Characteristics of Seasonal Variation of Temperature in the Arid and Semi-arid Regions

In a recent investigation, Jagannathan (1963) analysed the series of temperature data of representative stations in the arid and semi-arid regions of India as also one or two stations each in the arid and semi-arid regions of the different continents. The aim was to determine if there are any long term changes in the characteristic parameters representing the seasonal variation of air temperature particularly over the arid and semi-arid regions and also to determine if these variations are related to solar activity. The following are some of the findings:

(i) The mean annual temperatures do not show any systematic increase or decrease but there is slight decrease of temperature though small, at practically all stations during period of maximum solar activity over those of minimum solar activity.

(ii) The annual ranges of temperature exhibit oscillatory tendency with a period of about two sunspot cycles and consequently the aggregation of periods of maximum and minimum solar activity does not show any significant difference between themselves. The variations at different stations in the same region e.g. the north Indian stations show considerable agreement in phase while they get out of phase when different regions are considered. Thus it indicates that the solar fluctuations observed should be associated with the fluctuations in the sub-tropical high pressure centres and on the general circulation patterns.

(iii) The components of the harmonic vectors of the annual oscillation do exhibit significant fluctuations though not in exact sympathy with the fluctuations in the sunspots. The date of maximum in the annual wave had the largest lag in 1906 and again in 1938. There is a distinct tendency though small, for the amplitude of the annual oscillation to increase with maximum solar activity in the northern hemisphere stations while in the southern hemisphere the reverse is true. Another interesting finding is that the peak in the annual wave, at least at the Indian stations, get delayed by about 3·5 days during years of maximum sunspot activity. It is known that the lag in the date of maxima is least in the most continental locations and increase at more maritime ones. If we extend this idea, it can be concluded that in years of maximum solar activity, the soil humidity is slightly increased due probably to slight increase of precipitation or at least to increased relative humidity. This, however, needs further study

(iv) The half-yearly wave is significant at the Indian stations, in particular with amplitudes of the order of 2-3°C and the maxima occurring in April and October. At the other stations the amplitude is less than 1°C but the maxima systematically occur in March or April (and September or October) in most cases; at Pheenix (U.S.A.) they occur in February and August. The occurrence of the significant half-yearly wave over the globe in general, should in all probability be associated with the change in the atmospheric general circulation. The amplitudes of the half-yearly wave exhibit oscillatory tendency with a period of about 2 sunspot cycles with the amplitude and date of maxima increasing in alternative period of high solar activity.

CONCLUDING REMARKS

It is well known that the variations in the solar constant occur primarily in the ultra-violet increasing with increase of solar phenomena. Much evidence exists of highly erratic fluctuations in the ultra-violet roughly paralleling the sunspot cycle. The marked variation in the ultra-violet radiation cause large variations in temperature in the higher atmosphere. The temperature increase in the higher atmosphere is propagated downward with marked lag (Haurwitz, 1946). The increase in the amplitude of the annual wave observed here is in consonance with this.

World's extremely arid regions are situated under the influence of sub-tropical high pressure cells where weak circulation and subsidence prevails. Semi-arid lands are marginal to pure deserts and are situated in regions dominated by varying circulation conditions. The sub-tropical jet stream is usually present at about 9 km over the sub-tropical high pressure belts during the winter season. During the monsoon the Equatorial jet comes over these latitudes at about 16 km. These probably are closely connected with the mechanism of dryness in arid regions. There is still considerable research needed to unravel the mysteries of nature.

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DISCUSSION

C. M. Mathur: Is there any significant increase or decrease of rainfall (trends) in Western Rajasthan during the last 70 years?

P. Jagannathan: No significant "trend" in the annual rainfall as such has been observed.

CRITERIA FOR THE DELIMITATION OF THE ARID ZONE OF RAJASTHAN[1]

by

A. Krishnan & K. A. Shankarnarayan[2]

INTRODUCTION

Several methods have been suggested for the classification of climates. Attempts have been made for obtaining a classification that will permit the establishment of regional boundaries between areas of uniform climatic conditions. But this task is beset with lot of difficulties. In addition to the changes in micro-environmental factors sets of limiting conditions for the classification of climates will vary according to the purpose for which classification is made, such as establishment of limits of areas suitable for a crop or regions comfortable for human settlement. However, some of the most widely known climatic classifications are bio-climatological in nature and actually attempt to relate the extent and type of natural vegetation on the surface of the earth to climatic conditions. Among these are the classifications of Koppen, De Martonne, Gaussen, Emberger and Thornthwaite. The delimitation of different bioclimatic zones by these different methods leads to different conclusions and an international agreement on the delimitation of the major bioclimatic zones is a paramount necessity since the problem is fundamental and these climatic territories concerned become *ipso facto* the major ecological divisions. In evolving such uniform criteria for the delimitation of the bioclimatic zones, only those climatic factors should be taken into account which have definite and direct interaction with the plants in the region.

The object of this paper is, therefore, to apply the internationally accepted standard methods of Koppen, De Martonne, Gaussen, Emberger and Thornthwaite for the delimitation of various climatic zones in Rajasthan. Since a study of the vegetation of the ground itself would provide a direct basis of the bioclimate, the vegetation pattern of Rajasthan was also studied. An evaluation as to how far different climatic classification methods reflect the actual vegetation pattern of Rajasthan has also been attempted.

CLIMATE AND VEGETATION PATTERN

The principal arid zone (hot) of India lies in Rajasthan. The rainfall of the state varies from 1000 mm in the south-east to 120 mm in the extreme west. Rainfall of Western Rajasthan is highly erratic. The standard deviation of annual rainfall at many places is equal to or even more than its average value. Rajasthan presents large extremes in meteorological conditions and the climate is seasonal. The major vegetation pattern over Rajasthan can be divided into the following distinct zones.

I. Mount Abu Zone.

II. East Rajasthan Zone. South — Banswara — Baran region; Middle — Chittorgarh — Kota region; and North — Jaipur — Alwar region.

III. Transitional Zone. Sirohi — Ajmer-Jodhpur region.

IV. Desert Zone of West Rajasthan. Ganganagar, Bikaner, Jaisalmer, Barmer regions.

The vegetation cover and its floristic characteristics in the above mentioned zones are described below:

I. Mount Abu Zone: The high altitude (1183 m) and rainfall exceeding 1200 mm contribute to the stratified closed type of forest. The vegetation type here is tropical moist deciduous forest. The chief species constituting the top canopy are *Mitragyna parvifolia, Eugenia jambolana, Mangifera indica, Sterculia colorata, Anogeissus acuminata, Erythrina indica, Acacia leucophloea* and *Hydnocarpus* sp. The middle storey has species like *Emblica officinalis, Wrightia tinctoria, Dendrocalamus strictus, Euphorbia neriifolia, Bauhinia racemosa* and *Kydia calycina*. The shrub layer consists of *Lantana camara, Zizyphus nummularia, Artimesia parviflora, Phoenix* spp., *Carissa spinarum* and *Vogelia indica*. Besides, *Justicea simplex, Achyranthes aspera* and *Hemigraphis latebrosa* are common.

The notable grasses occurring are *Pennisetum hohenackeri, Eulalia trispicata, Themeda quadrivalvis, Dichanthium annulatum, Themeda triandra, Setaria glauca, Panicum maximum* and *Arthraxon ciliaris*.

II. Eastern Rajasthan (Southern): This zone carries pure formations of *Tectona grandis* with admixture of *Anogeissus latifolia, Terminalia tomentosa, T. bellerica, Madhuca indica, Sterculia urens, Cochlospermum religiosum, Acacia leucophloea, Lannea grandis* in the top canopy. The underwood consists of *Helicteres isora, Holarrhena antidysenterica, Diospyros melanoxylon, Aegle marmelos* and *Zizyphus xylocarpa*. The main grasses are *Themeda triandra, Pseudanthistiria heteroclita* and *Heteropogon contortus*.

1. Contribution Central Arid Zone Research Institute, Jodhpur.
2. Climatologist and Systematic Botanist respectively of this Institute.

II. Eastern Rajasthan (Central): *Anogeissus pendula* is by far the commonest forest trees in this Zone and tends to form practically pure formations in localities with reasonably good soil. The top canopy comprises of *Anogeissus latifolia* (occurs on higher slopes), *Mitragyna parvifolia, Terminalia tomontosa, Terminalia belerica, Acacia catechu, A. leucophloea, Lannea coromandelica, Garuga pinnata, Lagerstroemia* sp., *Albizzia procera, Acacia senegal*. The dominant species in the middle storey are *Aegle marmelos, Diospyros melanoxylon, Butea monosperma, Zizyphus jujuba, Boswellia serrata, Phoenix* sp. and *Emblica officinalis*. The prominent shrubs are *Cassia tora, Tephrosia strigosa* and *T. tenuis* — The herbs consist of *Alysicarpus longifolius, A. vaginalis, Indigofera cordifolia* and *Phaseolus trilobus*. It is not uncommon to find grasses like *Bothriochloa pertusa, Dichanthium annulatum, Cymbopogon jwarancusa, C. martinii, Chrysopogon montanus, Sehima nervosum, Digitaria marginata, Setaria glauca* and *Dactyloctenium aegyptium*.

Chittorgarh area carried pure colonies of *Santalum album* before the reorganization of Rajasthan State. But now only poles and saplings of it exist, because of indiscriminate felling. There is no stratification into tiers and it is merely a scrub forest comprising *Lantana camara, Carissa carandas, Zizyphus nummularia, Butea monosperma* and teak coppices. The main grasses are *Bothriochloa pertusa, Cymbopogon martinii, Dichanthium annulatum, Digitaria rovleana* and *Urochloa reptans*.

II. Eastern Rajasthan (north): *Boswellia serrata* is found on the upper ridges of the Arawalli hills in almost pure patches on shallow boundary strata. The lowest level to which this species comes down is about 1410 ft altitude. The common associates are *Lannea coromandelica* and *Sterculia urens*. The other associates are *Emblica officinalis* and *Anogeissus latifolia* in varying proportions. In rocky soils there is practically no grass but where the soil is fairly deep, grasses become fairly dense and generally consist of *Apluda* species, *Eragrostis* species, *Themeda quadrivalvis* and *Heteropogon contortus*.

III. Transitional Zone: Ajmer-Pali-Sirohi to the west of Aravallis up to Jodhpur forms the transition zone III where the elements of eastern and western Rajasthan occur in association with each other. Here the vegetation gets thinner and there is no distinct stratification of vegetation. The principal trees towards Pali-Sirohi-Ajmer consist of *Anogeissus pendula, Acacia senegal, Acacia leucophloea, Prospois cineraria, Tecomella undulata, Salvadora oleoides* and *Balanites aegyptiaca*. In the same transition zone, going towards Jodhpur there is preponderance of *Tecomella undulata, Prosopis cineraria* and *Acacia senegal*, thereby indicating sign of aridity westward. The shrubs are formed of *Capparis decidua, Calotropis procera, Acacia jacquemontii* and *Zizyphus nummularia, Fagonia cretica, Indigofera cordifolia, Tephrosia purpurea* and *T. tenuis* are not infrequently met with. The grasses commonly encountered are *Lasiurus hirsutus, Dichanthium annulatum, Dactyloctenium sindicum, Cymbopogon jwarancusa, Aristida hirtigluma, Melanocenchris jacquemontii, Eragrostis ciliaris*.

IV. Desert Zone of Western Rajasthan: The arid zone, on the extreme west, comprising Jaisalmer, Gadra Road, part of Barmer, Bikaner and part of Ganganagar have annual rainfall of less than 200 mm and that is also very erratic. This zone is very sandy. There is paucity of species and only few can be observed dotting the landscape at considerable intervals. The notables among them are *Prosopis cineraria, Acacia senegal, A. leucophloea* and *Tecomella undulata*. The shrub layer is formed by *Calotropis procera, Capparis decidua, Lycium barbarum, Calligonum polygonoides* and *Tecomella undulata, Crotalaria burhia* and *Aerua persica*. The predominant grasses are *Lasiurus hirsutus, Eleusine compressa, Cymbopogon jwarancusa, C. parkerii, Aristida funiculata, A. hirtigluma* and *Melanocenchris jacquemontii*.

While dealing with this tract, it would not be irrelevant to state about the aggressive exotic species *Prosopis juliflora*, which has established itself very well both in the semi-arid and arid tracts. It has remarkable powers of drought resistance and comes up easily on sheer rock and has phenomenal capacity of coppicing and throwing root suckers. The foci of spread are the vicinity of towns and road side plants. Apart from the above vegetation there are a few edaphic formations and, hence, a passing reference to them would be quite befitting. In the depressions and 'ranns' of the arid and semi-arid zones where salinity is very high, as at Pachbhadra, Sanwarla, Kanod and Birantsar, halophytic plant communities comprise of *Haloxylon salicornicum, Suaeda fruticosa, Zygophyllum simplex, Atriplex* species and *Tamarix dioica*. The conspicuous grasses are *Aeluropus lagopoides, Sporobolus marginatus, S. arabicus* and *Eleusine compressa*.

DELIMITATION OF CLIMATIC ZONES OF RAJASTHAN BY VARIOUS METHODS

Normals of meteorological elements published in Climatological Tables for observatories in India (India Met. Department, 1953) have been utilized in this study. For stations, Phalodi and Jaisalmer etc. whose normals are not included in the above table, the same have been worked out from data of individual years. While drawing the isopleths under different climatic classifications, all available data of neighbouring stations in India and Pakistan were also taken into account.

(1) Koppen's method: Koppen (1923) set out the following limits for the boundaries between desert and steppe and dry and tree climates for regions having rainfall maximum in summer which is the case with Rajasthan also.

Boundary between dry and tree Climates

$$r = 0{\cdot}44t - 3$$

Boundary between steppe and desert

$$r = \frac{0{\cdot}44t - 3}{2}$$

where t and r are mean annual temperature (°F) and mean annual precipitation (inches) respectively.

According to Koppen's classification, Western Rajasthan inclusive of Jodhpur is in the desert while east Rajasthan is classified as steppe with the exception of Jhalawar Dungarpur and Mount Abu regions which work out to be tree climates. Fig. 1 gives the map of Rajasthan showing classification by this method. Evidently this classification is comparable with the vegetation pattern both with regard to desert and tree climate regions. Steppe is, however, completely absent under Indian conditions.

(2) De Martonne's method: De Martonne (1928) employed the following index to delimit different vegetational zones of the earth.

$$I = \frac{\text{Annual precipitation (mm)}}{\text{Mean annual temperature (°C)} + 10}$$

According to him, indices below 5 characterize true desert from botanical as well as hydrographical point of view. Indices above 10 correspond to dry steppe, 20-30 correspond to prairies and above 30 correspond to forest vegetation. Fig. 2 showing the isopleths of De Martonne's indices reveals that true desert is confined only to the western most portion covering Jaisalmer and part of Bikaner

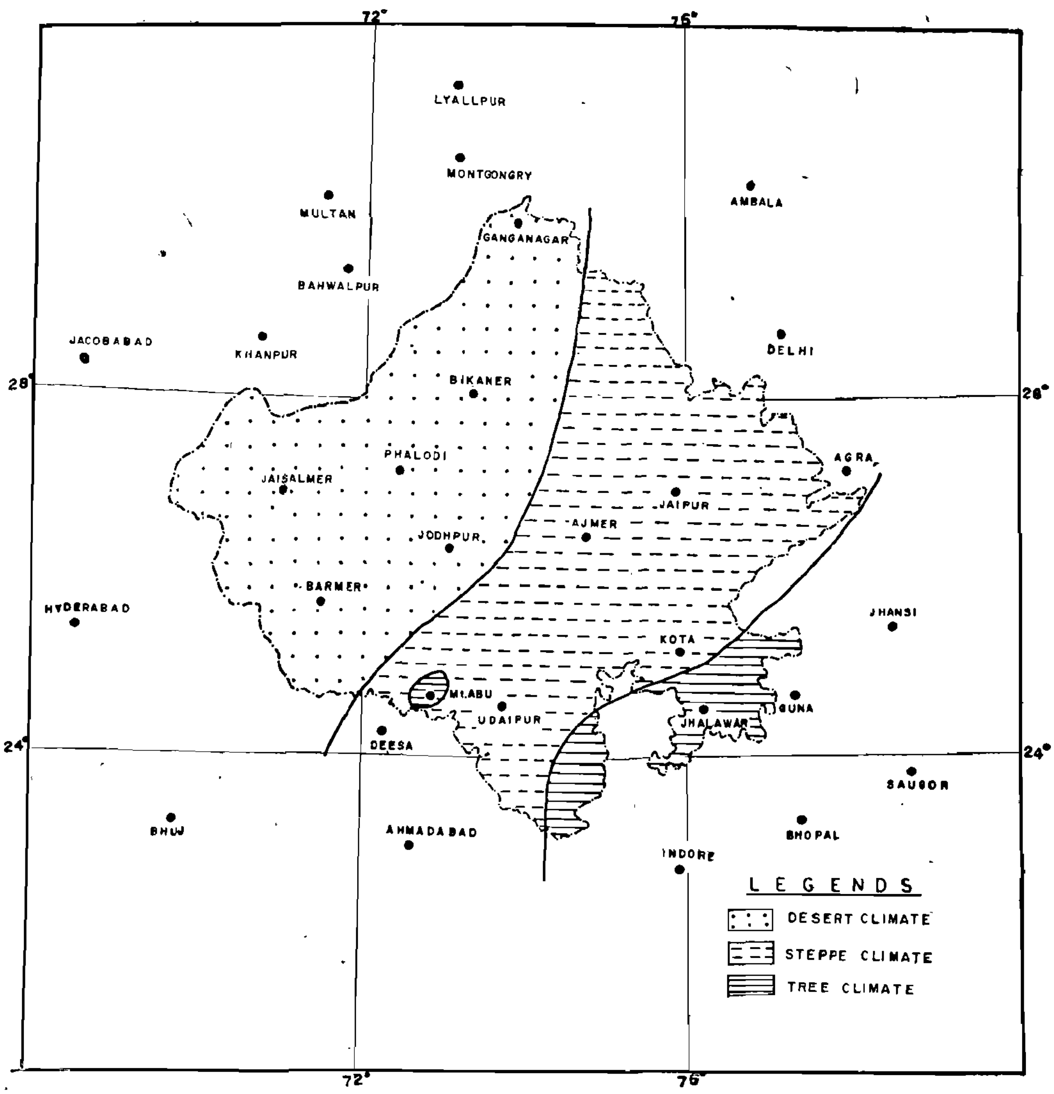

Fig. 1 — Koppen's climatic classification

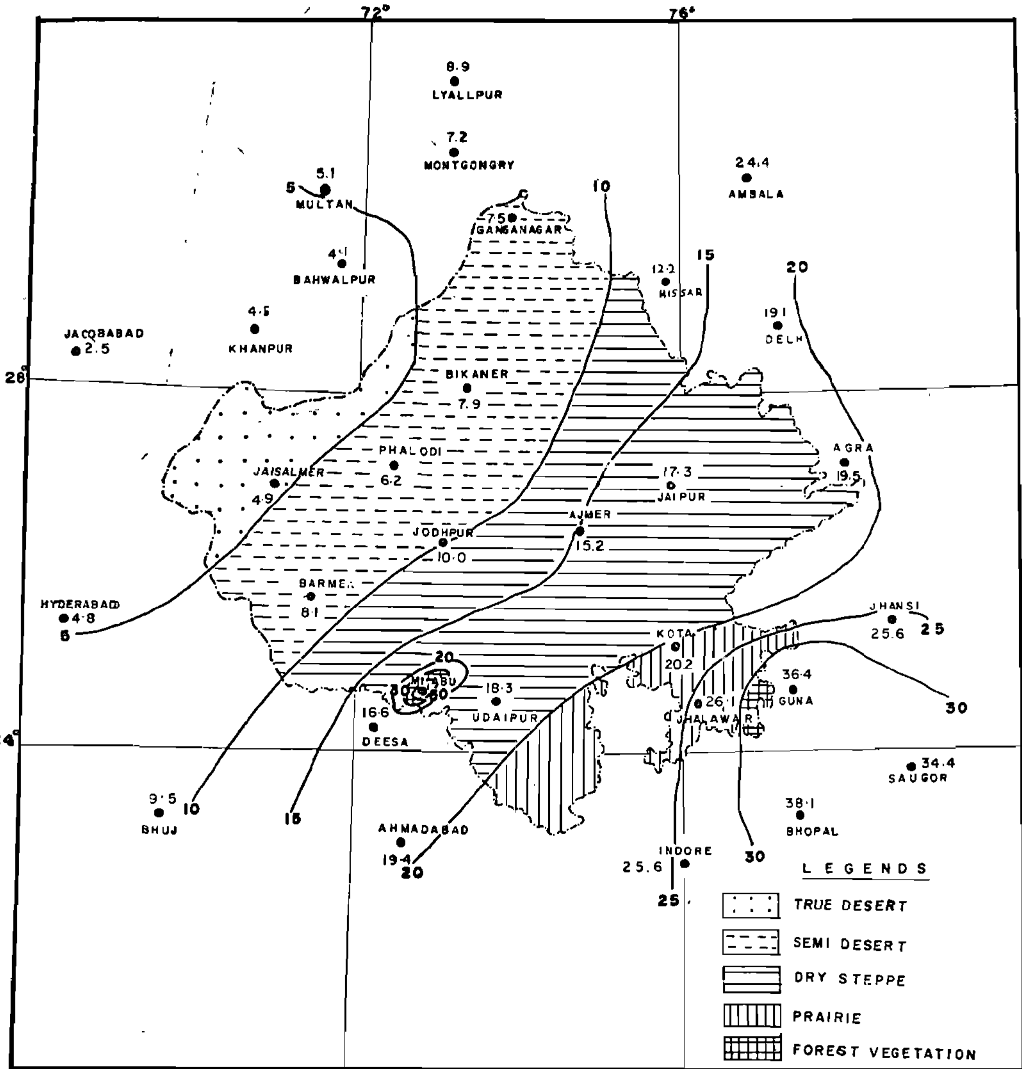

Fig. 2 — Demartonne's bioclimatic classification

districts. The regions east of it covering the rest of Bikaner district, Jodhpur, Barmer and Ganganagar are classified as semi-desert. In East Rajasthan the southern part is classified as the region of prairies and the remaining as dry steppe. Mount Abu is, of course, classified as a region of forest vegetation. This classification showing true desertic conditions in Jaisalmer regions has some relationship with the vegetation there, which is a degraded open thorn forest. However, his limits for semi-desert do not satisfactorily explain the vegetation, further, prairies and steppe zones are not found here.

(3) Gaussen's method: This method involves use of embrothermic diagrams and xerothermic indices (i.e. indices of hot weather or drought). The essential factors taken into account in this climatic classifications are temperature, precipitation, number of days of rain, atmospheric, humidity, mist and dew.

The climates are classified as warm, warm temperate and temperate if annual mean temperature is positive. Among these regions, if xerothermic index exceeds 300, that climate is desert. If it is in the range 200-300, it is hot sub-desert. This sub-desert can be further sub-divided into accentuated ($250 \angle \times \angle 300$) and attenuated ($200 \angle \times \angle 250$). Fig. 3 shows the distribution of xerothermic indices over Rajasthan. Gaussen's method indicates that there no true desert in Rajasthan except for the region around Jaisalmer and small western portion of Bikaner district. The remaining state falls under sub-desert climate being accentuated in west Rajasthan and attenuated in east Rajasthan with a

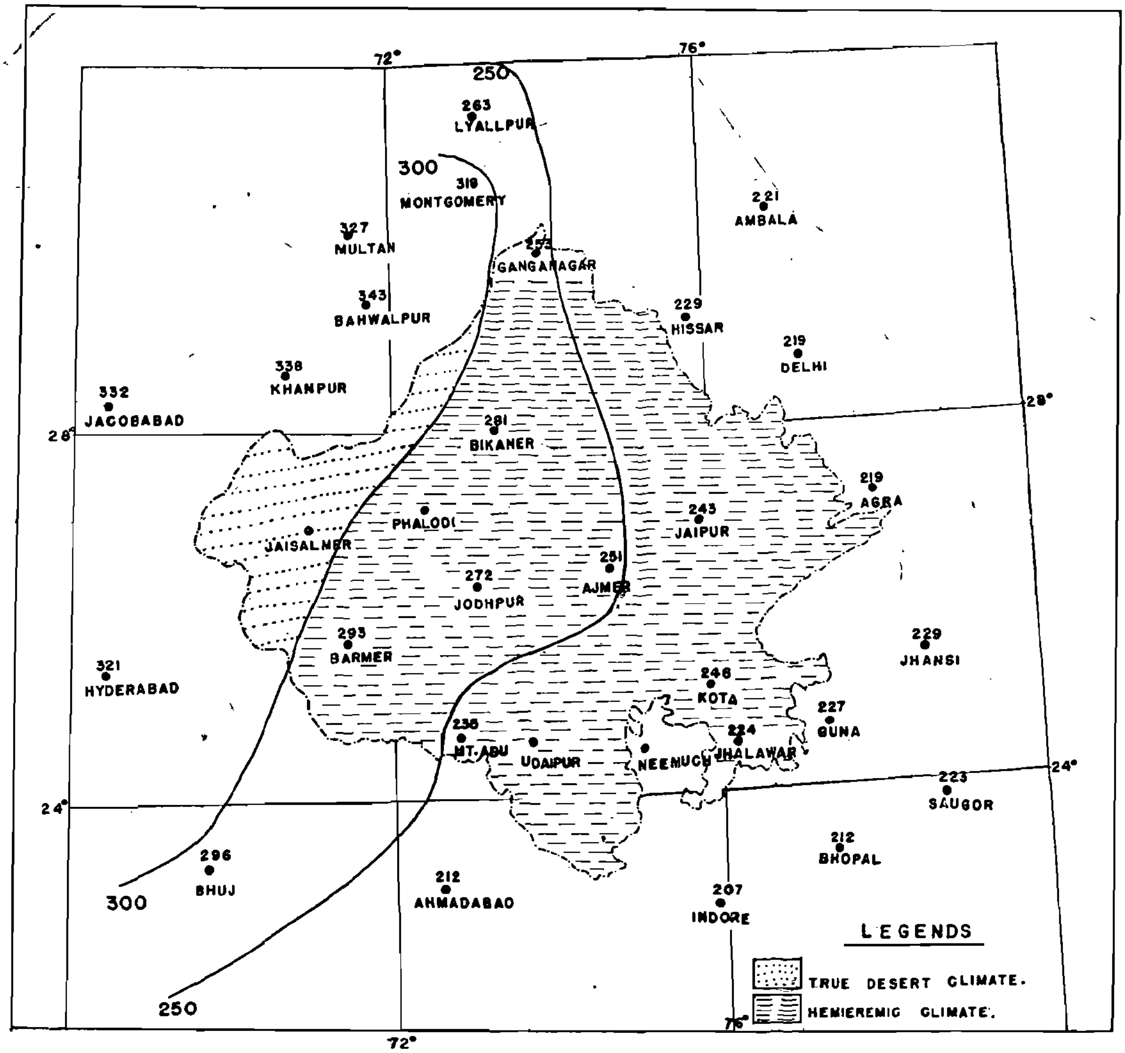

Fig. 3 — Gaussen's bioclimatic classification

transitional zone around Jaipur, Ajmer and Kota. Classifying the entire Rajasthan with the exception of Jaisalmer region as heme-eremic or sub-desertic is not reflected in vegetation which ranges from thorn forest to moist deciduous forest.

(4) Emberger's method: Emberger (1955) suggested the delimitation of various bioclimates by means of the pluviothermic quotient (Q) defined as

$$Q = \frac{100P}{M^2 - m^2}$$

where P = annual rainfall, M = average of maximum temperature in the hottest month, and m = average of minimum temperature in the coldest month. Fig. 4 showing the isopleths of Emberger's pluviothermic quotients, gives a true representation of the aridity with Q values below 40 occurring in west Rajasthan, values increasing from 60 to 100 from the northern to southern portions respectively of east Rajasthan and values above 300 occurring in Mount Abu region. This classification reflects the vegetation very closely since the arid portion as delineated by Q values less than 40, is a typical open degraded thorn forest with scattered *Prosopis cincraria* and *Salvadora oleoides* associated with a fair cover of *Lasiurus sindicus* in the interspaces. The semi-arid regions have *Tectona grandis Anogeissus latifolia* in south-east portion and *Boswellia serrata* in the north-east portion.

(5) Thornthwaite method: Thornthwaite (1948) introduced the concept of potential evapo-transpiration which is defined as the amount of water which will be lost from a surface completely covered with the vegetation if there is sufficient water at all times

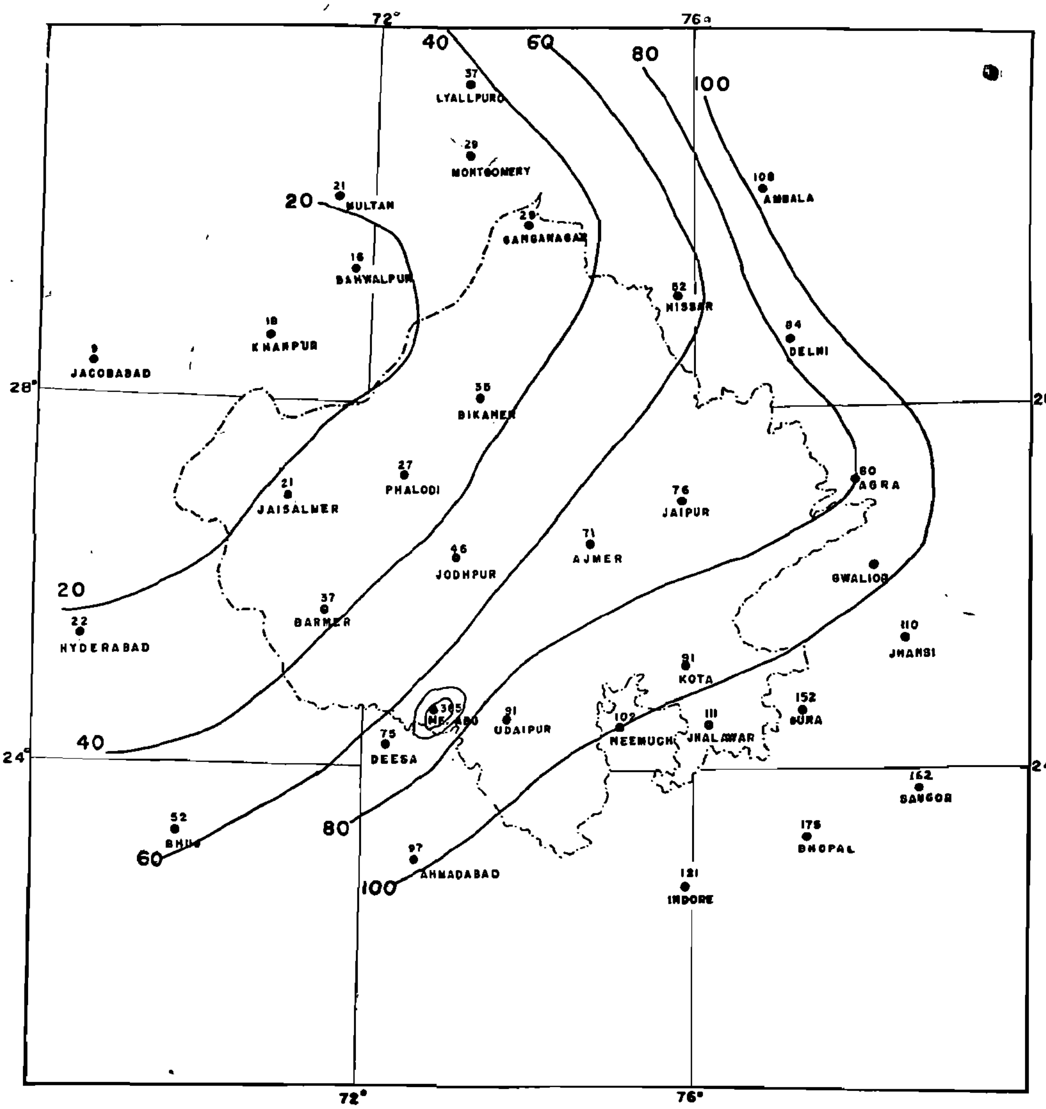

Fig. 4 — Emberger's bioclimatic classification

for the use of vegetation. A moisture index has also been defined by him relating the amount of precipitation necessary to meet the demands of potential evapo-transpiration (water need) to the amount of water available through rainfall and stored as soil moisture. Climates of a region are classified as follows according to the value of the moisture index.

Moisture index	*Climatic type*
∠ −40	Arid
−20 to −40	Semi-arid
+20 to −20	Sub humid
>20	Humid

According to this classification, there are 2 distinct climatic zones in Rajasthan, viz. arid and semi-arid with the exception of Jhalawar region which falls in Sub-humid zone and of Mount Abu which comes under humid climate (Fig. 5). The line of separation between these zones passes through Rann of Cutch, Pali and Jhunjhunu and runs in between Hissar and Rohtak in Punjab which is roughly in slignment with the Aravalli hills. This classification also corresponds well to the vegetation types described above. There is a good correlation with the thorn forest type on the one hand and dry deciduous and moist deciduous forest types on the other. The high moisture index of +84 for Mount Abu indicates clearly the moist deciduous vegetation type there.

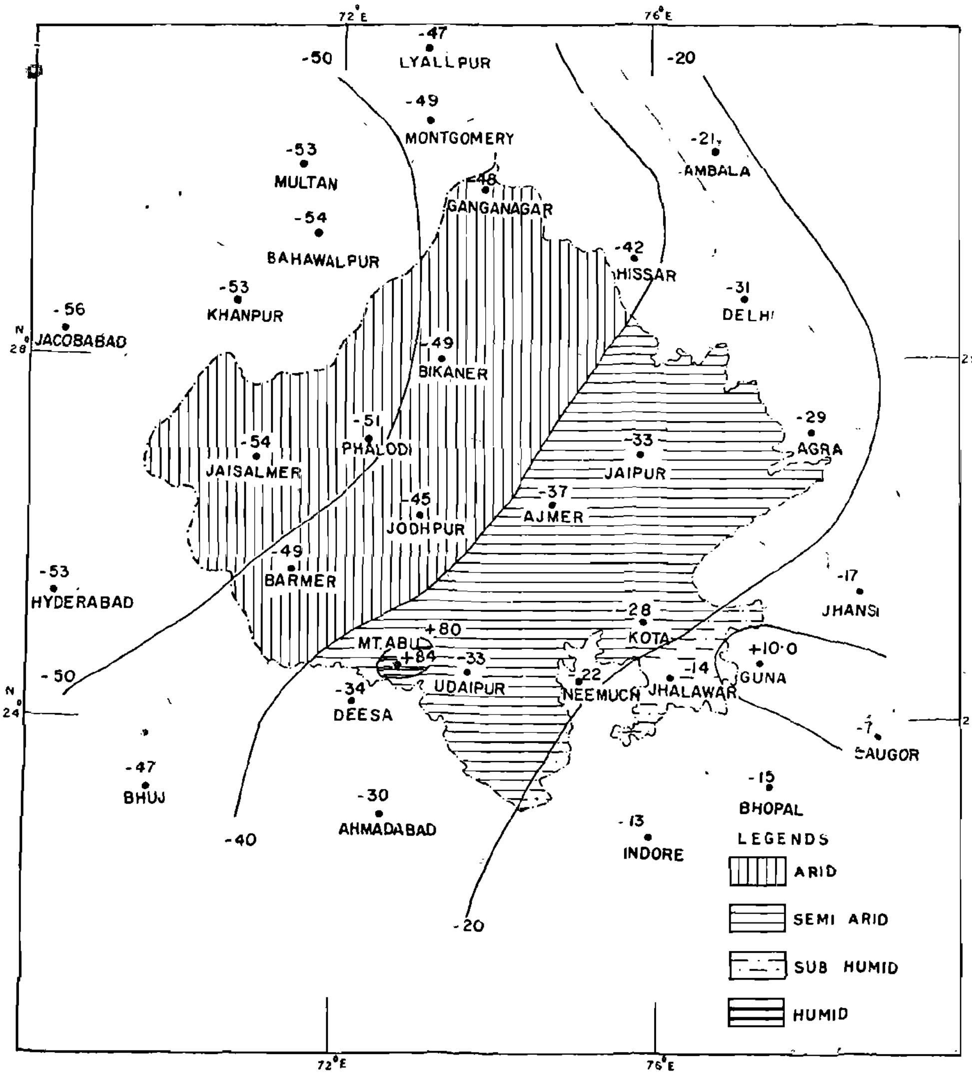

Fig. 5 — Thornwaite climatic classification

ACKNOWLEDGEMENT

The authors wish to thank Shri P. Rakhecha and Shri Narain Singh for the help rendered by them in computation of various indices and in preparation of diagrams.

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DISCUSSION

V. P. Subrahmanyam: De Mortonne aridity indices are too low for arid and semi-arid zones. Meigs suggested 10 and below for arid and 10-20 for semi arid. The classification made was also supported by work of Rao and Subrahmanyam for south India and of Bhatia for Rajasthan.

P. Jagannathan: Every climatic classification is directly linked up with the purpose for which such a classification is attempted. All empirical classifications naturally do not meet all the requirements. As De Mortanne, Thornthwaite, etc., indices have been evolved not for Indian conditions, they cannot be directly applied to these regions and suitable criteria have to be evolved. In particular Thornthwaite's criterion may not be applicable uniformly.

IS INDIAN DESERT A CONTINUATION OF SAHARA DESERT?[1]

by

P. P. SAJNANI

INTRODUCTION

PEVERIL NEIGS in his paper on ' World distribution of Arid and Semi-Arid Homoclimates ' states that there are five great provinces of dry climate over the world. The biggest of these is the North Africa-Eurasia dry province, which is larger than all the remaining dry areas of the world combined. It includes the world's largest desert, the Sahara, and a series of other hot deserts and semi-arid areas, continuing eastwards through the Arabian peninsula and along the Persian Gulf to Pakistan and India. Ramanathan, K. R. has also expressed a similar view that the Indian or Thar desert is a continuation of the arid regions of North Africa, Arabia, Iran and Baluchistan. These conclusions had been drawn on the basis of surface data. In the present paper the author has examined the upper air data of a number of stations over a vast area extending from long. 20°W to 80°E bounded between lat. 15°N and 35°N to see whether evidence can be found from upper air in support of the above view.

DATA USED

Monthly mean upper air temperatures and humidities of 21 Radiosonde stations in the area under study for the five-year period 1956-1960, collected from ' The Monthly Climatic Data of the World ', have been used. The five-year averages of these elements have been calculated by the usual method of averaging, giving equal weightage to the values for individual years.

DISCUSSION OF RESULTS

D.B. Temperature: The temperature isopleths indicate a zonal type of flow during the period November to April at both the 700 and 500 mb levels. Another noteworthy feature is that throughout the year, during each month, the temperatures at 700 mb level are nearly of the same order over the entire belt extending from Sahara to Thar. The small differences observed, range from 1 to 3 deg. C which are obviously due to purely local causes. The same feature is observed at 500 mb level also, but during winter months only.

It is interesting to note that the difference between January and July temperatures at this level is practically of the same magnitude right from Sahara to Thar. This, however, is not true of 500 mb level.

The striking similarity and closeness between the monthly variations of 700 mb temperature at Fort Trinquet in Sahara and Jodhpur in Thar indicates that these two places are situated within a degree of latitude from each other and may be taken as representative of the conditions in Sahara and Thar deserts respectively.

Study of the variation of temperature with height and time over Fort Trinquet and over Jodhpur indicates:

Temperatures over Fort Trinquet reach a maximum in July-August at all the levels. The minimum temperatures occur in December-January at 850 mb level and in January at the higher levels. At Jodhpur the maximum temperatures are found in May-June at 850 mb level shifting to June-July at 700 mb level and July-August at higher levels. The lowest temperatures occur in January upto 700 mb level and in March at the higher levels. It would appear that the hot weather period sets in a month or two earlier at Jodhpur than at Fort Trinquet which, however, experiences the arrival of cold weather a month ahead of Jodhpur. Apart from this lag in the setting in of warm and cold weather epochs the temperature curves at both the places show a marked similarity in space and trend.

Humidity Mixing Ratio: An examination of the isopleth charts, shows that in winter months (January and February) humidity mixing ratios at 700 mb level are of the order of 1 to 2 gm/kg over Sahara, Arabia and Thar. June-September values are generally higher than January-February values and show an upward trend from west to east. Thus in the month of July, the humidity mixing ratio in gm/kg at Fort Trinquet in the extreme west is 1·9, at Transaresect 2·7, Assam 3·9 and 9·0 at Jodhpur in the extreme east. The values of humidity mixing ratio over the Thar area are appreciably higher than over Sahara during June-September obviously due to the effect of Indian southwest monsoon over this region.

Isopleths at 500 mb level show a similar pattern though the absolute values of mixing ratio are considerably lower than at 700 mb level.

A comparison of the humidity mixing ratios over Fort Trinquet and Jodhpur shows that the air over Fort Trinquet is drier at all levels than at Jodhpur

1. Contribution from Indian Meteorological Department, Poona.

throughout the year, the differences being more pronounced during the period June to September. This is as should be expected because during these months weather in the Indian subcontinent is controlled by the system of southwest monsoon winds bringing in large quantities of moisture over the area, which benefit is denied to the air over Sahara.

The vertical gradient of moisture is generally more steep over Jodhpur than at Fort Trinquet particularly during June to September.

CONCLUSION

From what has been stated above it will be seen that the temperature and moisture distribution in the lower and middle troposphere over Sahara and Thar exhibit strikingly similar characteristics. Except for minor variations due to purely local features, the entire area stretching from Sahara to Thar appears to be a meteorologically homogeneous one. This evidence supports the view that the Thar desert is not an isolated desert patch but forms a part of an extensive desert belt comprising of the great Sahara and the Arid regions of Arabia, Iran and West Pakistan.

SUGGESTIONS FOR FURTHER STUDY

Modern researches in Physical Climatology show that the different types of climates owe their individual characteristics to the nature of the exchange of momentum, heat and moisture between the earth's surface and the atmosphere. The climate at a place or over an area represents the net balance between incoming and outgoing fluxes of heat and moisture. Computation of these fluxes at different points over the area comprising the deserts of Sahara, Arabia and Thar would be illuminating.

ACKNOWLEDGEMENT

The author wishes to express his sincere thanks to Dr. P. R. Pisharoty and Dr. G. C. Asnani for going through the manuscript and offering helpful suggestions.

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DISCUSSION

S. P. Chatterji: Whether the Indian desert is a continuation of the Sahara desert ?

P. Jagannathan: The world's extremely arid regions are situated under the subtropical high pressure cells where weak circulation and subsidence prevail. The studies indicate that the Sahara and the Thar come under the influence of the same cell.

C. S. Christian: The relation between Sahara and the desert of Rajasthan had been established by Mr. Dubief. Such relations existed during past geological times also although the climatic changes during the Pleistocene period are not well known as far as the southern part of Sahara and the Indian desert are concerned. More research on this subject is desirable.

FREQUENCY ANALYSIS OF RAINFALL DATA FOR USE IN SOIL CONSERVATION PLANNING[1]

by

S. K. GUPTA[2]

INTRODUCTION

ONE of the most common phases of hydrologic design is related to the frequency with which rainfall or flows of given magnitude will be equalled or exceeded or what is the average lapsed time between the occurrence of two rainfall or flow equalling or exceeding a specified rainfall or discharge? Information may be concerning probable extremes which proposed structures may be required to withstand; and many other hydrologic problems can be solved by frequency analysis using past records of rainfall, flood peaks, flood volumes, minimum flows, etc.

Frequency analysis has long been a controversial topic among engineers and general agreement as to the methods is not yet in sight. The use of flood or rainfall frequency method met some criticism, largely because it has been misused. These methods have little place in determining maximum limits of rainfall or flood design that is to determine maximum possible flood with the ordinary rainfall or stream flow record of say 25 years length, errors of sampling introduce large errors in judging the magnitude of greater events. However, if properly computed and conservatively interpreted, flood frequency analysis is a valuable hydrologic tool. The design of hydraulic structures must rest on some form of frequency analysis is unquestionable. Those responsible must through experience or otherwise, agree on basic criteria. Frequency analysis should then provide the reasonable basis for transposing the experience.

For planning various mechanical soil conservation measures Soil Conservationists need the rainfall of various frequencies. As for example for bunding, terracing, grass waterways the rainfall for 10 years frequency is required while for detention dam, permanent structures etc., the rainfall of 25, 50 and 100 years frequency is used. In the absence of these hydrological data, the Soil Conservationist faces great difficulty. The attempt is made to analyse the rainfall data of Chambal Catchment above Kota Barrage.

BASIC DATA AND TYPES OF SERIES

The basic data for frequency analysis are the series of recorded daily rainfall or rainfall charts from the recording raingauges. For this analysis, the daily rainfall data of 24 hr was taken for 26 stations. The period of these data varied from 14 years to 50 years. The recording raingauge data is only available for Kota Centre since 1956 and same was used for analysis of frequency for short duration.

As regards types of series there are two types which are widely used (i) Annual series, and (ii) Partial duration series. *Annual series* uses only the largest value in each year and ignores the second and lower order events of each year which may even be greater than annual values of the other years, while *partial duration series* uses all the values equal to or above, an artificial base. Usually the lowest of annual series is used as base.

The two types of series generally do not provide much variation for the large return period; but for shorter return period there is quite different distribution. Compared to annual series, partial duration series are very laborious and time consuming. Due to this fact both the series have been worked out for Kota only and for other stations only annual series have been used.

Fig. 1 illustrates the plotting of partial duration curve and Annual Series for Kota. It will be found that the curve in general follows almost the same lines except for frequency less than 12 years (i.e. below 50 per cent chance). Tables 1 and 2 give the estimation of plotting position by use of Hazen's method.

COMPUTATION OF THE RAINFALL FOR VARIOUS FREQUENCY

The analysis of rainfall or flood frequency is done by various methods. These frequencies can be found by plotting on log paper on computing mathematically.

PLOTTING POSITION

The analysis of a series of flood data starts with a listing of all the 24 hours maximum rainfalls of

1. Contribution from Soil Conservation Research, Demonsration, and Training Centre, Government of India, Kota Jn. (Rajasthan).
2. Assistant Soil Conservation Officer, (Engineering).

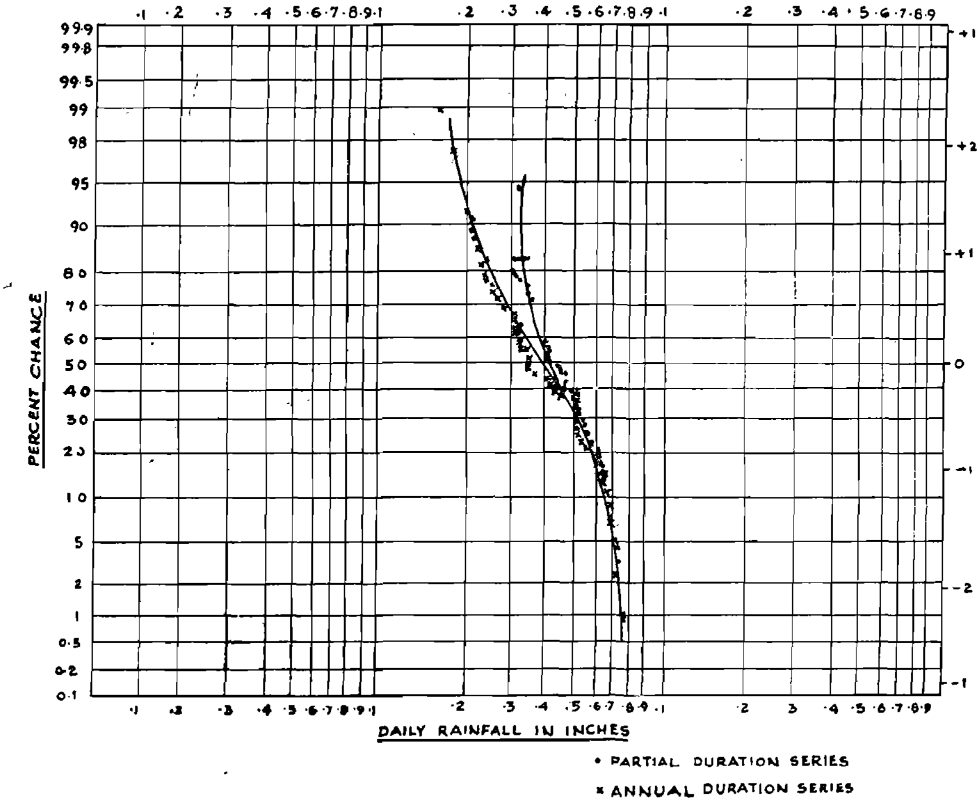


Fig. 1 — Comparison annual series and partial duration series for Kota by Hazen method

TABLE 1: Computation of maximum annual rainfall of 24 hr of Kota

Collection of data year & date	*Annual Max. 24 hrs rainfall (inches)*	*Rank No. n.*	*24 hrs rainfall*	*Plotting position Fa.*
	Arrangement in decanting order			
23rd July, 1891	2·97	1	7·80	1
13th July, 1892	5·06	2	7·30	3
21st August, 1893	2·70	3	7·29	5
21st August, 1894	3·30	4	7·12	7
7th July, 1895	5·00	5	6·97	9
31st July, 1896	7·12	6	6·79	11
11th July, 1897	2·64	7	6·34	13
16th September, 1898	6·02	8	6·38	15
8th July, 1899	7·29	9	6·04	17
20th August, 1900	4·37	10	6·02	19
26th July, 1901	2·00	11	5·65	21
2nd July, 1902	2·62	12	5·46	23
7th August, 1903	4·17	13	5·41	25
16th July, 1904	5·25	14	5·36	27
28th August, 1905	6·34	15	5·25	29
2nd July, 1906	6·97	16	5·20	31
25th July, 1907	6·08	17	5·06	33
21st July, 1908	6·04	18	5·00	35
27th August, 1909	5·65	19	4·64	37
16th June, 1910	3·50	20	4·46	39
2nd August, 1911	3·20	21	4·37	41
13th July, 1912	2·58	22	4·17	43
25th August, 1913	3·93	23	3·93	45
26th July, 1914	2·32	24	3·86	47
31st July, 1915	2·89	25	3·85	49

Collection of data year & date	*Annual Max. 24 hrs rainfall (inches)*	*Rank No. n.*	*24 hrs rainfall*	*Plotting position Fa.*
	Arrengement in decanting order			
9th July, 1916	5·36	26	3·70	51
17th June, 1917	5·20	27	3·50	53
22nd June, 1918	2·75	28	3·30	55
23rd August, 1919	2·75	29	3·30	57
26th July, 1920	3·21	30	3·21	59
8th September, 1921	2·60	31	3·20	61
6th September, 1922	3·10	32	3·20	63
29th July, 1923	5·41	33	3·10	65
28th July, 1924	6·79	34	3·10	67
18th July, 1925	2·70	35	2·97	69
8th September, 1926	7·30	36	2·89	71
20th August, 1927	5·46	37	2·75	73
21st August, 1928	3·50	38	2·75	75
27th August, 1929	3·70	39	2·70	77
30th October, 1930	3·86	40	2·70	79
17th July, 1931	3·10	41	2·64	81
10th August, 1932	3·20	42	2·62	83
17th September, 1933	1·62	43	2·60	85
9th August, 1934	7·80	44	2·58	87
12th July, 1935	4·64	45	2·32	89
2nd July, 1936	1·85	46	2·20	91
23rd July, 1937	3·85	47	2·00	93
21st July, 1938	4·46	48	2·00	95
16th July, 1939	2·20	49	1·85	97
25th August, 1940	2·00	50	1·62	99

TABLE 2: Computation of partial duration series of Kota by Hazen's method

Sl. No.	Maximum 24 hrs. rainfall	Fpd	Fa
1	7·80	100·0	0·99
2	7·30	33·3	2·90
3	7·29	20·0	4·90
4	7·12	14·3	6·80
5	7·04	11·1	8·70
6	6·97	9·09	10·60
7	6·79	7·70	12·50
8	6·34	6·70	14·30
9	6·08	5·90	16·10
10	6·04	5·30	17·80
11	6·02	4·80	19·60
12	5·85	4·30	21·70
13	5·65	4·00	23.20
14	5·46	3·70	25·00
15	5·41	3·40	27·00
16	5·36	3·20	28·50
17	5·25	3·03	30·30
18	5·20	2·90	32·20
19	5·07	2·70	33·30
20	5·06	2·60	34·40
21	5·01	2·40	37·00
22	4·92	2·30	38·40
23	4·81	2·20	40·00
24	4·80	2·10	41·60
25	4·73	2·04	43·40
26	4·64	1·96	43·40
27	4·60	1·90	45·40
28	4·60	1·80	47·60
29	4·46	1·80	47·60
30	4·37	1·69	50·00
31	4·35	1·60	52·60
32	4·30	1·60	52·60
33	4·17	1·50	55·50
34	4·15	1·50	55·50
35	4·05	1·40	58·80
36	4·04	1·40	58·80
37	3·93	1·40	58·80
38	3·90	1·30	62·50
39	3·86	1·30	62·50
40	3·85	1·30	62·50
41	3·76	1·20	66·60
42	3·74	1·20	66·60
43	3·72	1·20	66·60
44	3·70	1·10	71·40
45	3·64	1·10	71·40
46	3·50	1·10	71·40
47	3·50	1·10	71·40
48	3·46	1·00	76·90
49	3·37	1·00	76·90
50	3·30	1·00	76·90
51	3·29	0·90	83·30
52	3·29	0·90	83·30
53	3·27	0·90	83·30
54	3·26	0·90	83·30
55	3·23	0·90	83·30
56	3·21	0·90	83·30
57	3·20	0·80	90·90
58	3·20	0·80	90·90
59	3·20	0·80	90·90
60	3·20	0·80	90·90
61	3·20	0·80	90·90
62	3·18	0·80	90·90
63	3·17	0·80	90·90
64	3·10	0·70	100·00
65	3·10	0·70	100·00
66	3·06	0·70	100·00
67	3·06	0·70	100·00
68	3·05	0·70	100·00
69	3·05	0·70	100·00
70	3·05	0·70	100·00
71	3·03	0·70	100·00
72	3·02	0·60	100·00
73	2·01	0·60	100·00
74	3·00	0·60	100·00
75	3·00	0·60	100·00

Formula used in proportion of above table:

$$Fpd = \frac{2Y}{2n-1} \quad \text{Where, } Y = \text{Number of years.} \quad n = \text{Rank number.}$$

After finding *Fpd.*, *Fa* value was found by the following formula:

$$Fpd = \frac{100}{Fa} - \left(1 - \frac{Y}{T}\right)$$

$$\frac{100}{Fa} = Fpd + \left(1 - \frac{Y}{T}\right)$$

$$Ta = \frac{100}{Fpd + \left(1 - \frac{Y}{T}\right)}$$

Where *Fa* is the percentage chance, *Y* is the number of years data and *T* total number of events.

In the above analysis $Y = 50$ years
$T = 75$ Nos.

each year at one gauging station. These are ranked according to magnitude, customary starting with the highest as 1 (col. 4, Table 1). Some measure of frequency is then computed so that "Plotting position" is obtained for the frequency scale. Plotting position is in terms of percent chances (*Fa*). The objective of the frequency analysis is to determine the magnitude of the rainfall which will be equalled or exceeded once in a specified period of years, which is known as recurrence interval (T_R). The recurrence interval (T_R) can be computed by equation:

$$T_R = \frac{100}{Fa} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots(1)$$

METHOD USED FOR DETERMINING PLOTTING POSITION

California method: This is the simplest form of computation in which plotting position is found by equation (2).

$$Fa = \frac{100 \times n}{y} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots(2)$$

where

n = Rank number where data is arranged in descending order (highest as 1); and
y = Total number of years records.

This is a straightforward approach with merit of simplicity but this has a minor objection, that the probability of the lowest flood occurring is computed as 1; which precludes the occurrences of any flood lower than this (such a point could not be plotted on probability paper). Also this method gives no weight to the probability that the highest rainfall of record may some time have a recurrence interval something over y years.

Hazen method: Hazen proposed the following equation for the plotting position:

$$Fa = \frac{(2n-1)}{2y} \times 100 \quad \ldots \quad \ldots \quad \ldots \quad \ldots(3)$$

The formula assigns the recurrence interval of $2y$ to the largest item of the record. This is an artificial lengthening of the period of record. This was proposed as the data being analysed may include high frequency rainfall. For example 25 years data may include their rainfall of 40 or 50 years rainfall frequency. It may be stated in another way by saying that since the actual frequency of occurrence of the maximum events in y years is not known, it may be assumed to be $2y$, But it is considered to have a drawback that no statistical device can lengthen the period of record accurately.

Gumbel method: Gumbel has suggested a derivation based on the characteristics of the distribution for a variable correction in lieu of Hazen's factor 2. The value of correction C is function of the relative serial number m/y and nature of distribution. Where m is the rank number when arranged with lowest as number one. As such $m = y - n + 1$, Fig. 2 shows the value of C applicable to the distribution of largest values. The plotting position is given by

$$Fa = \frac{100(y - m + c)}{y}$$

$$Fa = \frac{100(n + c - 1)}{y}$$

The theory assumes that mth value of a series is the most probable or modal, value of mth value of such series. Hence, its location is skew towards the mode of the distribution.

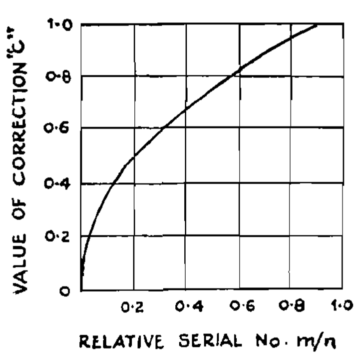


Fig. 2

Geological survey method: The formula used by the Geological survey is:

$$Fa = \frac{n}{y+1} \times 100 \quad \ldots \quad \ldots \quad \ldots \quad \ldots(6)$$

It is reported by Dalry-m-ple, that this formula gives essentially the same results as Gumbel's computed value and is much simpler to use.

Comparison of various methods: There are many other recommendations like these. Each one has its advantages and limitations. But if the data for good length of the period is available, there is not much difference in value arrived by various methods. The reliability of the recurrence interval increases as value of n increases. The main difference is only for plotting position of maximum value. The data is plotted on logarithmic normal probability paper also called log normal Hazen paper. This paper has a three cycle logrithmic scale for the data and for both percent chance and standard deviation scales for normal distribution.

The data of Kota was analysed by various method and Table 3 gives the various plotting position arrived at by different formulas. Fig. 3 shows the various curves obtained by each method.

From Fig. 3 it will be seen that curves plotted by various methods, follow almost the same curve for practical purposes. As stated earlier when the data is available for a long period it is immaterial which method is used. The short length of most hydrologic records is responsible for the need for extrapolation of frequency curves.

Testing of hydrological data for sufficient length of record: The data should be checked for sufficient length of record before being used. Generally the check is either (i) for hydrologic design purposes, where assurance is needed only that the record is long enough to give reasonably close estimates, or (ii) for watershed project evaluation, where the assurance is needed that the record is neither too shorter nor too long; since a too short record will usually give a poor estimate of the project benefits and a too long record will increase the evaluation labour without significantly increasing the accuracy of the benefit estimates.

The method for estimating required sample size is based on the equation (7).

$$t_h = (\bar{x} - m)\Big/\frac{n-1}{s}$$

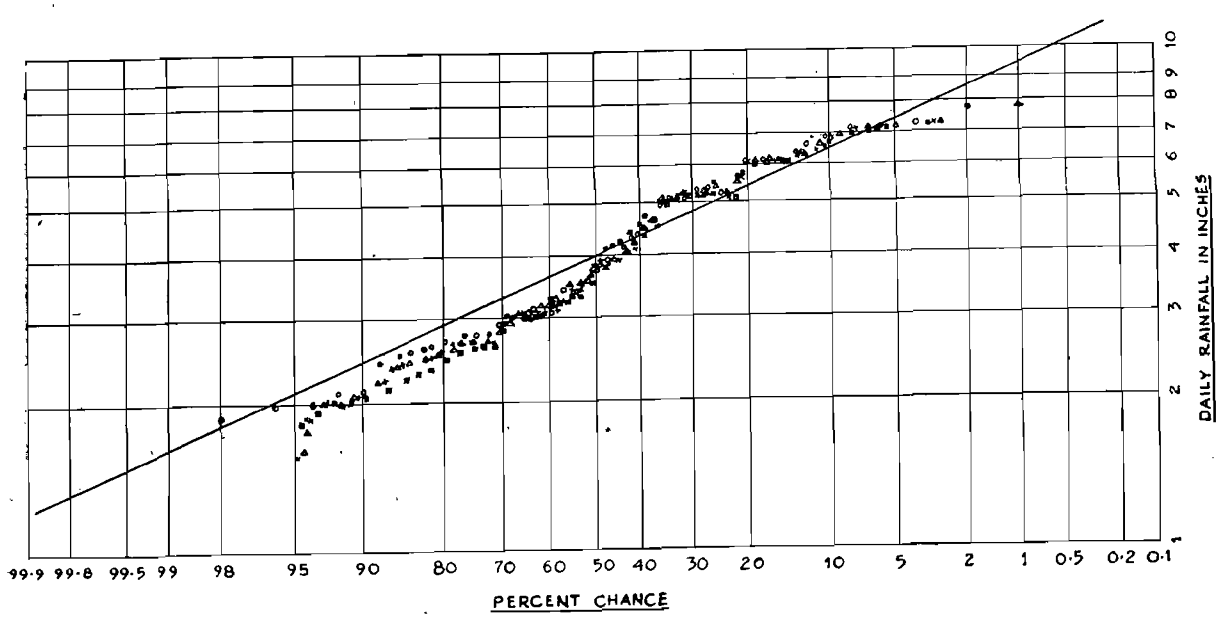
where

t = Students t at the h-level of significance.
$\bar{x}$ = Mean of sample.
m = Given value with which $\bar{x}$ is compared.
n = Number of items in the sample.
s = Standard deviation of the sample.

A 10 per cent plus or minus error at a 10 per cent level of significance provides sufficient accuracy for soil conservation use. Fig. 4 gives the curve used by Soil Conservation Service, USDA. The

TABLE 3: Comparison of frequency analysis by various methods

Sl. No.	*Year*	*Annual daily max. rainfall*	*Plotting position* Hazen EQS	Gumbel EQS	California EQS	Geological EQS	*Sl. No.*	*Year*	*Annual daily max. rainfall*	*Plotting position* Hazen EQS	Gumbel EQS	California EQS	Geological EQS
1	1934	7·80	1	2·00	2	1·96	26	1929	3·70	51	51·44	52	50·96
2	1926	7·30	3	3·96	4	3·92	27	1928	3·50	53	53·42	54	52·90
3	1898	7·29	5	5·92	6	5·88	28	1910	3·50	55	55·36	56	54·88
4	1896	7·12	7	7·92	8	7·84	29	1894	3·30	57	57·34	58	56·84
5	1906	6·97	9	9·90	10	9·80	30	1920	3·21	59	59·32	60	58·80
6	1924	6·79	11	11·90	12	11·76	31	1911	3·20	61	61·30	62	60·67
7	1905	6·34	13	13·88	14	13·72	32	1932	3·20	63	63·28	64	62·72
8	1907	6·08	15	15·86	16	15·68	33	1931	3·10	65	65·26	66	64·68
9	1908	6·09	17	17·84	18	17·64	34	1922	3·10	67	67·24	68	66·64
10	1898	6·02	19	19·82	20	19·60	35	1891	2·97	69	69·22	70	68·60
11	1900	5·65	21	21·80	22	21·53	36	1913	2·89	71	70·16	72	70·56
12	1927	5·16	23	23·76	24	23·52	37	1918	2·75	73	73·14	74	72·52
13	1923	5·41	25	25·74	26	25·48	38	1919	2·75	75	75·12	76	74·48
14	1916	5·36	27	27·70	28	27·44	39	1925	2·75	77	77·10	78	76·44
15	1904	5·25	29	29·68	30	29·40	40	1893	2·70	79	79·06	80	78·40
16	1910	5·20	31	31·66	32	31·33	41	1897	2·64	81	81·00	82	80·36
17	1892	5·06	33	33·64	34	33·33	42	1902	2·62	83	82·96	84	82·32
18	1895	5·00	35	35·62	36	35·28	43	1921	2·60	85	84·92	86	84·28
19	1935	4·64	37	37·60	38	37·24	44	1912	2·58	87	86·90	88	86·24
20	1938	4·46	39	39·58	40	39·20	45	1940	2·32	89	88·84	90	88·20
21	1900	4·37	41	41·54	42	41·16	46	1939	2·20	91	90·80	92	90·16
22	1903	4·17	43	43·52	44	43·12	47	1901	2·00	93	92·74	94	92·12
23	1913	3·93	45	45·50	46	45·08	48	1940	2·00	95	94·70	96	94·08
24	1930	3·86	47	47·54	48	47·04	49	1936	1·85	97	96·64	98	96·04
25	1937	3·85	49	49·46	50	49·00	50	1933	1·62	99	98·04	100	98·00



O CALIFORNIA METHOD
Δ HAZEN "
□ GEOLOGICAL "
X GUMBEL "

Fig. 3 — Comparison of frequency analysis of rainfall at Kota by California, Hazen, geological and Gumbel method

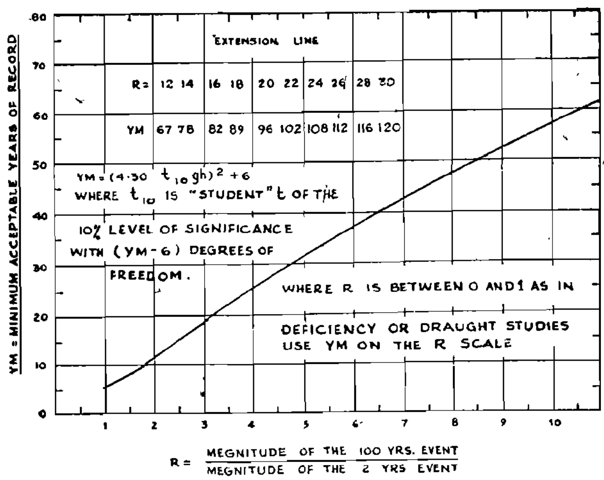


Fig. 4 — Hydrology frequency analysis criterion for minimum acceptable year of record

same was used to test the data of sufficient length of record.

Method used by various agency in United States: Soil Conservation Service USDA uses the Hazen method, U.S. Weather Bureau uses Gumbel method, while Geological survey department recommends the use of Geological method.

Computation method where the facility of computing machine (Calculator) is available the frequency analysis can be done as shown in the Table 4. But it has been found that graphical solution gives good results in general and is to be preferred to the arithmetic mean since it avoids large errors due to occurrence of intense rainfall within a short period.

Analysis of frequency for duration less than 24 hr: Similar methods for frequency analysis are used for the rainfall of 15 min, 1 hr, 4 hr, 6 hr, 12 hr, etc. These various frequency analyses are done for Kota, from the data of recording raingauge by Hazen's method (for example) and the same is given in Table 4.

Plotting isopluvial lines: Isopluvial lines are the lines of same rainfall. These are drawn in same way as the contours are interpolated in topographic survey.

The rainfall data of 26 stations was collected and various expected 24 hr rainfalls were computed for 2, 10, 25, 50 and 100 years frequency. Table 5 shows the list of the stations, the number of years of record used, and various values for different frequencies. These values were plotted at location of each station and Isopluvial maps of 24 hr rainfall for 2, 10, 25 and 50 and 100 years frequency are prepared. These are illustrated in Fig. 5.

SCOPE OF FURTHER EXTENSION OF ANALYSIS ON SIMILAR LINES

For design of contour bunding, the soil conservationists need 24 hr fainfall of 10 years frequency while for drainage they need 2 year frequency 24 hr rainfall. For design of permanent structure, the designer needs the information of rainfall of 10, 25, 50 and 100 years frequency rainfall of various

TABLE 4: Analysis of rainfall intensity of Kota for duration less than 24 hr

Year	*Observed maximum intensity in inches/hr for various duraticn*								*Remarks*
	5 *Minutes*	15 *Minutes*	30 *Minutes*	1 *Hour*	2 *Hours*	4 *Hours*	6 *Hours*	12 *Hours*	
1956	4·80	3·20	2·84	1·96	1·23	0·64	0·43	0·22	
1957	4·80	3·20	1·62	0·84	0·55	0·55	0·33	0·19	
1958	4·80	2·44	1·86	0·94	0·59	0·33	0·22	0·12	
1959	4·56	1·82	1·82	1·82	0·91	0·48	0·37	0·19	
1960	5·66	3·36	2·69	1·37	0·70	0·30	0·24	0·12	
1961	2·40	1·60	1·24	0·80	0·43	0·33	0·27	0·17	
1962	4·10	1·81	1·29	0·65	0·46	0·28	0·26	0·16	
1963	5·42	3·68	2·76	2·41	1·88	1·00	0·67	0·34	
	Design intensity for various frequencies								
2 Years frequency	4·60	2·60	1·80	1·50	0·78	0·47	0·34	0·14	
10 ,, ,,	5·50	3·70	3·30	2·60	1·40	0·78	0·50	0·25	
25 ,, ,,	5·60	4·30	3·90	3·30	1·80	0·94	0·58	0·28	
50 ,, ,,	6·00	4·70	4·40	3·70	2·10	1·10	0·64	0·31	
100 ,, ,,	6·40	5·20	5·00	4·30	2·40	1·20	0·70	0·34	

Note: 1 — The analysis is done by Hazen's method.
2 — Data computed does not pass through the test for required length of record. Till more data is collected this may serve as guide.

TABLE 5. Frequency analysis of Maximum 24 hr Rainfall in Chambal Catchment Area

No. of years	*Sl. No.*	*Name of the station*	*2 Years*	*5 Years*	*10 Years*	*25 Years*	*50 Years*	*100 Years*
50	1	Kota	3·92	5·49	6·53	7·84	8·82	9·79
33	2	Tarana	4·76	7·37	9·09	11·27	12·89	14·49
50	3	Dewas	4·71	6·97	8·46	10·35	11·75	13·14
33	4	Mahidpur	4·85	7·24	8·81	10·81	12·29	13·76
33	5	Mandsore	4·39	6·30	7·56	9·16	10·34	11·52
56	6	Ujjain	4·54	6·64	8·03	9·79	11·09	12·39
33	7	Garoth	4·36	6·73	8·30	10·29	11·76	13·22
56	8	Mandsore	3·86	5·59	6·74	8·19	9·27	10·33
68	9	Jaora	4·03	5·71	6·83	8·24	9·28	10·31
73	10	Dhar	3·91	5·70	6·89	8·39	9·50	10·60
41	11	Swasra	4·06	5·78	6·93	8·37	9·44	10·50
33	12	Mahu	4·52	6·20	7·30	8·70	9·74	10·77
73	13	Ratlam	4·83	7·00	8·43	10·24	11·59	12·92
73	14	Neemuch	3·84	5·14	6·00	7·00	7·89	8·69
14	15	Alote	4·14	6·32	7·77	9·59	10·94	12·29
12	16	Sanwer	4·00	6·35	7·89	9·82	11·26	12·69
14	17	G. S. Colony	3·69	5·24	6·27	7·58	8·54	9·50
14	18	Naraingarh	3·35	5·70	5·60	6·74	7·58	8·41
9	19	Hatod	4·29	7·00	8·79	11·05	12·73	14·39
33	20	Deepalpur	4·37	5·92	6·94	8·23	9·19	10·14
67	21	Sitapay	3·89	6·00	7·41	9·18	10·50	11·80
73	22	Pratapgarh	4·00	6·07	7·44	9·17	10·45	11·73
56	23	Barnagarh	3·80	6·01	7·48	9·34	10·34	12·08
31	24	Badnawar	4·19	6·19	7·53	9·22	10·47	11·71
72	25	Indore	5·29	6·35	7·72	9·44	10·72	11·99

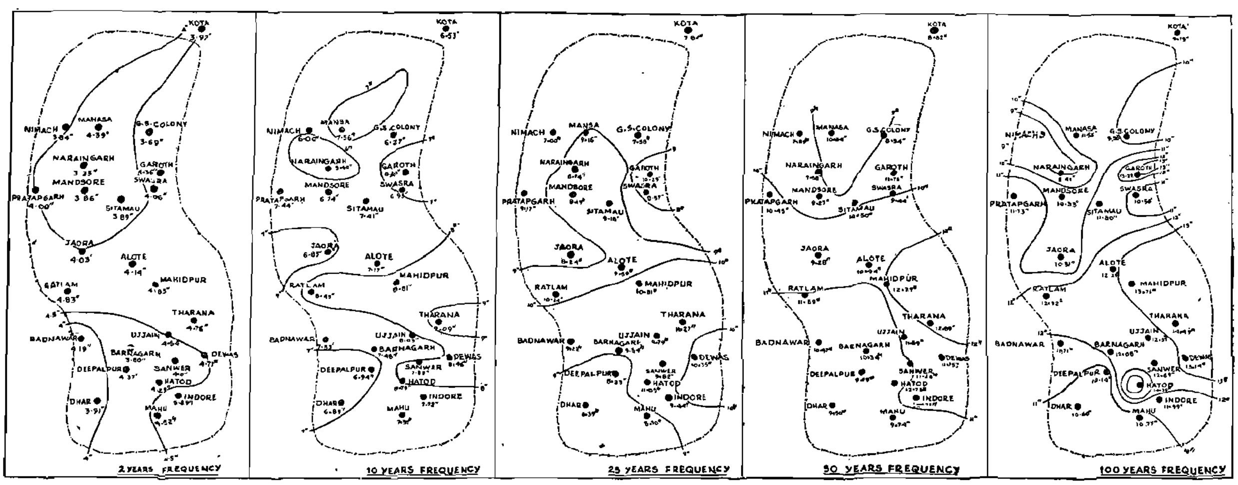


Fig. 5 — Isopluvial maps showing 24 hours' rainfall in Chambal catchment area

duration. Due to lack of availability of these data great inconvenience is being experienced and no standardization method is possible for the same. It is essential that the work on these lines should be expanded and Isopluvial map of 5 min, 10 min, 15 min, 30 min, 1 hr, 2 hr, 6 hr, 12 hr and 24 hr, are prepared for 2, 10, 25, 50 and 100 years frequency. Kota Centre proposes to extend also the study in catchment area of Chambal downstream of Kota Barrage to provide the information for the region.

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The basic data was mainly collected from the office of the Chief Engineer, Rana Pratap Sagar Dam. The facility and cooperation given by the staff of his office is highly appreciated, and I express my gratitude for the same. All the analysis and computation of these data which required laborious work of collecting data, comprising of good number of sheets, arranging and doing necessary computation was done by Shri D. P. Handa, Statistical Assistant of this Centre. The same is acknowledged.

DISCUSSION

R. V. Tamhane: Out of the four methods for analysis of rainfall data, which method is good for a short period data and has any work been or utilizing such data say for a period of less than 2 years?

S. K. Gupta: The Hazen method is generally adopted for short period data.

DROUGHT AND ARIDITY STUDIES OF THE INDIAN ARID ZONES

by

A. R. Subramaniam[1]

Of the several systems of climatic classification, since Thornthwaite's scheme (1948) is a most rational and well-recognized method of delineation of climates, it is used widely and, in particular, for the study of arid zones of the World (Meigs, 1953). Hence, in the present study, it has been adopted for the demarcation of the arid zones. According to Thornthwaite (1955) the absolutely arid zone occupies the whole of the Western India and appears as an island to the South to the east of the Western Ghats. Of the many workers that attempted a climatological study of arid conditions, particularly in North India, special mention may be made about Bhatia (1957), who concluded from his work on the Rajasthan region that Thornthwaite's method gave the best and most realistic results. Perhaps the only mentionable work so far on the aridity in South India is that of Rao and Subrahmanyam (1962), who made a study of the arid zone in the Central Deccan according to Thornthwaite's Scheme. According to them the zone lies between 14°N and 16°N and Longitudes 76°30'E and 78°30'E.

Drought is a relatively temporary departure of the normal or average climate toward aridity, this is because the economy of the region is more or less in step with the climate and is, therefore, not seriously affected by the normal fluctuations of weather. In this sense, drought becomes a climatic anomaly characterized by deficient supply of moisture. Such a deficiency may result from sub-normal rainfall, inopportune rainfall, excessive water need or, as is generally the case a combination of all the three. This suggests that a comparison of the ratio of water deficiency to water need (or Potential Evapotranspiration) in the year of study against the normal for the region under investigation to estimate the drought anomaly. With such an estimate not only the severity of the drought but also a comparative assessment of drought intensity at the same and different places can be made.

For analytical study of droughts in India the aridity index I_a of Thornthwaite (ratio of annual water deficiency to total annual water need) is found to be a very useful parameter (Subramanian and Subrahmanyam, 1962), and was successfully employed by Palmer (1957) for United States of America. Since the amplitude of the departure of the aridity index from its normal value determines the severity of a drought situation, in the classification of droughts according to their intensity it is necessary to fix limits of departure. For this purpose a statistical procedure using standard deviation 8, is employed, as was done by Ramdas (1950) in his former study of floods and droughts of India on the basis of precipitation alone. On an examination, and careful comparison with famine and other reports it was seen that the minimal departure of aridity index for drought occurrence in any climate was about $\frac{1}{2}\sigma$; with this clue an arbitrary, yet practical, scheme was adopted for categorization of droughts as given in Table 1.

Table 1: Classification of Droughts

Departure of aridity index from normal	*Drought intensity*
$< \frac{1}{2}\sigma$	moderate
$\frac{1}{2}\sigma$ to σ	large
σ to 2σ	severe and
$> 2\sigma$	disastrous

This classification of droughts was for the first time given (Subramaniam) in 1961. The climatic water balances for all the years of meteorological record (1891-1960) were computed according to the procedure of Thornthwaite (1957) for four stations, two from North Indian Arid Zone namely Jodhpur and Bhuj and two from South Indian Arid Zone i.e., Bijapur and Bellary. From the water balance elements, aridity indices for each station for the entire period of record were calculated and analysed. The results of the analysis are given below:

COMPARATIVE STUDY OF DROUGHTS AND ARIDITY

In order to study the relative intensities of droughts, years of their occurrence or periodicities, if any, the departure of the aridity index at each of the four stations, expressed as percentage of the normal for the station were plotted. It will be observed that Bellary, which is the capital of Bellary district in Mysore State, whose normal annual rainfall is 22·76 in. suffered from 'Disastrous' droughts in the years 1891 and 1923, when the rainfall amounts were 10·03 in. and 15·96 in. respectively. Bellary district

1. Contribution from Dept. of Meteorology & Oceanography, Andhra University, Waltair (A.P.)

consists of two natural divisions formed by the Sandur hills that run right through the middle from North-West to South-East. The two division are widely different in soil characteristics, but have one thing in common that they both slope gradually northward towards the river Tungabhadra. The entire district is in the rain shadow of the Western Ghats from the South-West monsoon and far from the path of the North-East monsoon current to receive any rainfall. The 'Great Famine' of Bellary occurred during 1876-78 lasting for 22 months, taking a toll of 3½ million lives costing Rs 630/- lakhs by way of relief works. The drought of 1891 was less disastrous than that of 1877, in spite of which only two-thirds of the arable land was cultivated with dry crops and over ¼ of the area, the crops withered totally. No human mortality was reported, except from cholera, but the loss of cattle was very great. One third of the breeding and young stock died and there was general loss of 8 per cent of the tilling cattle. The drought which occurred in 1923 was the least disastrous of the three; even so, many people were on relief rolls. Thus at Bellary whenever disastrous droughts occur, appalling famine conditions may be expected.

Bijapur, also in Mysore State indicates lesser liability to drought than Bellary. The district of Bijapur is barren and dreary; tillage is confined to the valleys and from a few uplands issue streams fringed with wild date trees. The Don valley which begins close to the old city of Bijapur crossing the district from east to west, has great scarcity of water. The district has fair capabilities of development as there are rivers and water courses. The rainfall is extremely irregular varying greatly both in amount from year to year and distribution through seasons in individual years. At almost all times of the year, most parts of the district, the Don Valley perhaps more than others, are exposed to strong blighting winds which are responsible for large evaporation losses. Owing to its capricious rainfall, Bijapur is very much subject to failure of crops and consequent scarcity conditions. The year 1791 is remembered by the people as the year of 'Skull Famine', caused by drought, the ground being covered with the skulls of the unburied dead. This district experienced the worst drought in 1896, however, the drought was not disastrous but was only in the range of severe ones. Even 'severe' droughts are less frequent here than compared to Bellary (Bellary 13 and Bijapur 8).

Bhuj is situated in the Kutch State which is almost entirely cut off from the subcontinent of India — on the north by the Great Rann, east by the Little Rann, south by the Gulf of Kutch and west by the Arabian Sea. Though, on the whole treeless, barren, and rocky, the aspect of this country is varied by ranges of hills and isolated peaks, by rugged and deeply cut river beds, and well-tilled valleys and tracts of rich pastureland. There are no permanent rivers and owing to the porous nature of the upper soil, storage of water in ponds and reservoirs is extremely difficult but brackish water is found in rocks at no great depth. In 1813 adrought was reported to have caused in the Kutch State such fierce famine conditions that many sold their children for food and a cat or a dog was a delicacy and even human flesh was eaten. During 1899, the State suffered from famine owing to very low rainfall, which was only 2 in., or one-sixth of the average; and Rs 24 lakhs were spent on relief works. The departure of the aridity index is highest for the year 1899 for the entire period of its meteorological record. Bhuj as in the case of Bellary has 13 years of 'Severe' water deficiency.

Liability to drought at Jodhpur is the least compared to the other three stations studied so far. Jodhpur is located in Marwar (= 'region of death', from Rajasthani) which as its name implies is sterile, sandy and inhospitable. The climate is dry even in the monsoon period, and is characterized by extremes of temperature variation even during the cold season. The hot months are intense in heat; scorching winds prevail with great violence in April, May and June and dust and sand storms are a frequent occurrence. Rainfall is so erratic and pitiable that local saying states, 'Some times only one horn of the cow lies within the rainy zone and the other without'. The drought in 1899 was the worst during the period under study and two other years of lesser distress were 1916 and 1918. However, a subsequent general decrease in liability to droughts is apparent as seen by the fact that in all the years from 1920 to 1946 the departures of aridity index were less than σ and from 1947 to-date they even fell below the normal value.

Since it is a matter of great interest to examine the years 1899 and 1918 when countrywide famines were reported to have occurred in the Indian Sub-continent, the departures of aridity index as percentages of normal at respective places are given in Table 2.

TABLE 2: Departure of Aridity Index as percent of normal in Famine Years

Station	1899	1918
Bellary	15·5 (S)	10·7 (M)
Bijapur	6·1 (M)	29·2 (S)
Bhuj	33·6 (S)	28·7 (S)
Jodhpur	27·2 (S)	26·4 (S)

here S = Severe drought and
M = Moderate drought.

One can readily see that none of the 4 stations recorded 'Disastrous' droughts in both the famine years, and further Bijapur in 1899 and Bellary in 1918 experienced only moderate droughts.

TABLE 3: Half period Averages of Aridity Indices (%)

Station	*Mean for 1st half (I)*	*Mean for 2nd half (II)*	*Difference (II minus I)*
Bellary	67·0	67·0	0·0
Bijapur	65·6	65·1	−0·5
Bhuj	73·0	74·7	+1·7
Jodhpur	78·2	75·6	−2·6

+ve values indicate increasing aridity and −ve values indicate decreasing aridity.

It is clear from the above that while Bijapur and Jodhpur indicate decreasing aridity, Bhuj points to increased aridity. On the other hand, Bellary shows no change in its value from the first to the second half and thus appears to be stable climatically at least from the aridity point of view.

FREQUENCY OF DROUGHTS

The frequency of occurrence of effective droughts (departure of aridity index exceeding $\frac{1}{2}\sigma$ limit), which have impact on agricultural yields and normal activities of life, namely, large, severe and disastrous in decade intervals at each station from the beginning of record is shown in Fig. 1. At Bellary (Fig. 1a) it can be observed that during the period 1891 to 1910 there were 4 droughts per decade (3 of them above the σ limit) and from 1911 to 1940 there were 5 drought years (with at least 2 severe ones) in every ten. The period 1941-'50 was more congenial compared to the rest in as much as only 2 severe droughts occurred. In the subsequent decade only 5 years were subjected to analysis and among them 2 years experienced drought conditions (one severe and one large). Thus, generally speaking, at Bellary a minimum of 4 drought years may be expected in a normal decade.

Bijapur (Fig. 1b) recorded 3 drought years per decade during 1891 to 1910 (two of them being severe). During the decade 1911-1920 the number of drought years was five (four severe and one large) and all time maximum until 1955. Subsequent decades from 1921 showed a gradual decrement in the frequency of drought; and the decade 1941-'50 was the most prosperous one having had only one year of severe drought. Once again during the period 1951-'55 (data for 1953 not available) there was one drought year. Hence, at Bijapur in a normal decade there are three probable drought years.

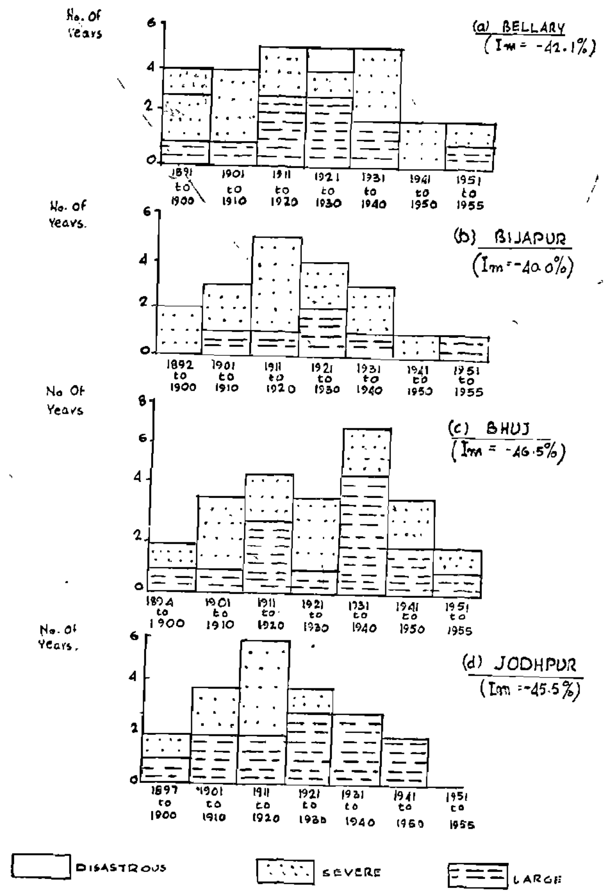

Fig. 1 — Frequency of drought occurrence in arid zones

Bhuj has a steady frequency of 4 drought years per decade (Fig. 1c) and the worst decade, (1931-'40), experienced as many as 7 drought years (5 large and 2 severe), while the worst drought decade at Jodhpur (1911-'20) had recorded only 6 drought years (5 severe and 1 large) as can be seen from Fig. 1d. The local maxim " one lean year in every three " in Rajputana has been entirely true at Jodhpur but only up to 1940. Curiously enough, this happens to be so even at Bhuj which shows two drought frequency peaks, the former one (1911-'20) being of a secondary nature. Jodhpur after 1940 appears to have undergone a definite change in its climate towards lesser aridity as witnessed by the fact that there were only 2 drought years (both of them being of the large category) in the decade 1941-'50 and no drought years (normal climatic situation) from 1951-'55.

Generally speaking, therefore in the arid zones of India the decade 1911-'20 was so bad that at least 5 drought years were experienced at each station. In contrast the decade 1941-'50 showed a trend normal or even sub-normal frequency of droughts at different places.

CLIMATIC SHIFTS

Considering the wide deviations in water balance, both in respect of water deficiency as well as water surplus, it is not unlikely that the normal climatic regime of stations is occassionally thrown entirely into one of more arid or more humid category. It is such abnormal occurrences that are of great academic interest and a systematic analysis of them may even provide clues to secular or periodic changes in climate. As a matter of fact several situations of this kind became apparent in course of the present study and in order to obtain clear evidences of climatic shifts, time trend graphs were prepared in each case with the moisture index (Im) of Thornthwaite rather than the aridity index as the ordinate.

TABLE 4: Climatic Shifts in Arid Zones

Station	*No. of years the Station Shifted to*		*Year and I_m % of greatest shift*
	Semi-arid	*Dry sub-humid*	
Bellary (S. India)	24	0	1917, −21·2
Bijapur („)	30	0	1892, −21·2
Bhuj (N. India)	6	1	1926, −7·7
Jodhpur („)	7	1	1917, −16·6

The two stations in the Central Deccan, namely Bellary and Bijapur show climatic oscillation only into the Semi-arid and they went nearly dry sub-humid each once during the period under study. Bhuj and Jodhpur have, on the other hand, wider ranges of oscillations in as much as in rare years they even become dry sub-humid as witnessed by the year 1926 at Bhuj and 1917 at Jodhpur. Their migration into semi-arid is far less frequent than in the case of Southern stations.

Studies on similar lines were carried out in the other dry climatic zones also, viz. Semi-arid and dry sub-humid (Subramaniam, 1961) and reported (Subrahmanyam & Subramaniam, 1963). Presently, investigation of droughts in the moist climates are under progress and will be communicated shortly. It is felt that such studies are of great concern from the point of view of improvement in our national economy.

ACKNOWLEDGEMENT

I wish to record my grateful thanks to my mentor Dr. V. P. Subrahmanyam and to the Council of Scientific & Industrial Research, India, in enabling me to present this paper at the Symposium.

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EFFECT OF HYDROXY ETHYLENE DOCOSANOL (OED) ON EVAPORATION OF WATER FROM SOIL SURFACE[1]

by

N. D. REGE, A. R. BHASKARAN & N. S. JAYARAM

INTRODUCTION

EVAPORATION losses from soils constitute a major problem in arid zone farming; use of evaporation suppression agents in the reduction of water loss by evaporation and free water surface is fairly well established; but, attempts at such use in lessening evaporation losses from wet soil surface have been few. Olsen, experimenting with hexadecanol, observed a 43 per cent decrease in water loss by evaporation from a Weld Loam soil. Woolley (1962) records a similar observations from wet sand treated with hexadecanol.

The sequel is a report on the results of an experiment designed to study the evaporation suppression effect of hydroxyethylene docosanol (OED) on a sandy loam soil (Andhra Soil Series I).

MATERIAL AND METHODS

Hydroxy ethylene docosanol, ($C_{22}H_{45}O.(C_{22}CH_2O)H$) is an hydrogenated product of erucic acid (source rape seed oil) synthesized by the National Institute of Agricultural Sciences, Japan. The chemical used in this study is OED, a proprietory product of M/s. Nikken Chemicals Co., Ltd., Japan.

100 g of sieved soil was spread evenly on eight 10 cm petri dishes and moistened to field capacity (approx. 20 ml) Four petri dsihes were treated with OED liquid (5 g/litre concentration) at 2 ml per dish, sprayed uniformly on the surface with a spray gun. The remaining four dishes were treated as control. The water loss from the dishes (at room temperature 33°C and humidity 52 per cent) every hour was determined, gravimetrically from the start of a drying cycle.

Hydroxy ethylene docosanol (OED) decreased evaporation loss from soil surface by 15·5 per cent on an average from hour to hour, the range being 21 to 12 per cent. The reduction in evaporation is very highly significant at 1 per cent level (F. test).

DISCUSSION

Hydroxy ethylene docosanol is preferred for its additional advantages such as very low toxicity (Tokita *et al.*, 1962) cheap raw materials, high stability, high velocity of molecular layering, desirable influences on growth, rooting, yields and vigour of vegetation (NIAS) besides, its evaporation suppression effect on wet soil surfaces.

The data recorded is presented in Table below:

TABLE 1: Mean effect of OED liquid (5 g/litre conc.) on water evaporation from 100 g of a sandy loam soil in 10 cm dia. petri dishes. (All treatments at field capacity at the start of the drying cycle)

Treatments	*Evaporation loss in g of water at hourly intervals (Mean of 4 replications)*						
	1st hour	*2nd*	*3rd*	*4th*	*5th*	*6th*	*7th*
Control	1·335	1·132	1·395	1·395	1·230	1·278	1·534
OED spray @ 1 g/m²	1·152	0·888	1·161	1·161	1·071	1·099	1·168
% of evaporation suppression	13·7	21·6	16·8	16·8	12·9	14·0	12·4

Mean suppression	15·5%		
SEM	0·01	% SE	2·21
C.D. at 1%	0·05		

Differences due to treatment are very highly significant.

1. Contribution from Soil Conservation Board, Ministry of Food & Agriculture (Department of Agriculture, New Delhi).

The mean suppression ratio of 15·5 per cent with OED use at the rate of 1 g/m² confirms the results, obtained by Mihara (1962) who obtained 30 per cent suppression with 2 g/m², 50 per cent with 7 g/m² and 70 per cent with 20 g/m². The results confirm that suppression of evaporation is due to multi-molecular filming on surface and not by mono-molecular filming as on free water surface. A molecule of OED is 3 m/m in length and 0·3 m/m in diameter and 1 g/m² spray on soil surface produces over 600 molecular layers of OED. The linear relationship between concentration of OED and suppression effect suggests that a cloddy soil surface should present no problem if adequate care is taken in spraying the surface evenly.

Olsen (1964) and Woolley (1962) report an initial lack of suppression effect with hexadecanol which according to them is probably due to low filming velocity in soil water medium. Observations in the present study with OED do not reveal any time lag in suppression effect; possibly OED is instantaneous in forming an hydro-phobic layer on the surface.

SUMMARY

Evaporation losses from soil surfaces is a major problem in arid zones. This study devoted attention to evaporation suppression effect of OED on soil surface. Results from a drying cycle reveal that OED reduces evaporation from bare soil surface by 15 per cent on an average. Higher suppression effects are indicated with the use of OED in higher concentrations.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the free supply of OED paste by M/s Nikken Chemical Co., Ltd., Tokyo; and, the guidance in and encouragement to this study by Dr. R. V. Tamhane, Advisor, Soil Conservation, Government of India, New Delhi.

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DISCUSSION

H. Nath : One of the limitations of the use of materials like cetyl alcohol for prevention of evaporation from water surfaces is the vulnerability of the films to be broken by high wind and also they require frequent use. Would the author state whether similar defects have been observed ?

P. G. Adyalkar : Have any experiments been done under field conditions in the arid zone of India ? What will be the cost per acre ?

A. R. Bhaskaran : This material acts in the polymolecular form and the layer does not break. No field experiments have been performed.

WATER BALANCE AND SELECTION OF SPECIES

CLIMATIC WATER BALANCES OF THE INDIAN ARID ZONES[1]

by

V. P. SUBRAHMANYAM

ONE of the most controversial problems in Applied Climatology today is the identification of arid and humid climates and the delimitation of their boundaries. The major difficulty in arriving at the definition of an arid zone is, as stated by Wallen (1962), that so many factors are involved — such as rainfall, temperature, insolation, evaporation, relative humidity, vegetation, soil composition etc., but all are agreed that the essential factor is the small amount of precipitation. In 1952 Pramanik, Hariharan and Ghose (1952) defined deserts in India as areas having rainfall of 10 in. or less and a mean annual diurnal temperature range of 24°F or more; the semi-deserts were defined by the same authors as areas having rainfall between 10 in. and 20 in. and a mean annual diurnal temperature range of 18°F or more. Taking vegetation as the basis for defining climatic zones, along with other factors that govern evaporation, such as wind velocity, barometric pressure etc., Bharucha (1955) found that the limit of the arid region in India as defined by Pramanik *et al.* viz., the 10-in. isohyet, was correct but that of the semi-arid region corresponded with the 30-inch isohyet.

According to the first comprehensive classification of world climates proposed by Koppen (1900), the limits of arid and humid areas were determined on the basis of empirical formulae which expressed the mean annual depth of precipitation for different seasonal distributions - uniform, summer maximum and winter maximum — at various mean annual temperatures along the moisture boundaries of dry climates.

The dry climates were designated Steppe or Desert depending on whether they received more or less than half the critical amount of precipitation.

Not being satisfied with Koppen's criteria, later workers, in particular de Martonne (1905), considered the effectiveness of precipitation by defining an index of aridity, I, given by $I = P/T - 10$. Vegetation studies in Tropical East Africa by Moreau (1938) and Perrin (1931), however showed that the numerical limits proposed by de Martonne for different climatic zones were rather too low. Meigs (1953) later stated that an index of 10 is more representative of the arid and 20 of the semi-arid regions. Bhatia's study of the arid zone of India and Pakistan (Bhatia, 1957) and more recently, of the Central Deccan by Rao and Subrahmanyam (1962), confirmed Meig's findings. Stenz earlier made an unsuccessful attempt (Stenz, 1946) at a climatic classification of the Afghanistan by applying his own idea of dryness index and Gorczynski's aridity factor (Gorczynski, 1943).

By far, the first attempt at a rational classification of climates was made in the year 1948 by Thornthwaite (1948) and his scheme for the delineation of moisture climates was based on the universal concept of the hydrologic cycle. He suggested that the precipitation received by a region should be compared systematically on a monthly basis with its water-need to arrive at a net annual water surplus (in which case the climate is moist) or a water deficit in case of a dry climate. For a quantitative evaluation of these water surpluses and water deficiencies, Thornthwaite proposed his famous book-keeping procedure for water balance, in which precipitation is treated as income, potential evapotranspiration as expenditure and the amount of moisture stored in the soil as a reserve that can be drawn upon in times of deficient precipitation. The term ' Potential Evapotranspiration as contrasted from the ' Actual Evapotranspiration ', was in fact coined by Thornthwaite himself to denote the maximum amount of evaporation and transpiration from a densely vegetated land area, provided there is no deficiency of water in the soil at any time. Since data of potential evapotranspiration were not readily available and experimental measurement of this parameter has not been simple, Thornthwaite evolved a semi-empirical formula for its computation from geographical and climatic factors. Most of the present day criticism against Thornthwaite's work is only about the hypothetical nature of potential evapotranspiration (abbreviated as P.E.) and its determination from an empirical expression but not about the water balance procedure derived from the universally accepted hydrologic equation. Strangely, it is the very hypothetical property of the P.E. that is its virtue, for, otherwise it can never represent the water need of a place. A few controversial items in the book-keeping procedure in regard to field capacity of the soil and utilization of the stored soil moisture for purposes of evapotranspiration have been rectified by Thornthwaite and Mather (1955) in their revised scheme.

The elements of the Thornthwaite scheme of climatic classification have been fully discussed

1. Contribution from Department of Meteorology and Oceanography, Andhra University, Waltair.

in the earlier publications of the present author (Subrahmanyam, 1956, 1958) and so are omitted here. In the present study the 1955 revised scheme of Thornthwaite has been used, for, in spite of a few deficiencies, it is based on rational concepts and its empirical content is no more serious than that of other schemes existing today.

The absolutely arid zone ($Im \angle -40\%$) occupies the whole of Western India and appears as an island in the central portion of South India, east of the Western Ghats. The semi-arid region (Im between -20 and $-39{\cdot}9\%$) runs from north to south, extending down to the tip of the peninsula. To the east of this semi-arid belt in North India lies the dry sub-humid fringe (Im between 0 and $-19{\cdot}9\%$) while in South India the transition of dry into humid climates is from east to west, closely following the isohyetal patterns in both cases. Interestingly, the existence of arid pockets in the Central Deccan has not been brought out by any previous schemes of climatic classification. Recent studies by Rao and Subrahmanyam (1962) have shown that this zone which lies between 14°N and 16°N latitudes and 76°30′E and 78°30′E longitudes receives poor rainfall from the south-west monsoon owing to its location on the lee side of the Western Ghats; storm tracks from the Bay of Bengal rarely pass over this area. So far as the north-east monsoon is concerned, this region is far to the north in the peninsular interior and, therefore, has no prospect of much rain during any part of the year.

Of the several aspects of Arid Zone Climatology, the study of water balance in relation to other factors is of vital importance. This is because all problems in arid lands primarily stem from an imbalance between water supply and water need. Table 1 below shows the monthly values of climatic water budget for two typical arid stations in India — Jodhpur in the north and Bellary in the south.

It may be seen that at neither station is there any excess of rainfall in any month, with the result there is only water deficiency accumulating month after month to enormous values for the year as a whole. All the rainfall received is thus seen to be used up for evapotranspiration and the amount of water need not met by precipitation naturally appears as water deficiency. This is a typical feature of all arid stations which normally experience water deficiency through out the year, as may be clearly seen from Fig. 1 which shows a graphical representation of the climatic water balances for Jodhpur and Bellary.

As briefly stated earlier, Thornthwaite's scheme for delineation of climatic types was on the basis of moisture index (Im) derived indirectly from the mean annual values of water surplus and water deficiency in relation to water need. Positive values of Im thus signify moist climates (Perhumid, Humid and Moist Subhumid) while negative values represent dry climates (Dry Subhumid, Semi-arid and Arid). However, when computations are made on a yearly basis for a series of years, Im will be found to exhibit fluctuations of such a magnitude that the climate of the station may be temporarily shifted by one or more steps onto the positive or negative side. It is such occurrences that are of extreme interest and a systematic study of them may even provide clues to the secular or periodic changes in climate. In the context of the arid zones, the magnitude and frequency of such climatic shifts into the humid category are of great practical value. Fig. 2 shows the graphical plot of the moisture index values for Jodhpur for a period of 59 years (1897 to 1955) and for Bellary 65 years (1891 to 1955). On the

TABLE 1: Climatic water balances (all values are in cm)

Item	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*August*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
						(a) *Jodhpur*							
P.E.	2·2	3·5	10·0	16·9	20·6	20·7	19·9	17·5	16·0	13·8	5·9	3·0	150·0
P.	0·4	0·6	0·3	0·3	1·0	3·6	10·1	12·3	6·1	0·8	0·3	0·3	36·1
A.E.	0·4	0·6	0·3	0·3	1·0	3·6	10·1	12·3	6·1	0·8	0·3	0·3	36·1
W.D.	1·8	2·9	9·7	16·6	19·6	17·1	9·8	5·2	9·9	13·0	5·6	2·7	113·9
W.S.	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
						(b) *Bellary*							
P.E.	8·1	12·5	16·6	18·1	19·3	17·3	16·7	15·9	14·8	14·1	9·5	7·3	170·2
P.	0·2	0·4	0·5	2·1	4·8	4·3	4·1	6·0	12·5	10·6	5·0	0·3	50·7
A.E.	0·2	0·4	0·5	2·1	4·8	4·3	4·1	6·0	12·4	10·6	5·0	0·3	50·7
W.D.	7·9	12·1	16·1	16·0	14·5	13·0	12·6	9·9	2·4	3·5	4·5	7·0	119·5
W.S.	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

where P.E. = Potential Evapotranspiration, P. = Precipitation, A.E. = Actual Evapotranspiration, W.D. = Water Deficiency and W.S. = Water Surplus.

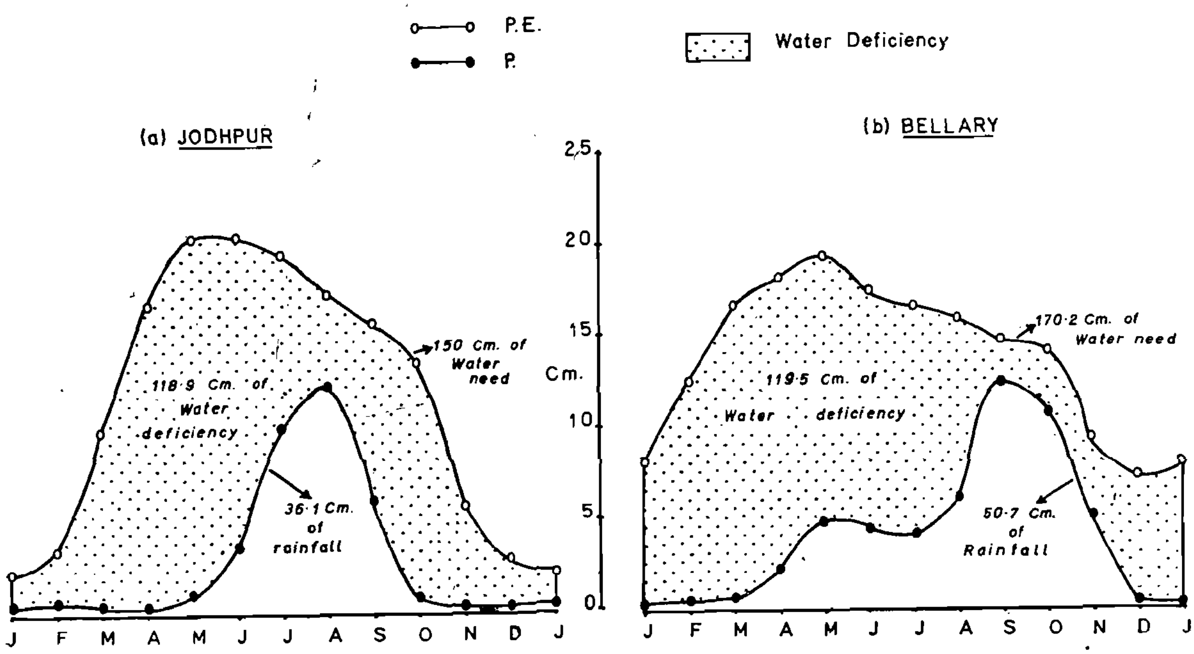

Fig. 1 — Climatic water balance

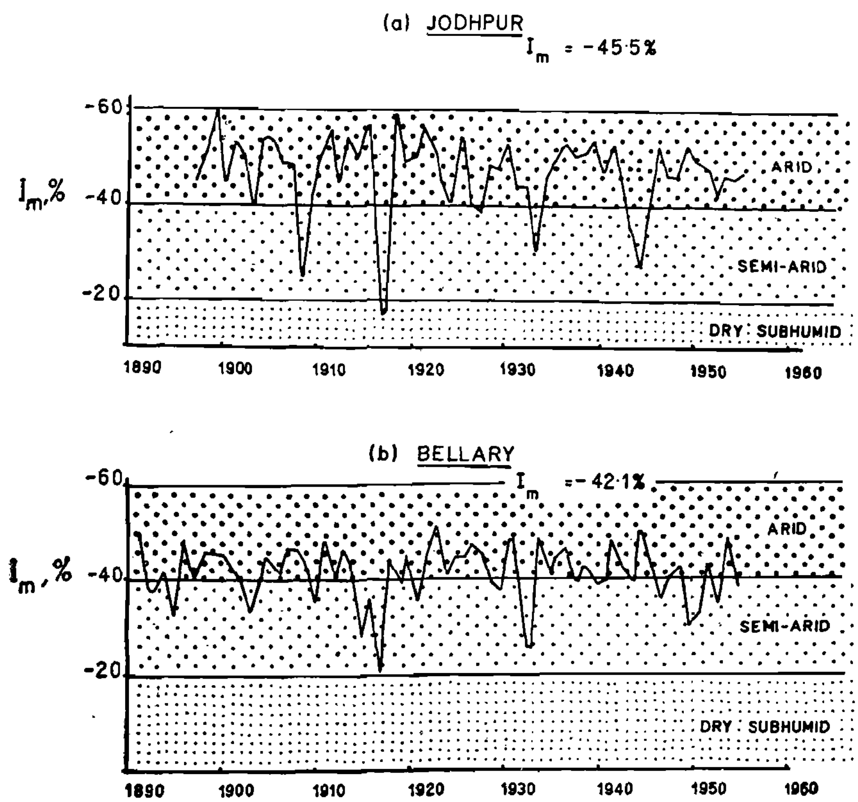

Fig. 2 — Climatic shifts in arid zones

same graphs are also drawn horizontal lines corresponding to the limiting values of Im for different climatic types according to the Thornthwaite scheme of categorization. It will be noticed that at Jodhpur the climate shifted during the period of study, 7 times into semi-arid and only once into dry subhumid while at Bellary, the shift was 24 times into semi-arid and *never* into dry subhumid. The year of maximum shift at both the stations was 1917 in which the normal moisture index of Jodhpur, namely −45·5 per cent, rose to −16·6 per cent and at Bellary, the rise was from the normal value of −42·1 to −21·2 per cent.

Similar analysis at other stations in the arid zones of North and South India showed that characteristically the climatic fluctuations in North India are of a low frequency with large magnitudes. On the other hand, in South India such shifts are more frequent but their magnitudes are comparatively smaller; Table 2 shows the results of analysis for four stations selected for the present study.

TABLE 2: Climatic shifts in Arid Zones

Station		*Number of years of shift into*	
		Semi-arid	*Dry Subhumid*
Bellary	S. India	24	0
Bijapur	S. India	30	0
Bhuj	N. India	6	1
Jodhpur	N. India	7	1

If the above finding is established by further work on more stations, it will be a significant contribution to the drought climatology of India and may eventually also provide clues to the occurrence and nature of floods and droughts in different parts of India.

For the year of maximum climatic shift — 1917 — at both Jodhpur and Bellary, the water balance data are presented in Table 3.

Graphical representation of the above data, shown in Fig. 3, may be seen to bear no resemblance at all to the normal water balance charts presented in Fig. 1. In 1917, Jodhpur received more than three times its normal yearly rainfall which consequently pushed the water balance into that of a dry subhumid climate. This resulted in a reduction of the water deficiency for that year to about a third of its normal value, in spite of the water need in that year having been higher than the normal value by about 13 cm. At Bellary, on the other hand, rainfall for the year 1917 was greater than twice the normal and the water need was lower than the mean annual value by about 8 cm still, the Im rose up only to −21·2 per cent — to almost the moist boundary of the semi-arid climate — being short of the dry subhumid limit by just 1·2 per cent. Though there was an enormous increase in rainfall at both the stations in 1917, the excess was hardly sufficient at higher station even for raising the soil to saturation at any time of the year. There was, therefore, no runoff but the vegetation had, perhaps, better use for the stored soil moisture.

Analysis of this kind, when performed over shorter intervals of time, would be extremely useful in regional planning, for the water balance charts clearly show the periods and amounts of water deficiency and water surplus, as well as the rapid accretion and gradual utilization of the soil moisture. In fact, the water deficiency obtained from the book-keeping procedure represents the amount by which precipitation has not been able to meet the demands of evapotranspiration and is, therefore,

TABLE 3: Water balances for 1917 (all values are in cm)

Item	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*August*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
						(a) *Jodhpur*							
P.E.	4·1	5·3	10·8	30·2	17·7	20·1	18·6	16·8	14·7	16·3	4·6	3·5	162·7
P.	0·1	1·9	0·1	1·4	9·9	18·3	16·0	38·5	15·0	16·3	0·0	0·3	117·8
A.E.	2·4	3·7	4·6	7·8	10·8	18·5	16·2	16·8	14·7	16·3	3·5	2·5	117·8
W.D.	1·7	1·6	6·2	22·4	6·9	1·6	2·4	0·0	0·0	0·0	1·1	1·0	44·9
W.S.	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
						(b) *Bellary*							
P.E.	7·6	9·8	15·6	17·8	18·4	16·4	16·7	15·7	13·8	12·9	10·0	7·4	162·1
P.	0·0	9·0	1·0	1·4	26·9	6·7	4·1	12·8	24·2	13·4	5·4	0·0	104·9
A.E.	2·4	9·2	4·1	3·4	18·4	9·9	6·9	13·3	13·8	12·9	7·7	2·9	104·9
W.D.	5·2	0·6	11·5	14·4	0·0	6·5	9·8	2·4	0·0	0·0	2·3	4·5	57·2
W.S.	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

where P.E. = Potential Evapotranspiration, P. = Precipitation, A.E. = Actual Evapotranspiration, W.D. = Water Deficiency and W.S. = Water Surplus.

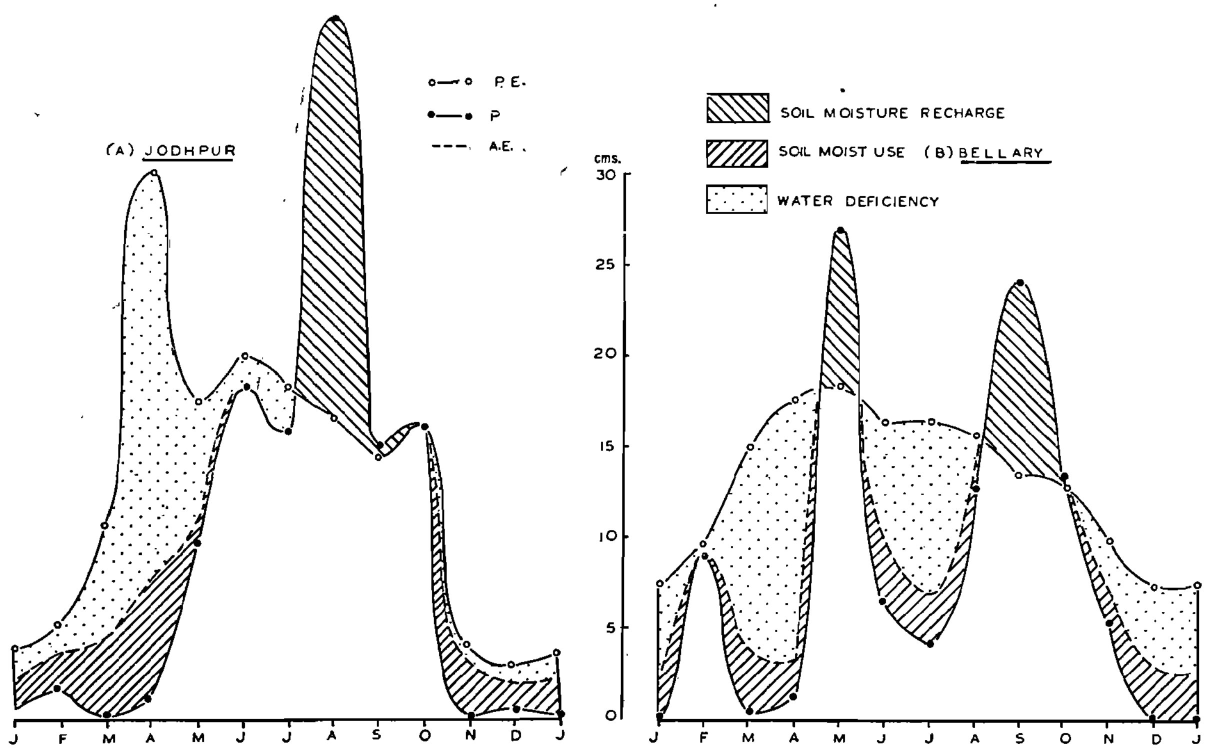

Fig. 3 — Water balances — 1917

nothing but the irrigation need of a region. Depending thus on the intensity and seasonal march of water deficiency at any place, the agriculturist may plan his irrigation scheduling in advance.

Since droughts are due to temporary imbalances of the water budget resulting in severe water-shortages, they are more or less common occurrences in all climates. The magnitude and frequency of occurrence of such water deficiencies determine the degree of dependability of a region for agricultural production or human settlement. In perhumid and humid climates, the frequency is very low and, therefore, droughts are either rare or almost non-existent. On the contrary, the drought frequency in dry climates is very high and in the limit tends to infinity in absolutely arid climates. In the intermediate climatic types, namely the subhumid, water balances may be highly variable throwing the normal moisture regime of climate to one of aridity in times of severe water deficiency or of humidity when water surplus becomes excessive. The general economy of a region is more or less in step with the average climate and is, therefore, not seriously affected by the normal fluctuations of weather. In this sense, droughts become a climatic anomaly resulting from a below-normal rainfall, inopportune rainfall, excessive water need, or as it often happens, from a combination of all the three.

Water deficiency, however, is only an absolute parameter, and, therefore, a clear understanding of the water scarcity experienced cannot be gained unless it is weighed against the region's water requirements. Thus the aridity index (of Thornthwaite, 1948) which is the ratio of total annual water deficiency to the annual water needed (expressed as a percentage) appears to be the most appropriate parameter for an analytical study of droughts. A comparison of the aridity index in the year of study with the normal for the locality in question provides a useful estimate of the drought anomaly; such an estimate will not only provide a measure of severity of the drought situation but also a comparative assessment of drought intensity at different places and at the same place at different times.

In order, therefore, to understand whether the stations, Jodhpur and Bellary, have been becoming drier, less dry or wetter, their yearly aridity indices were plotted graphically and are shown in Fig. 4; the percentage departures of the aridity indices from their respective climatic averages have been used for the purpose. Since the amplitude of departure of the index from its normal value determines the intensity of the drought situation, in the classification of droughts according to their severity, it is necessary to fix limits of departure for different kinds of droughts. For this purpose, a statistical procedure was employed as was done by Ramdas (1950) in the study of floods and droughts of India on the basis of rainfall deviations. Examination showed that in most regions drought reports

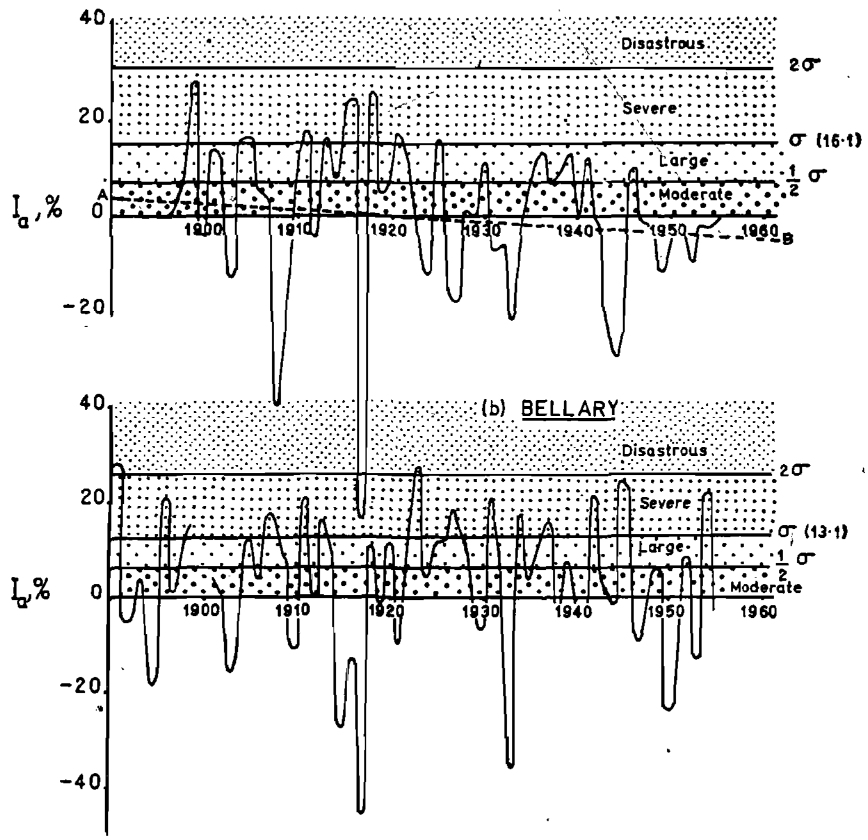

Fig. 4 — Drought occurs in arid zones

coincided with departures of the aridity indices in excess of ½σ and this clue has been taken as the basis for the following categorization of droughts:

Departure of Aridity Index from normal	*Drought Category*
Less than ½σ	Moderate
Between ½σ and σ	Large
Between σ and 2σ	Severe
Above 2σ	Disastrous

So, for determining the number of years of effective drought, a drought was considered to have occurred whenever the departure of the aridity index, Ia, exceeded the ½σ limit. The decennial frequency (number of drought years in successive decade intervals) on this basis was then determined from the curves of departure of aridity indices of Jodhpur and Bellary, shown in Fig. 4. The frequencies of occurrence of such droughts which have impact on agricultural yields or other normal activities of life, namely Large, Severe and Disastrous, in decade intervals at each of the above two stations from the beginnings of their meteorological record are shown in Fig. 5. At Bellary, during the period 1891-1910, there were 4 droughts per decade (3 being above the σ limit) and from 1911 to 1940 there were 5 drought years (with at least 2 severe ones) in every ten. The only two disastrous droughts during the period of study were in 1891 and, more recently, 1923. The period 1941-1950 was more genial compared to the earlier decades, in as much as only 2 severe droughts occurred. In the subsequent period, only 5 years were subjected to analysis and among them 2 years alone experienced droughty conditions, one being severe and the other large. Thus, generally speaking, at Bellary a minimum of 4 drought years may be expected in a normal decade.

At Jodhpur, the worst drought decade (1911-1920) recorded 6 drought years, 5 being severe and 1 large. After 1920, Jodhpur appears to have undergone a definite change in its climate towards decreasing aridity, with 4 3 and 2 drought years respectively in the succeeding decades up to 1950. In the 5 years from 1951 to 1955; no drought was recorded at all according to the present criteria, the aridity index during the period having remained at or below its normal level. In order to get a general idea of the aridity trends at these stations, the half-period

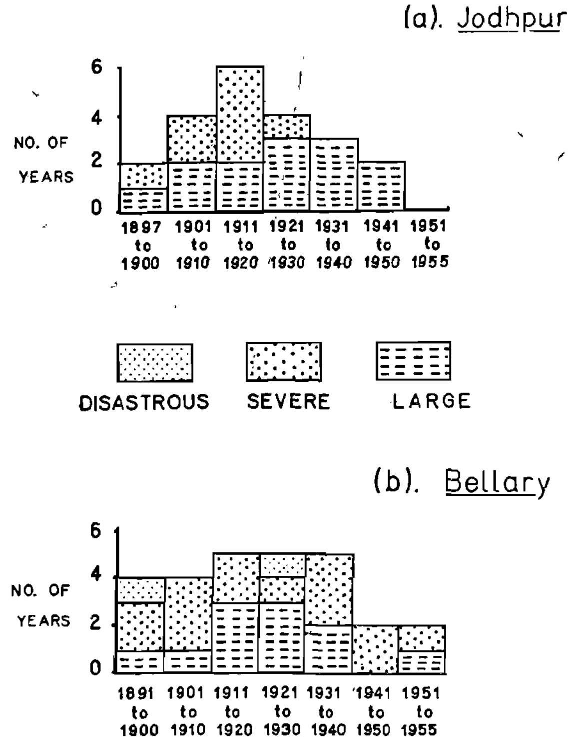

Fig. 5 — Frequency of Drought occurrence in arid zones

averages of their aridity indices have been worked out and are shown below:

TABLE 4: Half-period averages of aridity indices (%)

Station	*Mean for 1st half (X)*	*Mean for 2nd half (Y)*	*Difference (Y minus X)*
Jodhpur	78·2	75·6	−2·6
Bellary	67·0	67·0	0·0

Dashed line AB in Fig. 4 for Jodhpur indicates the linear trend of the aridity index for the two halves of the period of study; this line as well as the negative sign in the last column for Jodhpur in the above Table clearly show decreasing aridity trends. At Bellary, on the other hand, the half-period averages were the same (and so the line AB in coincident with the central line), thus signifying the climatic stability of Bellary, at least from the aridity point of view.

Similar studies in the other dry climatic zones — semi-arid and dry subhumid — of India were also made by us (Subrahmanyam and Subramaniam 1963, 1964) and the results obtained have been extremely interesting. It is suggested that such studies at other stations and in humid climates too must be intensified. Without doubt they will lead to very significant conclusions, in respect of the origin, nature and characteristics of droughts — an aspect of climatology of vital importance to the national planning of our country.

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MICRO-CLIMATE AND VEGETATION OF THE ARID ZONE[1]

by

I. M. QURESHI & B. K. SUBBA RAO[2]

INTRODUCTION

WITH the advent of modern civilization, with all its mechanization, and because of the increased population, man has proved himself to be the most significant and effective biotic factor affecting large scale changes on the face of this earth in a very short time. One of the serious ill-effects of his acts is acceleration of aridity and spread of desert conditions in areas where luxuriant vegetation once flourished. Often the changes brought about by disafforestation are initially imperceptable but their cumulative effect over years of misuse of land and natural resources becomes a menace of gigantic proportions to admit of any speedy solution. This is probably the genesis of expansion of all focii of desert conditions.

The past history of origin and development of the Rajputana Desert has been thoroughly examined by various workers in their papers contributed to the 'Symposium on the Rajputana Desert' organized by National Institute of Science of India in 1952. One significant opinion expressed in that symposium was that 'though the original cause of desert formation can be traced to geological events, its deterioration since 600 A.D. can definitely be attributed largely to man'. Hence, it is for the man, having become wise by his own faults, to study and assess the cause and extent of the damage done by him and his animals and try to repair as best as he can. This can be done effectively by an intensive study of climatic and growth factors required for afforestation purposes or for promotion of vegetation in general.

The main feature of arid zones is the lack of vegetation due to adverse climatic and edaphic conditions coupled with biotic influences which aggravate the situation. Besides light and heat which are abundant in the arid zone, the vegetation also essentially requires adequate moisture and favourable soil. These are most important factors which govern the vegetational complex of any given locality.

Also the absence of the protective vegetational cover creates many other problems such as wind erosion, shifting sands, desiccation due to wind, etc. Afforestation of arid zones is a stupendous task which can be successful only by an integrated study of all the locality factors and judicious selection of the proper species for introduction.

GENERAL CLIMATE AND MICRO-CLIMATE

When studying the 'climate' and 'micro-climate' one has to be clear about the connotations of these two terms and also the other related word, viz. 'meteorology'. 'Meteorology' is the science which deals with the atmosphere as a whole whereas 'climatology' is concerned with the relations between the atmosphere and the earth's surface. These relations are generally studied on very broad lines and over vast areas or regions. The climatological observations are generally made at a certain height above the earth's surface and as a rule, are never made very near to the ground. As such, they pertain to the conditions prevailing above this plane of observation.

But, while studying the effect of environmental factors on plants — or in fact life on this earth — it is the conditions that prevail very near the ground that are really important. Whereas the general climatic conditions determine the major forest type and its distribution over a wide area, the 'climate near the ground determines the variations in structure and composition of the vegetation in a localized site. The word 'micro-climate' is used generally to mean the climate of this type and is important in influencing the development and growth of vegetation on a limited area. This is too general a definition and for the purposes of forestry, some specific criteria come into play. It is the climate created by such 'plant communities' within themselves that is important for their existence and continuation. Hence, the word 'micro-climate' in addition to its meaning as climate very near to the ground should also mean the climate inside a plant community. A further expansion, rather an addition to this, is to include the climate inside the soil, up to the depth of at least root penetration, as this is also one of the most important factors to be studied while studying the environmental conditions of a plant community. Mohr and Baren (1954) have given the following nomenclature for the various climates.

1. Contribution from Forest Research Institute, Dehra Dun.
2. Director of Forestry Research, and Senior Research Officer (Forest Influences), respectively.

- Climate
  - Soil climate
    - Lifeless-soil climate (a)
    - Life-containing soil climate (b)
  - Atmospherical climate
    - Near-the-soil (surface) climate (c)
    - Overhead atmospherical climate (d)

Bio-climate = (b + c)

In addition to climate under (a), it is the climates (b) and (c) which are more important for the vegetation. This has been termed as ' Bio-climate ' by Mohr and Baren. In the case of vegetation, we can call this as the " plant environment " or simply ' micro-climate ' as applied to plant communities.

The climate of a tract is generally determined by the physical conditions over which man has little or no control. Such physical conditions are latitude, altitude, prevailing winds, rainfall, topography, geomorphology etc. Locally, or in a small area certain climatic elements such as temperature, wind, evaporation etc., are modified by certain factors like aspect, type of rock and soil and also the growth of vegetation. The extent of these modifications as related to seasonal changes in the general climate defines the characteristics of the ' micro-climate '.

Large scale activities such as construction of large reservoirs, draining of swamps, large scale irrigation projects, extensive afforestation or clear-felling do modify the local climatic environment more particularly for the vegetation that has to grow there. The information regarding these micro-climatic factors and changes in them due to various activities of man is very necessary for a number of purposes such as, afforestation of denuded lands, prevention and behaviour of forest fires, erosion control, water conservation on agricultural land and the use of trees as wind breaks, shelter belts, and introduction of new species into a given area etc.

The study of soil climate is also necessary, as in the course of its growth, a plant passes through different stages and the nature of its growth in a given locality is but a composite effect of what the plant draws from the soil at different stages.

Apart from general climate of the tract, the various physiological processes of plant life are influenced by the soil temperature, soil moisture, and the composition and structure of the soil. Also, in the case of seeds, germination and establishment depend largely on the conditions that prevail inside the soil or the germinating medium. Thus microclimate including the soil climate is very important in the initial stage of development of vegetation as also subsequently.

Micro-climatic conditions exert much influence also on the micro fauna and flora, within a vegetation zone, which is of importance in case of insect pests and fungal diseases. A study of the micro-climates of arid zones would, therefore, be highly rewarding.

CLIMATE AND VEGETATION

In forest climatology, micro-climatic factors are considered first. The forester consults the climatic data of meteorological stations when he wants to determine the relation between weather-cycle and growth. It is impossible to select suitable species without a knowledge of the micro-climate, especially when it is a question of exotics.

Next comes the ' Micro-climate '. This is of prime importance for the forest manager because it is the habitat climate of the young seedlings. The plant life is never more sensitive to climate than in its formative years. The habitat climate of the plantation is, however, influenced by the cultural and management practices employed by the forester. Consequently, forester has a direct practical interest in the habitat climate (Geiger, 1957).

The inter-relationship of climate and vegetation is as complex as it is interesting. The growth of vegetation on land immediately brings about complex changes in the micro-climate. Among the various factors that constitute this complex, the following are the most important:

(i) Solar radiation
(ii) Wind
(iii) Air and soil temperature
(iv) Humidity
(v) Soil moisture

(i) Solar Radiation: Plants entirely depend upon solar energy for various physiological processes. Much of this energy is also used up in the process of transpiration. Obviously, the insolation of solar radiation inside a plant community is very much different both in quality and quantity. An interesting study by Burns as quoted by Kittredge (1948) is given in Table 1. These studies were conducted in jack pine plantations 12 to 14 ft high but with different spacing.

TABLE 1:

Spacing (ft)	*Trees per acre*	*Average solar radiation %*
2 × 2	10,890	15·9
4 × 4	2,722	36·0
6 × 6	1,210	46·6
8 × 8	680	55·4

The above data shows how different the radiation could be inside plantations with different spacings. This also explains why some species are " light demanders " while others are " shade-bearers ".

(ii) Wind: Turbulance of the moving air transfers the heat energy and water vapour from the earth's surface to the atmosphere above. The eddy thermal conductivity and the eddy diffusion are dependent upon the vertical gradient of wind speed, which is, therefore, a very important micro-climatic factor (Fournice, 1958). Wind has other direct effects such as mechanical pressure on plants, soil erosion, etc. One of the most important aspects where vegetation has been used to reduce the ill effects of wind is in shelter-belts and wind-breaks. Caborn (1957) has made an exhaustive study of the shelter-belts and micro-climate.

(iii) Air and Soil Temperature: Amongst the series of complex environmental factors affecting plant life, temperature is ranked as one of the most important factors influencing growth and development. Considering temperature and growth relationships, three cardinal points are recognized: The minimal, optimum and maximal temperatures which vary from plant to plant and with age (Seth *et al.*).

The two important physiological functions, viz. photosynthesis and plant growth are essentially of bio-chemical nature and hence are affected by temperature. The process of germination, water and nutrient absorption and transpiration are also affected by temperature. The phenomenon of physiological drought occurring due to very low temperatures or high concentration of salts in soil is well known.

(iv) Humidity: The humidity of the air that surrounds the plant determines the rate of transpiration from leaf surfaces, at a given temperature. Also, the vapour pressure in the ambient air affect the rate of evaporation from the soil surface. Thus the humidity of the air plays an important role in the growth of the vegetation.

(v) Soil Moisture: Precipitation, which is the main source of water for soil moisture, is the most governing factor in determining the growth and distribution of trees. Also, the seasonal distribution and amounts of rainfall have pronounced effect on the vegetation. The growth of trees is also dependent on the available moisture. Hence, the soil moisture regime holds an important position in the study of the inter-relationship between vegetation and environment. The other factors are dew, wind and frost. Stone (1957) has made an excellent review of the available literature regarding dew and its importance.

PROBLEMS OF ARID ZONE

Besides lack of soil moisture, excessive heat, high winds and consequent desiccation and wind erosion are the most severe problems of arid zones. Some of these problems are also prevalent in sandy shores of lakes and oceans and rivers and even in cultivated areas with loose sandy soil. Shifting sands are a constant source of trouble for plants and inhabitants of the desert region. Due to the absence of the protective vegetational cover on the surface and moisture in the soil the exposed fine grained top-soil is easily blown away by the wind.

The only practical solution is to provide an effective vegetational cover to the soil. This requires careful selection of grasses, herbs, shrubs and trees which can survive and thrive in the severe climate of arid zones. By a clear understanding of the micro-climatic requirements and cultural and management practices, it should be possible to maintain an effective cover. It may even be necessary to encourage initially growth of economically less important species in order to create suitable ecological conditions for more valuable species to come up later on.

Shelterbelts and wind-breaks reduce the wind velocities on the leeward side and prevent desiccation and soil erosion by wind. It would be very necessary to have shelter belts in semi-arid areas where conservation of moisture is very important.

SPECIES SUITABLE FOR INTRODUCTION IN ARID ZONES

The basic principle for selection of species for introduction in arid areas is that they should be capable of withstanding adverse factors in an inhospitable environment. Xerophytic species with deep roots, and low demand of nutrients have better chances of establishment than others. In such a selection the existing remnants of the vegetation may at times be entirely misleading. It is generally the more primitive spp. in the ecological scale that can be successfully introduced and successfully built up. Plant associations developing naturally on the sites to be afforested or nearby under similar conditions may indicate the probable species. In each locality the existing flora consists of one or more species suited for the initial colonization of the site. They may be anything from herbs and grasses to shrubs and trees.

Though indigenous species may generally thrive better than the exotics, the latter in certain cases have proved exceptionally good. Generally, it would be better to have a mixture of species of compatible combination. Pure stands are more susceptible to insects and diseases, particularly in the case of exotics, and under difficult growth conditions such as those of arid and semi-arid regions.

Some of the species (both indigenous and exotic) which could be useful in the establishment of a vegetative cover in the arid zone under different conditions are given below. The list is not exhaustive but represents only a cross-section of wide range of species, right from grasses to trees, which could be employed for different purposes. Any large scale introduction should be first preceded by experimental trials.

SPECIES SUITABLE FOR SANDY SOILS

Trees

Acacia senegal	*Eucalyptus oleosa var glauca*
Acacia cynophylla	*E. tesseleris*
Acacia sieberriana	*E. terminalis*
Acacia tortilis	*E. melonophloia*
Acacia modesta	*E. papuana*
Acacia arabica	*E. populifolia*
Ailanthus excelsa	*Holoptelia integrifolia*
A. gregii	*Prosopis juliflora*
Albizzia lebbek	*Prosopis spicigera*
A. amara	*Parkinsonia aculeata*
Azadirachta indica	*Pongammia pinnata*
Balanites aegyptiaca	*Salvadora oleoides*
Butea monosperma	*Tecomella undulata*
Cordia rothii	*Tamarix articulata*
Dalbergia sissoo	

Shrubs

Aerva javanica	*Clerodendron phloemoides*
A. pseudotomentosa	*Euphorbia nivula*
Capparis aphylla	*Grewia tenex*
Calotropis procera	*Indigofera argentea*
Crotolaria burhia	*Leptadenia pyrotechniea*
Calligonum polygonoides	*Zizyphus* spp.
Cassia auriculata	

Grasses

Aristida spp.	*E. ciliaris*
Cenchrus prieurii	*Lasiurus hirsutus*
Cenchrus setigerus	*Panicum antidotale*
Erianthus munja	*P. turgidum*
Eragrostis spp.	*Schima nervosum*
E. tremula	

SPECIES SUITABLE FOR SHALLOW AND ROCKY SOILS

Trees

Acacia senegal	*Boswellia serrata*
Anogeissus pendula	*Dichrostrachys cinerea*
Acacia catechu	*Prosopis juliflora*
A. leucophloea	*Salvadora oleoides*
Azadirachta indica	*Tecoma stans*

Shrubs

Acacia jacouemontii	*Cassia auriculata*
Aerva tomentosa	*Euphorbia nerifolia*
Aerva pseudotomentosa	*Euphorbia royleana*
Barleria acanthoides	*Grewia tenax*
Commiphora mukul	*Indigofera argentea*
Capparis aphylla	*Zizyphus nummularia*

Grasses

Aristida spp.

SPECIES SUITABLE FOR SEMI-ROCKY AND GRAVELLY AREAS

Trees

Acacia senegal	*Cassia siamea*
Acacia catechu	*Dalbergia melonoxylon*
Anogeissus pendula	*Hardwickia binata*
Azadirachta indica	*Prosopis spicigera*
Boswella serata	*Prosopis juliflora*

Shrubs

Boehmeria diffusa	*Tribulus terrestris*
Cassia auriculata	*Zizyphus nummularia*
Euphorbia royleana	

Grasses

Aristida spp.	*Eleusine compressa*
Aristida mutabilis	*E. aristata*
Dactyloctenium sindicum	*E. aegyptica*

SPECIES SUITABLE FOR SALINE AND ALKALINE SOILS IN ARID TRACTS

Trees

Azadirachta indica	*E. gomphocephaea* (in winter rainfall zone only)
Albizzia lebbeck	*E. robusta*
A. procera	*Parkinsonia aculeata*
Acacia modesta	*Prosopis juliflora*
A. tortilis	*Pongammia pinnata*
Acacia arabica	*Salvadora oleoides*
Butea monosperma	*Tamarix articulata*
Eucalyptus teretecornis	

Shrubs

Clerodendron phloemoides	*Salsola foetida*
Calotropis procera	*Scaevola putascens*
Capparis decidua	*S. koeniqii*
Leptadenia pyrotechnica	*Zizyphus* spp.

Grasses

Aristida spp.	*Dicanthium annulatum*
Cenchrus ciliaris	*Eragrostis* spp.
C. setigerus	*Panicum antidotale*
Chloris montana	*Saccharum munja*
Cynodon dactylon	*Sporobolus pallidus*

Considerable and patient research is required to select suitable species for the arid zones where silviculturists, ecologists and hydrologists have to join hands in the common goal. One of the basic needs in any arid zone development is a detailed ecological study of the plant and animal life of the arid zone. Then only it can be assessed how far the existing vegetation could be improved and what exotic species could be introduced. Study of the physiological and genetical basis of frost and drought resistance is also necessary.

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DISCUSSION

Hovmoller: The definition of climatology given in the text needs correction in accordance with the accepted definition.

K. S. Sankhala: What type of shelter-belts can be recommended for Rajasthan as raising of trees itself is a problem ?

I. M. Qureshi: Initially suitable conditions have to be created for raising trees by planting xerophytic shrubs and similar vegetation like *Calotronis procera*, *Zizyphus nummularia*, *Indigofera* species, *Clerodendrum phlomoides*, *Calligonum polygonoides*. Even *Sacharum munja* or *Munj* grass could be used. After this strip of vegetation has established, it will be easier to plant trees for shelter belts for which both local species as well as some tested exotics can be raised. Amongst the indigenous species *Azadirachta indica*, *Albizzia lebbek*, and some others can be planted. Amongst the exotics some species of *Eucalyptus* like *E. globosa*, *E. terestris*, *E. paerana*, *E. melonophloia*, *E. terctiocornis*, *E. camaldulensis* and some others hold promise. What is important is that seeds from correct provenance should be obtained. These are only some of the species which could be suggested on a very general basis but before selection of species for different sites is made the characteristic features of micro-climate and micro-site have to be taken into consideration and species selected accordingly. If a proper study is made of the local factors, and proper species, planting techniques and soil and moisture conservation measures are adopted, there is no reason why success should not be achieved.

SALINE WATER CONVERSION

CONVERSION OF SALINE WATER INTO FRESH WATER, TECHNIQUES AND ECONOMICS[1]

by

S. D. GOMKALE, S. Y. AHMED, R. L. DATTA & D. S. DATAR

ALTHOUGH water appears to be a common commodity, its availability in many parts of the world is not adequate. Increasing population, industrialization and increase in the standards of living of the people are essential factors which will require increasing quantity of water. The water consumption of a country is usually recorded in terms of water index, defined as the amount of water in gallons which is at the disposal of a person, directly and indirectly, per day. In developed countries like U.S.A. the water index is of the order of 1700 (Michael, 1962), and in European cities it is 150 whereas in big Indian cities like Bombay and Madras, the values are only 55 and 20 respectively. Scientists and technologists were quick enough to realize the gravity of such a situation and concentrated their energies on exploitation of the vast raw material, namely, saline or sea water to remove the water scarcity. It may be pointed out here that World Health Organization (1962) has recommended the salt concentration of 500 ppm for drinking purposes. For industrial, agricultural and for other requirements no definite specification has been laid down so far.

The techniques known so far for conversion of saline water into fresh water may be classified under two groups as, (I) the techniques in which the water is separated from saline water as evaporation, freezing, etc.; (II) the techniques in which salt is separated from saline water as in electrodialysis, ion-exchange, etc. Different techniques known are given in Table 1 where the state of development for each technique is also indicated.

An examination of table indicates that only a few of the techniques are developed to high capacity plants, and most of the work is being done in U.S.A. At the same time intensive work is also going on in Russia, Israel and countries like Great Britain, Japan, France, Australia in various aspects.

EVAPORATION PROCESSES

The principle of these processes is simple and is well understood. The major techniques are briefly discussed.

1. Contribution from Central Salt & Marine Chemicals Research Institute, Bhavnagar.

TABLE 1: Conversion techniques and their state of development (Muller, 1963)

Group	*Technique*	*State of development*
I	Evaporation techniques i) Solar evaporation	Pilot plant working in Florida (U.S.A.); CSMCRI, Bhavnagar
	ii) Multi-effect evaporation	Plants working at Aruba, Kuwait, Curacao (all of submerged tube type). Demonstration plants of 1 million gallons/day ($3{\cdot}78\times10^6$ litres/day) at Freeport, USA. (Long tube vertical type)
	iii) Multi-stage flash	Plants working at Kuwait, Nassau, Virgin islands etc. Demonstration plant of 1 million gallons/day ($3{\cdot}78\times10^6$ litres/day) at San Diego USA.
	iv) Vapour compression (Forced circulation)	Demonstration plant of 1 million gallons/day $3{\cdot}78\times10^6$ litres/day) at Roswell, USA. One plant working at Kingley AFB (Bermuda)
	v) Whiped film evaporator	Proposed pilot plant, 35,000 gallons per day ($1{\cdot}32\times10^5$ litres/day) in USA
	vi) Centrifugal compression evaporation stills	Units are available in USA upto a capacity of 400 gallons/day ($1{\cdot}5\times10^3$ litres/day)
	vii) Flash compression evaporation	Proposed pilot plant of 1 million gallons/day ($3{\cdot}78\times10^6$ litres/day) is under construction in USA
	viii) Vapour reheat flash evaporation	Easy for operation and is under development
	ix) Direct contact heat transfer evaporation	Easy for operation and is under development
	x) Fluidized bed evaporation	Under development in USA
	xi) Thin film vapour compression evaporation	Under development in USA
	xii) Wiped film fluted tube thin film evaporation	Under development in USA

Continued

TABLE 1 — *continued*

Group	*Technique*	*State of development*
I	Freezing	
	i) Direct freezing	Plant working, with a capacity of 15,000 gallons/day ($5 \cdot 67 \times 10^4$ litres/day) at Harbour island
	ii) Indirect freezing	Plant working with a capacity of 35,000 gallons/day ($1 \cdot 32 \times 10^5$ litres/day) at St. Petersburg in USA
	iii) Zone freezing	Under investigation for economical use
I	Other techniques	
	i) Hydrate	Pilotplant with 800 gallons/day ($3 \cdot 024 \times 10^3$ litres/day) working at Dallas and a plant with 20,000 gallons/day ($7 \cdot 56 \times 10^4$ litres/day) under construction
	ii) Solvent extraction	A pilot plant with 2000 gallons/day ($7 \cdot 56 \times 10^3$ litres/day) under erection in USA.
	iii) Reverse Osmosis	Demonstration model with 300 gallons per day ($1 \cdot 34 \times 10^3$ litres/day) was unveiled (5)
	iv) Vapour-gap reverse osmosis	Under development in USA
II	i) Electrodialysis	Plants working at Buckeye (Arizona), Dhahran (Saudi Arabia). Demonstration plant of 2,50,000 gallons/day ($9 \cdot 45 \times 10^5$ litres/day) working at Webster, USA
II	ii) Ion exchange	Suitable for low salinity water and is under development
	iii) Osmionis	Under development in USA
	iv) Algae	Process worthy of further investigation

Solar evaporation—In this process of evaporation freely available solar energy is utilised in evaporating sea water kept in vessels with black bottom. The evaporated water in the form of vapours is condensed over the transparent surfaces, glass or plastic and is collected as product.

Multi effect evaporation—The multi-effect evaporation has an advantage over single effect evaporation in that the production per unit weight of steam consumed is more as the latent heat of the vapours coming out from one effect is used for heating in the next effect and so on. The number of effects which is to be used depends on the economic aspect. The types of evaporators experimented on are submerged tube and rising film with forced circulation. But the performance of long tube vertical falling film type of evaporators has been found to be good. These types of evaporators are used in the 12-effect demonstration plant at Freeport, Texas.

Multi-stage flash evaporation—In this process the operation is at a temperature lower than that of multi-effect evaporation. The hot sea-water is continuously fed through a series of evaporators each maintained at a pressure lower than the previous one. Hence as the sea water or brine enters each stage it flashes and water vapours formed are condensed over the tubes carrying feed sea water which gets heated up. Additional necessary heat is supplied by a separate heater for which a continuous supply of steam is necessary. The demonstration plant at San Diego has 36 stages.

Vapour compression evaporation—In this process continuous supply of steam is not necessary except for the initial start-up. The vapours coming out of the evaporator are compressed to a higher pressure and these vapours are circulated in the calendria of the evaporator where they condense on heating the water. The compressor is the heart of this process and to run it, electrical energy is necessary which can be used for initial start-up also.

Freezing processes—Separation of fresh water from salt solutions by freezing is based on the fact that ice crystals which are formed when see water is cooled are essentially salt free. In the freezing processes the system must be protected from heat gains or cold losses and in addition the ice separated has to be transported and purified. Following this principle, direct and indirect freezing processes have been experimented and developed to pilot plant stage. In direct freezing water vapour is used as an refrigerant and in indirect freezing hydrocarbon butane is used as refrigerant.

Solvent extraction—Out of the many solvents tried, triethylamine is found to be the best. It dissolves about 30 per cent by weight of water at 20°C and only 2·5 per cent at 50°C. Thus on heating to temperature of about 50°C water will be separated. The problems facing this method are recovery of solvent and toxic nature of water due to dissolution of solvent.

Hydrate—When propane is brought in contact with sea water hydrates are formed which contain 17 molecules of water. Decomposition of hydrate results in separation of water and propane which is recycled back.

Electrodialysis—In this process the salts are pulled out of the salt water by electric forces and concentrated in separate compartments. The higher the salinity more electric power will be required thus limiting the applicability of the process to brackish water only. Electrodialysis units consist of narrow compartments through which saline water is pumped. These compartments are separated by alternating kinds of special membranes, which are permeable to positive ions (cations) or negative ions (anions) respectively. The terminal compartments are bounded by electrodes for passing direct current through the whole stock. When the electrodes are connected to the direct current supply, ions start moving towards respective electrodes through the membranes. Due to the specific selectivity, the concentration takes place in alternate compartments giving fresh water in the middle one. For electrodialysis membranes, spacers, electrodes are the important requirements.

Ion exchange—This process uses the resins capable of exchanging ions and after a certain period these resins have to be regenerated. The amount of regenerants required are proportional to the amount of salts removed. Hence this process is mostly suitable for low salinity waters only.

Some of the above techniques have been studied thermodynamically and the results are quite interesting (Dodge *et al.*, 1960). The minimum work of separation is reported as 3·19 Kwhr/1000 gallons. The process which utilizes a power equivalent or nearabout this value will be the most efficient one; whereas, actually, the efficiency of a technique is of the order of only 2 to 5 per cent. This has led some to the conclusion that great improvement is easily possible and that as a consequence, costs can be greatly reduced. Efficiencies can be increased by reduction of driving force but his reduction always entails an increase in size and hence increase the cost of equipment. If total cost of a desalting process is equally divided between the cost of energy and of fixed cost on equipment, one reaches a minimum at an efficiency which is generally less than 20 per cent (Dodge *et al.*, 1960). One generally feels that for the freezing technique energy requirement should be much lower than those of evaporation techniques but thermodynamic analysis indicates that it is not too less (Dodge *et al.*, 1960).

Table 2 gives operating conditions along with the costs of converted water for demonstration plant in U.S.A.

Amongst the various difficulties in the development of desalination techniques the major ones are the corrosion and scale deposition problems. Efforts are still going on to solve these as best as possible.

Corrosion—Sea water due to its constituents is corrosive for ordinary metals. With the increase of temperature and concentration the corrosive nature of sea water increases. The corrosion of different metals in sea water at various concentrations and temperatures have been studied, and it is found that cheaper metals like steel and iron can be used for constructional work but they are unsuitable for tubes in heat transfer equipments. For such application (Frederick, 1960) titanium is the best. But it being costly, alloys like cupro-nickels (70:30 and 90:10), aluminium brass, monel, K. monel, inconel, hastelloy and stainless steel are getting popular. One can say that corrosion problem affects the investment for the evaporation. Cupro-nickel and aluminium-brass are widely used.

Scale deposition—The scaling problem causes many difficulties in the operation. Sea water contains many dissolved salts. On heating, some of the salts precipitate out and deposit over the hot metallic

TABLE 2: Demonstration plant in U.S.A.

Sr. No.	*Name of process*	*Location of plant*	*Degree of purification*	*No. of effects/stages*	*Operating temperature*	*Investment costs $/1000 gallons of daily capacity*	*Cost of manufacture $/1000 gallons*	*Scale prevention technique used*
1.	Multieffect evaporation	Freeport (Texas)	35,000 ppm to 50 ppm	12	250°-120°F	1255·00	1·25	Acid treatment and Sludge technique
2.	Multistage flash evaporation	San Diego (California)	35,000 ppm to 50 ppm	36	200°-90°F	1663·24	1·20	Acid treatment
3.	Forced circulation vapour compression evaporation	Ros-well (New Mexico)	24,470 ppm to 50 ppm	2	232°-223°F	1794·00	1·40	Sludge technique
4.	Electrodialysis	Webster (South Dakota)	1,450-1,600 ppm to 356 ppm	4	48°F	1730·00	1·00	pH adjustment and control of operating conditions
5.	Solar evaporation (17) (Pilot Plant)	Florida (U.S.A.)	35,000 ppm to 50 ppm		—	2·04 $/sq. ft. (for 3000 sq. ft.)	6·3	

surfaces in the form of scale. This deposited scale reduces the overall heat transfer rate and hence the production. This sets the limit on the maximum temperature to be used for evaporation. Removal of scale becomes necessary and frequent shut-downs will affect the output. Calcium carbonate, calcium sulphate and magnesium hydroxide are the three major scale forming compounds. The calcium sulphate scale is very hard to remove. The methods known for the prevention of scales are (i) acid treatment, (ii) seeding of crystals of scale forming compounds, (iii) pretreatment of sea water for the removal of scale forming compounds, (iv) addition of compounds which will retard scale deposition and form a soft and easily removable sludge. Out of these methods acid treatment or pH control method and seeding method are more common. But in case of pH control slight excess of acid will bring in corrosion problem. But if one has to work up to the saturation concentration of calcium sulphate, then, effluent concentration in desalination plants is about 10 per cent dissolved solids.

With the above background of the techniques it is necessary to discuss more in detail some of the techniques which are developed.

Though the technique of solar evaporation utilizes freely available solar energy getting an advantage of negligible operational charges, it faces two major drawbacks. Investment costs are very high, as a huge area has to be covered for higher capacities. This is due to the fact that yields per unit area are very low or in other words the efficiencies are low. At a place where the solar radiation intensity is about 2000 BTU/day per sq ft one can expect an yield of about 2 lb or 0·2 gallons of water per day per sq ft. But in practice the yields are about 0·06 to 0·08 gallons/day per sq ft indicating the efficiencies of the order of 40 per cent. Thus if attempts are made to increase the efficiency and reduce the investment cost per unit area it is quite likely that this technique may prove successful in areas where radiation intensities are high, and dry and hot weather prevails for longer periods. The maximum capacity specified for such plants is 50,000 to 1,00,000 gallons/day.

Of the other evaporation technique, multi-effect multi-stage flash and forced circulation vapour compression evaporation are the important ones. All of these suffer from the corrosion and scaling troubles. In case of flash evaporation technique heat transfer or the high temperature exists in the liquid only and hence the scaling problem is not severe. This is a major advantage for this technique. In case of all other evaporation techniques major problem is of scaling. If some method is found out to tackle this problem successfully, working at higher temperatures will be possible which will result in higher yields. In San Diego flash evaporation plant the working at a temperature of 240°F instead of original 200°F resulted in 40 per cent increase in yield. We find that the energy requirements for these evaporation techniques are independent of initial salinity. In order to overcome this problem new evaporation techniques as developed are mentioned in Table 1. Of these, the vapour-reheat and direct contact heat transfer evaporation techniques are completely free from scaling troubles and it is quite likely that these may prove very successful for desalination purposes. One British patent is given recently for direct contact heat transfer evaporation using heavy oil as the transferring media.

It is observed that (1) the steam economy in multi-effect evaporation is dependent on the number of stages, which depends on the economics depending on the operational and investment charges (Michael, 1962). Usually the expression for optimum number of effects is

$$n_{\text{opt}} = \sqrt{S/A}$$

where S = cost of steam per unit of water produced in single effect evaporation; and A = fixed charges for each evaporator per unit of water produced.

Energy consumption increases in the following order. Vapour compression, multi-stage flash and multi-effect evaporation. The investment cost of these follow the reverse order but the differences are relatively small. If cheap fuel and electricity are available, multi-stage flash evaporation will often be the most desirable technique. This is especially true if waste steam is available which has not other use. On the other hand, vapour compression will usually be most economical process when fuel and electricity are cheap. At present multi-stage flash evaporation is known to be very good.

Freezing technique — In case of direct freeze, the volume load on the compressor is very high, though pressurs load is low, as the vapour pressure of water is low. Due to this drawback indirect freeze is getting popular. Apart from cold losses, second drawback lies in the fact that the ice crystals have to be washed completely from the adhering brine. Nowadays hydrocyclones, rotocells, etc. are widely used for the washing purposes. This process is having some inherent advantages (Muller, 1963). These include (i) due to operation at low temperatures scaling problem is not much, (ii) corrosion rates are also low due to low temperature, (iii) energy requirements are lower.

Electrodialysis — Energy requirements for this process is dependent on initial salinity. Thus this technique is quite suitable for brackish waters only. This method also suffers from scaling problem as the scales deposit over the membranes. Efforts are being made to point out cheaper and better membranes to improve the technique economically.

Ion exchange — As mentioned earlier this method is not suitable for sea water. But emergency desalting kits are available which can be used for sea water. Similar type of kit is prepared by scientists in National Chemical Laboratories, Poona (1964).

COST OF CONVERTED WATER

The cost of water may be defined as the sum of the charges assignable to the entire production process. Normally the components of cost are divided into three general categories; namely, the cost due to capital investment, those due to fuel or power requirement and those due to maintenance and operation items. Table 3 which is in continuation with Table 2 indicates the costs of converted water and conventional waters.

TABLE 3: Comparative costs of converted and conventional water

Process	*Converted water cost* $/1000 *gals.* A	*Conventional* water cost $/1000 *gals.* B	*Ratio* A/B
1) Long tube vertical evaporator Freeport, Texas	1·25	0·2	6·25
2) Forced circulation vapour compression, evaporation, Roswell	1·4	0·4	3·5
3) Multi-stage flash evaporation, San Diego	1·2	0·2	6·0
4) Electrodialysis Webster	1·0	0·3	3·33

Examination of the above table indicates that the converted water costs are about 5 times more than conventional water costs.

These high costs are due to high energy costs which amount to about 40 per cent, may be as high as 50 per cent or more (Dodge, 1963). A reasonable reduction in the energy cost will bring down the water cost. Now-a-days all the efforts are concentrated on bringing down the costs. The probable ways of doing it are outlined below. To tackle the problem there are two direct ways, (i) reduce the energy requirement, (ii) use the cheap sources of energy.

Reduction of energy requirement: The energy requirement can be reduced by reduction of driving forces. Let us consider the evaporation techniques. The heat flux, $q = U.A.\Delta t$, where Δt is the driving force, A = area, U overall heat transfer coefficient. If this Δt is reduced keeping q and U constant, A will increase which means the size of equipment will increase, increasing thereby the investment cost. In case of multi-effect evaporation the minimum value of Δt will be equal to rise in boiling point which being of the order of 1°F to 2°F to get an overall temperature drop of 100°F we will require about 100 effects which will definitely not prove economical.

Use of cheaper source of energy: In solar stills, we utilize freely available solar energy but as discussed before we find that unless the efficiencies are increased and the compact design of stills is evolved fresh water obtained by this technique may be costly. For the pilot plants at Florida we see from Table 2 that the converted water costs for solar stills are about \$ 6·3/1000 gallons thoughs it is expected that it may come down to \$ 2 to 3/1000 gallons. For the sake of comparison let us see under what conditions or at which rate of capital investment the solar stills will supply water at a cost equal to that of the conventional water.

Assumptions: The solar stills have a life of 50 years and the operational and maintenance charges amount to 20 per cent of investment (this is on the high side as the operational charges but for human labour, are negligible). Average annual yield is 0·06 gallons/day per sq. ft and working days in year are 300. Let,

C = cost of water/1000 gallons
X = capacity in gallons/day
Y = total cost of investment
Z = investment cost/sq. ft area

Following equations can be formed:

$$\frac{X}{0{\cdot}06} Z = Y \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (1)$$

$$\frac{1{\cdot}2Y}{50} = \frac{X \times 300 \times C}{1000} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots (2)$$

From these two equations (1) and (2) we will get,

$$Z = 0{\cdot}75C \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (3)$$

This means that the necessary condition is that investment cost per sq. ft area should be 75 per cent of conventional water cost. Such a condition is difficult to achieve. On the basis of the above equations the expression for Z changes according to annual average yield as given in following Table 4.

TABLE 4

Average yield, gallons / day/sq. ft	Z = *constant* $\times$ C
0·06	0·75 C
0·08	1·0 C
0·1	1·25 C
0·12	1·50 C
0·14	1·75 C
0·15	1·825 C
0·20*	2·50 C

*0·2 is the yield at 100% efficiency if the solar radiation is 2000 BTU/sqft/day.

These values of Table 4 confirm the view that with better and higher efficiencies and compact design with cheaper materials of construction will make this technique highly feasible for arid zone where solar energy will be in abundance.

Experiments have given quite good results when diesel engine waste heat was used for converting sea water into fresh water with 24 stages flash evaporator.

Next comes the use of cheaper source of energy of future, i.e. nuclear energy. The pre-estimates as given in Table 6 indicate that converted water will cost about \$ 0·2 to 0·3/1000 gallons at capacities of 100 million gallons/day which is encouraging. Recently Russian, American and Israeli scientists have come to an agreement to work together and develop the use of nuclear energy for the purpose. Apart from these, other measures involve: (1) Plants of higher capacity, (2) Combination plants, (3) Recovery of by-products.

Plants of higher capacity — With scale up of the plant we find that both investment per unit capacity and operation costs are reduced and hence the scale-up results in the lower cost of production. Table 5 gives the effect of plant capacity on cost of production.

TABLE 5

Plant	*Long tube vertical multi effect evaporation*			*Multi stage ash evaporation*			*Electro-dialysis*	
Capacity million gallons/day	1	4	8	1	7	14	0·25	2·0
Cost in \$/ 100 gallons	1·46	1·02	0·86	1·3	0·75	0·65	1·4	0·95

But in any case there is a limit to the maximum capacity also. Under these considerations maximum limits of capacity for multi-effect long tube vertical evaporators and mult-stage flash evaporators are 8 million gallons and 14 million gallons/day, as reported.

Table 6 gives the effect of scale-up and use of nuclear energy on the cost of converted water.

TABLE 6

Plant capacity in million gallons/day	15		100		1000	
Type of fuel used	F*	N**	F*	N**	F*	N**
Water costs in \$/ 1000 gallons	0·39	0·65	0·36	0·21	0·35	0·10

*F — Fossil
**N — Nuclear

Combination plants — The working temperature (maximum) particularly in multi-stage flash evaporation is not high and hence use of low pressure steam is quite suitable. The exhaust steam from back-pressure turbines which is at lower pressure is condensed. If that steam be used for desalination purpose the cost of converted water will be definitely lower. This is the main idea behind combination plants, and the desalination plant at Aruba is working in combination with power plant. It is reported that such combination plants will reduce the cost to about \$ 0·4/1000 gallons.

Similarly the combination of various techniques is also possible. Combination (Badger *et al.*, 1961) of vapour compression and multi-effect evaporation with power plant is suggested. Such combination will definitely produce water at still cheaper rates.

Recovery of by-products — It is known that by-products recovered in a process reduce the cost of main product.

In pre-treatment of sea water for the prevention of scale magnesium ammoniumphosphate is formed. This is a very good fertilizer.

In most of the desalination plants the effluent concentration of brine is about 10 per cent dissolved solids. This can be given to the nearby salt farm for the recovery of salt or in other words the salt becomes the by-product of desalination. The volume is reduced to almost 1/3 when the brine concentration is about 10°Be'. Now let us consider a salt farm of 100 acres. As per the calculations the area required for getting 10°Be' concentrated brine from an initial sea water of 3°Be' will be about 40 acres.

Normally for the salt farms, the construction cost with 12 per cent depreciation is about Rs 1,000/acre with all bunds, channels and pathways. 10°Be' is obtained from the condensers. Construction cost for condensers only, we can assume, equal to 700 Rs/acre. Hence cost of construction for 40 acres will be $40 \times$ Rs 700 = Rs 28,000.

Annual expenses will be taken as sum of annual depreciation and operating charges. One man will be sufficient to look after the condenser of 40 acres. For salt farm, working months are 9 only, taking Rs 60/- month as the salary for the operator, the annual expenses will be:

$= (28{,}000 \times 0{\cdot}12 + 60 \times 9)$
= Rs 3,900

$\therefore$ expenses per day for getting 10°Be' brine $= \dfrac{3900}{9 \times 30} =$ Rs 14·4

For a 100 acres salt farm, the sea water (3°Be') feed rate should be about 173 gallons/min. At 10°Be' feed volume is reduced to about 1/3.

$\therefore$ volume of 10°Be' obtained from 40 acres of condenser area = 57·6 gallons/minute.

$\therefore$ Brine (10°Be') flow rate $= 57{\cdot}6 \times 60 \times 24$
$= 8{\cdot}3 \times 10^4$ gallons/day

To get this amount of brine from the desalination plant the capacity of it should be about twice the brine volume.

$\therefore$ Capacity of desalination plant $= 2 \times 8{\cdot}3 \times 10^4$ galllons/day
$= 1{\cdot}66 \times 10^5$ gallons/day

We can now consider that the effluent will be worth Rs 14·4 for $8{\cdot}3\times10^4$ gallons which means the reduction in cost of fresh water per 1000 gallons, by such operation, will be about:

$$\frac{14{\cdot}4\times10^3}{1{\cdot}66\times10^5} = \text{Rs } 0{\cdot}086/1000 \text{ gallons} \approx 10 \text{ paise}/1000 \text{ gallons}$$

Heavy water — The percentage of heavy water in fresh water is about 0·0145 mole per cent. In experiments (Datta, 1964) it is found that when 100 litres of sea water are reduced to 2 litres by volume by natural evaporation to obtain concentrated brine, the heavy water content in it is about 0·0208 to 0·0224 mole per cent. Thus the concentration is quite high and hence if the heavy water is recovered, the cost will be definitely be less than the heavy water obtained from natural water. It is estimated that on winning of 6 million tons of salt, the bittern will contain about one thousand tons of heavy water. Thus we find that if this quantity is recovered the cost of converted water will definitely come down.

Other valuable by-products like potassium chloride, bromine and magnesium salts contained in bitterns (the processes for the recovery of which have been worked out at this Institute) will certainly give a good rebate to the cost of converted water.

ADDITIONAL NOTES

Since this paper was presented a 250 gallons per day capacity pilot plant of desalination of sea water by solar still technique was designed, constructed and operated at this Institute to obtain the necessary operational data for further design, basing on which a plant has been commissioned in July 1968 by the Department of Light Houses (Ministry of Transport and Shipping) at Naviner point near Jamnagar for drinking and other household purposes. The details of the above mentioned pilot plant have been described in a few communications elsewhere. In the higher capacity ranges of production of fresh water, a newly developed solar heat powered or waste heat powered method known as Humidification-Dehumidification technique has been developed at this Institute, and the results of a 1000 gallons/day pilot plant has been reported from time to time elsewhere.

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POSSIBILITIES OF DESALINATION IN INDIA[1]

by

S. Y. AHMED, S. D. GOMKALE, R. L. DATTA & D. S. DATAR

THE natural supplies of water in India are plentiful, and most of the requirements are being met from these sources only. Data (Aggarwala *et al.*, 1963) on water utilization have shown that only 19 per cent of the total available supplies have been utilized, and yet water shortage is being felt in different parts of the country. There are a number of reasons for the water shortage, namely, (i) the total supplies, which are the result of rainfall, are not available to the full extent as part of it (20-30 per cent) is carried back to the sea by rivers etc., part of it (10 per cent) is drawn for use and the rest evaporates (Revelle, 1963). However, these figures vary from place to place; (ii) secondly, it is due to the increase in the standards of living; (iii) thirdly, due to the uneven distribution of rainfall (less than 5 in./year in Kutch area to more than 425 in./year in Khasi, Assam) over and above which another point is that about 75 per cent of the total rainfall comes within a period of 4 months i.e., from June to September. This requires adequate storage facilities to ensure availability throughout the year, and which are lacking in certain areas.

The water shortage has resulted in restricted use, and may retard industrial growth of the country as the cost of obtaining an adequate supply may be so high that the location of industries in water short areas may be ruled out. This being of vital importance to our country, requires intensive efforts to minimize the shortage. The possible solutions for the above mentioned problem are as follows:

I. Development of new resources
II. Conservation of existing supplies by way of:
   (a) Minimization of losses due to percolation and evaporation
   (b) Use of treated waste waters
   (c) Use of sea water
III. Desalination of sea or brackish water

DEVELOPMENT OF NEW RESOURCES

The development of new resources is governed by factors connected with geographical, political and economical situation, particularly of the latter, in the selection of an alternative source. The cost of water transported from areas having excess supplies or that obtained from newly developed sources are comparatively high due to the following reasons, and sometimes may involve a dispute between adjoining states on legal rights.

(i) Rise in the construction costs,
(ii) High investments required because of the distance of the source, as nearest and easiest sources have already been utilized,
(iii) High pumping costs which depends upon distance and the amount of water transported.

The water costs from such sources as a function of distance, and capacity along with existing water costs as a function of monthly use rate for U.S.A. have been presented in Table 1 (Saline water conservation

TABLE 1: Water costs from desalination plants

Sl. No.	*Name of the process*	*Location*	*Capacity mgd.**	*Purification ppm*		*Cost $/1000 gallons*	*Cost of power %*
				From	*To*		
1.	Multieffect evaporation	Freeport (Texas)	1·0	35,000	50	1·25	33·6
2.	Multieffect evaporation	Aruba (Caribbean)	3·5	35,000	50	1·75	—
3.	Forced circulation vapour compression evaporation	Roswell (N.M.)	1·0	24,470	50	1·40	—
4.	Multi stage flash evaporation	San Diego (California)	1·0	35,000	50	1·20	33·1
5.	Electrodialysis	Coalinga (California)	0·028	2,000	300	1·50	—
6.	Electrodialysis	Buckeye (Arizona) (48% load factor)	0·65	2,200	500	0·50	28·0
7.	Electrodialysis	Buckeye (Arizona) (98% load factor)	0·65	2,200	500	0·33	42·0
8.	Electrodialysis	Webster (S.D.)	0·25	1,800	350	1·00	8·6

*mgd = million gallons per day

1. Contribution from Central Salt and Marine Chemicals Research Institute, Bhavnagar.

research, 1963, Hirchleifer *et al.*, 1960). The data for U.S.A. have been purposely taken so as to make the comparison of desalination water costs and water costs from other sources meaningful, as converted water costs are available only from U.S.A. These data indicate that economic considerations dictate, the selection of an alternative source, namely the cost at which additional supplies could be obtained.

CONSERVATION OF EXISTING SUPPLIES

Conservation of existing supplies in water short areas for their fullest utilization might be an immediate partial solution to the water problem which can be achieved in the following ways:

(a) *Minimization of losses due to percolation and evaporation*

The evaporation and percolation losses from storage tanks, reservoirs and distribution canals as calculated from the data, reported by Kulkarni & Parashare, 1962, were found to range between 30-85 per cent. These losses if prevented by some means at negligible costs may give some partial relief to the water problem.

Practically no efforts have been made for the reduction of seepage losses from reservoirs. Physical and physioco-chemical methods like reworking and compaction, application of chemicals as NaCl, Na_2SiO_3, $CaSo_4$ mixed with fine clay, lining with cement, concrete and blanketing with asphalt-sand mixture or plastic membranes, can be used. The choice of the method depends upon local conditions, and economics, that is the cost of water saved which otherwise would have been lost by percolation. However, sufficient data on such methods are not available to warrant the cost of saving of water.

Evaporation losses can be reduced in two ways (i) by decreasing the surface area of reservoirs per unit volume of water stored. Data of Kulkarni and Parashare, 1962, indicate that the evaporation losses in flat reservoirs may be as high as 50 per cent where as in high dams these may amount to 10 per cent based on total contents. However, proposals for increasing the depth of the reservoirs by the removal of sediments, etc., have proved to be very costly; (ii) the evaporation losses can be reduced by the use of mono-molecular films on the surface of reservoirs, and is reported to be efficient, and economical way of conserving the supplies (La Mer, 1963). This method is particularly suitable for arid and semi-arid areas and tropical countries like India, where the evaporation losses are quite high and where many of the dams are of the flat type. Some work has been done in this field, at the Central Salt and Marine Chemicals Research Institute, Bhavnagar, and other places. Studies on evaporation control with cetyl-stearyl alcohols indicate that about 10 to 30 per cent of the evaporation losses can be saved by this method at a cost of Rs 0.40 to 0.50 per 1000 gallons (Kulkarni & Parashare, 1962; Ganapathy, 1962). It has been stressed that evaporation control should be taken up during the hot season namely from February to June, as the evaporation losses during this period amount to 50 per cent of the total. Based on data for this period costs of Rs 0.22/1000 gallons have been indicated. The above mentioned figures are quite promising in comparison to existing water cost of Rs 1.00 per 1000 gallons. However, the economics is reported to be, further improved by the use of indigenous materials like Octa decoxyethenol.

(b) *Use of treated waste waters*

The other means to conserve the supplies of water is the use of treated waste waters for industrial or agricultural purposes. This is highly practicable as well as economical as about two-thirds of the water used is available at the place where it is required for reuse except for the contaminants. Moreover, many of the wastes are being treated before discharging and further treatment may make it reusable. Investigations on some processes which make water indefinitely reusable have been undertaken (Louis Koeing, 1963).

(c) *Use of sea water*

Since a high percentage of the water consumed is used up in carrying industrial or domestic wastes, duplication of water supply lines is desirable— one for fresh water for drinking purposes and another for sea water for toilet and industrial uses like cooling, carrying wastes, etc. Cast iron and steel pipings are reasonably satisfactory for short durations, but cement lining has proved especially successful (Heinmann, 1963) on long term applications. In coastal areas, where concentration of population and industries are quite high and additional fresh water supplies could be obtained at high costs, the piping system may be duplicated inspite of the heavy investment costs, which avoids the wasteful use of fresh water.

Attempts are being made to partially replace fresh water by sea water for agricultural purposes, which is of interest to arid and semi-arid areas. Some work on the salt tolerance of certain field crops has been done in the Central Salt and Marine Chemicals Research Institute, Bhavnagar, with encouraging results.

DESALINATION OF SEA OR BRACKISH WATER

Sea water cannot replace fresh water for human consumption, because the maximum concentration of salts in water for drinking and other purposes is limited to about 500 parts per million (ppm) as per the recommendations of World Health Organization

(1962). The only alternative, to meet the water shortage in areas where new sources do not exist within a reasonable distance, is the desalination of sea or brackish water.

Desalination is the conversion of saline water namely sea water (about 35,000 ppm total dissolved solids, T.D.S.) and brackish water (1000-10,000 ppm T.D.S.) (Deutch, 1962) to obtain fresh water. Thermodynamic considerations indicate that the separation of pure water from sea water requires a minimum amount of energy of the order of 3·19 Kwh/1000 gallons (Dodge & Eshaya, 1960). There are a number of technically satisfactory methods but the real problem is an economic one so that converted water costs are comparable with the existing cost of conventional water. Studies on desalination techniques (Speigler, 1962) have shown that (i) high cost of converted water is partly due to the high energy consumption, owing to lower efficiencies of utilization of energy as shown in Table 1 (Seko, 1962; Muller, 1963). However, it has been indicated that power generation desalination combination plants designed for very high capacities, and plants using nuclear power from duel-purpose reactors can produce water at a comparatively cheaper rate. (ii) Of the various techniques evaporation is suitable for sea water conversion, and electro-dialysis for brackish water conversion (containing not more than 5000 ppm) (Minken, 1962). (iii) Solar evaporation has favourable economics in areas where solar radiation intensity and prevailing temperatures are quite high in plant capacities not exceeding 50,000 to 1,00,000 gallons per day. (iv) Freezing processes are becoming attractive because of less operational troubles due to scaling and corrosion. However, plant data are not available for this process.

APPLICABILITY OF PROCESS UNDER INIDIAN CONDITIONS

The selection of a technique for desalination depends on the following factors (a) the kind and quality of salt in solution, (b) purity of product required, (c) capacity or requirements, (d) cost of fuel and electricity in the area, (e) labour costs, (f) facilities for disposal of brine, (g) availability of materials of construction.

An examination of the conditions in India with respect to the above mentioned points reveals that there are possibilities of desalination of sea water in the coastal regions, and of brackish water in the inland areas. In India, fuel, electricity and mechanical equipments are quite costly where as land and labour costs are comparatively cheap. As far as the availability of the materials of construction is concerned materials like titanium, hastelloy, monel and aluminium brasses are not available in India and we are totally dependent on imports. The different evaporation techniques employed for the conversion are: (i) Multi-effect evaporation, (ii) Vapour compression evaporation, (iii) Multi-stage flash evaporation, and (iv) Solar evaporation.

The applicability of the first two techniques can be ruled out because of high converted water costs and the non-availability of materials of construction required for the evaporators namely, aluminium brass, cupro-nickel, etc. Another point against vapour compression evaporation is that it requires a costlier form of energy source (i.e. electrical or mechanical) and requires mechanical equipment which are quite costly in India.

Flash evaporation is promising in India for augmenting water supplies of coastal areas like Madras, Bombay, Gujarat etc. in large capacities due to the following reasons: (i) it is the cheapest among other evaporation techniques; (ii) evaporation vessels are simple to construct; (iii) requires cheap materials like steel, which are available in India; (iv) troubles due to scaling are less; (iv) it is independent of the initial salt concentration and gives a product of very high purity. It is worth mentioning here that some improved flash evaporation processes known as "vapour reheat" and "direct contact evaporation" are under development, and these are attractive choices of the future. The economics of flash evaporation can also be improved by utilizing nuclear power; however, such possibilities depend upon the establishment of nuclear power stations in India.

Solar evaporation technique appears to be suitable for providing water to houses and small communities in the arid and semi-arid regions of India like Rajasthan and Gujarat. High solar radiation intensity, atmospheric temperature and low requirement of water, make this process quite attractive. Investigations on this technique have been undertaken in the Central Salt and Marine Chemicals Research Institute, Bhavnagar. Although it has proved to be costly in U.S.A. but it is at a distinct advantage in India because of low land and labour costs. Another point in favour of this process is that it requires very simple materials and can be fabricated by indigenous materials, which are easily available in India. It can be operated either on sea water or brackish water and gives a quite pure product. The only drawback with the process is its low capacity which puts a limit to its maximum capacity which might range between 50,000-1,00,000 gallons/day.

For inland areas of India, where brackish underground waters are available, the selection of the process depends upon the salt contents and the water requirements. The selection of technique might be restricted to electrodialysis and ion exchange for low salinities of raw water. If the requirements are low then solar evaporation can be used which is independent of the salinity. In case the salt content is quite high and requirements are more, then, flash evaporation might be the suitable choice. Electrodialysis is suitable for brackish water conversion (containing not more than 5,000 ppm). Work on electrodialysis and ion exchange desalination techniques are under progress in National Chemical Laboratory, Poona. The results of the requirements indicate that fresh water can be obtained from brackish waters containing 9,000-14,000 ppm T.D.S. at a cost ranging between Rs 6-10/1000 gallons whereas by ion exchange technique it costs Rs 30/1000 gallons from raw water source containing 1300 ppm T.D.S. Adaptation of flash evaporation and electrodialysis for the conversion of brackish water in high capacities depends upon the establishment of nuclear power stations in inland areas, and such possibilities do exist for Rajasthan. Similarly, for regions like Gujarat, solar stills have possibilities of development for smaller requirements of water, whereas for higher requirements multi-stage flash evaporation has promise of development.

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DISCUSSION

S. P. Raychaudhari: Whether any work was being done at the Central Salt and Marine Chemicals Research Institute, Bhavanagar for demineralizing saline water for agricultural purposes ?

R. L. Datta: Some work was done at the National Chemical Laboratory, Poona but the economics of it for application to agriculture has not been worked out.

N. D. Rege: Whether the salt industry could be combined with efforts for desalinization ?

R. L. Datta: This was quite possible for the saline water concentrated by the desalinization plant could be directly fed to condensation and drying pans from which cake salt could be easily obtained.

THE PRESENT STATUS OF DEMINERALIZATION OF SALINE WATER[1]

by

MOHAN LAL KHANNA

WATER is abundant in some regions, scarce in others. Springs, lakes, rivers, wells, etc. are the main sources of water supply for large populations. However, most of the world's water is in the oceans, which are close to many water deficient areas and sea water is unfit for human, industrial or agricultural purposes. It is, therefore, natural that a great deal of attention is given nowadays to conversion of brackish water into pure or fresh water. UNESCO through its Arid Zone Committee and the Government of the United States through the Office of Saline Water, Department of the Interior, Washington D.C. are spending large sums of money on research and development work on this problem. To produce pure water at a price competitive with those of water from the conventional sources, ways and means are being tried to build equipment of high efficiency at low costs and low operation and maintenance costs.

Brackish water contains upwards from 1,000 parts per million (ppm) of dissolved salts and sea water generally contains 35,000 ppm or 3·5 per cent salts. The U.S. Public Health Service (Spiegler, 1962) recommends that the salinity of drinking water should be less than 500 ppm. The demineralization of sea water becomes expensive and difficult on account of the amount and complexity of the salts in it.

Purification plants have been in operation for many years in the Virgin Islands, in the refinery in Kuwait, in Aruba, in the copper mines in Welcom, Union of South Africa. In these cases the supply of water for both industrial and human consumption is an absolute necessity and its production cost is of secondary importance. The results of research and development work on sea water purification have been published from time to time. The proceedings of the UNESCO Teheran Symposium in 1959, the proceedings of the Symposia on saline water conversion jointly sponsored by the National Academy of Sciences and the National Research Council of U.S.A. in 1957 and 1960 detailed reports and technical papers published from time to time from the T.N.O. Laboratory, the Hague, the Heliological Laboratory of the Academy of Sciences of the U.S.S.R., Moscow, the Salt Water Conversion Project of the State of California at the University of California, Berkeley, and the Office of Saline Water, U.S. Department of the Interior, Washington D.C. give detailed information on different aspects of the problem. In the present paper it is intended to review briefly the present status of demineralization of saline water. No originality is claimed by the author and the material discussed presently is based mostly on the information available from the last two organizations mentioned above. The overall position has been surveyed in some of the recent publications (Spiegler, 1962; Ellis, 1953).

In tropical arid zones, natural water is generally unfit for drinking and agricultural purposes. In the North-Western semi-arid region of Rajasthan desert, trial borings made revealed the existence of sub-soil water at many places at depths ranging from 40 to 350 ft. Chemical analysis of 150 water samples collected from drinking wells in Barmer district showed considerable variation in the salinity as well as in the total dissolved solid contents (Chaudhuri *et al.*, 1962). The former varied between 224 and 10,605 ppm expressed as sodium chloride and the latter, from 314 to 13,388 ppm. Some surface waters and a few well waters from Jodhpur district have also been included. Leaving aside Luni river water, the salinity of these waters is much below that of sea water. The Rajasthan region, therefore, offers vast scope for undertaking demineralization of brackish water and its economical conversion to pure water offers a challenge to scientists. Secondly, river water, as it flows down to the ocean, is subjected to pollution by mines, factories and sewage. The future water supply may be most important factor affecting the distribution of man's population on this planet. The different methods discussed here are applicable to the purification of sea water as well as brackish water and India is equally interested in the successful development of these methods.

Sea water is a solution of certain salts in pure water. Its purification could be effected by the removal of water leaving behind salts or vice versa. This is the principle, on which the different methods presently used for sea water demineralization are based. These methods may be classified as under:

1. Distillation
   - 1.1 Multiple effect
   - 1.2 Multi-stage flash
   - 1.3 Vapour compression
   - 1.4 Flash compression
   - 1.5 Centrifugal compression
   - 1.6 Solar

1. Contribution from National Physical Laboratory, New Delhi.

2. Freezing
3. Ion exchange
4. Electrodialysis
5. Solvent extraction
6. Miscellaneous
7. Combination plants

DISTILLATION

Though this process is very simple, yet it becomes very expensive when large quantities of water are involved. Distillation is carried out on a fairly large scale abroad passenger ships, which consider it cheaper to convert sea water than to carry large quantities of fresh water all the way across the ocean. Its production cost depends upon the cost of available fuel or power. The efficient use of the *free heat* available in the exhaust gases of diesel engines or the exhaust steam from the steam engines used for ship propulsion, considerably brings down the high cost of water purification.

The important variable in the different distillation processes is the temperature of boiling saline water, which determines the properties of steam raised. Scale formation inside the still is a major problem and is overcome by operating the plant within certain restricted limits and by incorporating certain features in the plant design. Fuels used for heating saline water are coal, fuel oil, refinery gases, electric power, hot gases from nuclear reactors, etc. This process is so well developed that according to recent estimates nearly 90 per cent of fresh water produced to-day from saline water is obtained by distillation in one form or the other.

Multiple-effect distillation: In the commercial plants installed in Aruba, Bahrein, Nassau and Curaco, the number of effects employed varies from three to six and depends on the installed capacity of the plant. Heating tubes and some parts of the evaporating still are made from copper, brass, nickel, admiralty metal or other alloys, which are corrosion resistant and good conductors of heat but expensive. The demonstration plant set up by the Office of Saline Water in Freeport, Texas (Badger and Standiford, 1961) has a twelve-effect evaporator, which has been made entirely of steel and cast iron at a much lower cost. To reduce corrosion due to sea water, water is deaerated and certain chemicals are added prior to its entry into the first still. In the long tubes verticle (LTV) evaporator, vapour condense outside the tubes and liquid sea water forms a falling film inside the tubes. The plant is flexible with respect to operating conditions and certain materials of construction.

Multi-stage flash distillation: In this process (Mulford, 1958) saline water is heated with low pressure cheap steam in tubes and is then made to flash off vapour in a chamber, in which pressure is lower than that prevailing in the heating tubes. Vapours produced heat the incoming saline water and condense to produce fresh water. Heat exchange in this way greatly improves the plant economy. Saline water at a lower temperature is passed into the bottom of the second chamber for re-flashing off vapours under reduced pressure. The earlier process is repeated and constitutes the second stage of flash distillation. This could be repeated any number of times, depending on the number of stages provided in the plant. Air and other gases are continuously withdrawn through a vent system so as to keep pressure in the different stages of the system constant at the prescribed levels. Saline water and fresh water are not allowed to mix but remain separate and are brought to atmospheric pressure through pumps.

During saline water evaporation scales are not formed on any boiler or heat exchanger surface but are precipitated in the saline water itself, which is ultimately withdrawn from the last flashing chamber. Though this process appears to be inefficient, yet the simple designs of flash evaporators and the minimum scale formation have contributed a lot to make this process compete successfully with multieffect distillation. On constructing large scale commercial plants this process becomes more economical than the multi-effect distillation process. Heat transfer tubes can be arranged vertically or horizontally, the latter arrangement being preferred for large capacity plants. At present plants operating on this principle, are working in Kuwait, in the Virgin Islands, on the Isle of Guernsey in the British Channel and the demonstration plant in San Diego.

To dispense with the costly special heat exchanger tubes used in flash distillation, vapour reheat process has been suggested. In this process an immiscible oil is heated in a counter-current heat exchanger with hot distilled water collected from the different stages of flash distillation. This oil in turn heats the incoming sea water in another heat exchanger. In both the cases heat is directly exchanged between oil and water. Flash distillation is interposed in between the two heat exchangers. How far this process will prove to be more economical than the flash distillation process is not yet known.

Vapour compression distillation (Spiegler, 1962): Preheated saline water boils in the evaporator. Vapours are compressed on their passage through a direct displacement type compressor. Compressed vapours are allowed to condense on the inside of evaporator tubes and provide the necessary heat for the boiling to occur outside the tubes. The compressor is the heart of the installation and supplies the required heat to raise the temperature of the vapour during compression. In other words, the energy requirements are mechanical or electrical rather than thermal, leaving aside the small amount of heat required to start the operation. The compressor is operated by an electric motor or a diesel engine and its energy requirements increase linearly with the condensation temperature. Optimum design conditions of the plant have been worked out taking into consideration the operating costs, investment and possible lowest condensation temperatures.

Before World War II small units to provide drinking water for ships were developed in compact sizes capable of producing between 0·5 and 10·0 cubic meters per day of pure water. The smaller the unit, the higher the power consumption per unit product on account of the relatively high heat losses through insulation. In larger units nearly half the electrical energy is used for running the compressor, the other half being consumed by the saline water to make up for the heat losses.

To make the unit self-contained, units with compressors driven by internal combustion engines have been developed. Heat from the exhaust gases is utilized for additional heating of the saline water. A serious problem is encountered on account of rapid scale formation on the saline water side of the heat transfer surfaces. Scraping devices to clean the surfaces continuously and acid injection are the best solutions. These difficulties have been overcome in the design of the flash compression and the centrifugal compression stills discussed below.

Flash compression distillation (Dodge & Eshaya, 1960): In this process scale formation is reduced by separating the heating and the boiling processes. After preheating the incoming saline water in conventional counter-current tubular heat exchangers, its temperature is raised to 100°C in the main heat exchanger. By maintaining pressure in the exchanger tubes slightly above the vapour pressure, no boiling takes place. The source of heat is steam or water vapours condensing on the tubes outside. Hot saline water is passed into a flash tank, where vapourization occurs. Only 0·5 per cent of the total vapours are allowed to flash off in each pass so as to avoid excessive load on the compressor, which is placed just after the flash tank. Vapours are adiabatically compressed and excess heat from the vapours is extracted in a desuperheater. Vapours return to the main heat exchanger for condensation and heat release. Part of the condensate is recirculated to the desuperheater and part is withdrawn.

The process has been designed for relatively high heat transfer brought about by high velocity due to rapid and forced circulation of the liquid and vapour. It is yet to be seen how far the experimental data obtained from the demonstration plant compares with the theoretical data.

Centrifugal compression distillation (Hickman, 1958): The novel idea in this process is a rapidly rotating heat exchange surface over which the evaporating saline water spreads as a thin film, which brings about a high coefficient of heat transfer operating at low temperatures and a small pressure difference and brings about considerable reduction in power requirements and scale formation. In a centrifugal compression still, saline water enters just near the axis of rotation into the partially evacuated space bounded by two rotating cones. Due to centrifugal force water spreads on the inner surface when partial evaporation occurs. Vapours are compressed by a blower, which rotates at a speed higher than that of the double cone. Compressed vapours condense at the outer surface of the cone and provide heat for the evaporation of saline water on the inside. Through a scoop tube, saline water remaining behind, is continuously withdrawn from the rotor periphery. For its efficient operation, the incoming water is deaerated and gases in the steam space are continuously withdrawn. Both laboratory scale models and small scale experimental units have been operated so as to gain further experience. Some minor corrosion and scale deposit problems still remain to be solved. Units, which will provide fresh water from sea water for households cut off from the fresh water supplies, would shortly be on the market.

Solar distillation (Khanna, 1964): As the cost of energy in distillation processes is a major recurring item, utilization of the enormous but difficult to capture solar energy for saline water distillation appears to be very attractive. Considerable progress has been made in this direction. In 1872, a solar still, supplying fresh water in an arid zone, was built and operated for many years in Chile. During World War II small plastic solar stills were developed in the United States to provide fresh water for life rafts when floating in the sea. Lot of research and development work has been undertaken to study in detail solar water distillation. Many types of stills have been constructed and operated. However, the low-roof flat solar still continues to be popular, since it is simple to construct and economical to operate.

It consists of a shallow basin whose bottom is blackened and above which sloping transparent surfaces of glass or plastics are provided. The transparent surfaces slope downwards into small channels at the sides along the length of the basin. Suitable connections are provided to fill the basin with saline water and to collect distilled water from the collecting troughs.

In operation, solar energy is entrapped within the glass hood and is absorbed on the black bottom of the basin. Water evaporates inside the hood and condenses as a film on the inside by contact with glass, which is cooled from outside by atmospheric air.

In Algeria and Australia, small solar stills capable of supplying drinking water for an average family or for a few domestic animals, have been developed. Units of 1 to 5 gallons per day capacity are being manufactured for distilling brackish ground water and consist of 15 to 30 sq ft asbestos-cement basins with sloping glass covers. The Office of Saline Water, U.S.A. is operating presently three solar stills at the Daytona Beach Field Station: a 2,500 sq ft glass covered, deep-basin still, a 2,500 sq ft distiller employing polyester film of Mylar for the transparent cover surface, and a small 500 sq ft plastic still using another polyester film of Teslar. Two additional solar stills of the tilted-wick type and the vertical-wick type enclosed in plastic are planned for field testing at this installation. However, compared to other demonstration plants, solar still has not proved to be economical. Though through the development of cheap materials of construction, new designs and low cost of operation and maintenance, it is possible that new economical still may be designed within the next 5 to 10 years.

FREEZING

In the freezing process, saline water instead of being heated is cooled. On cooling, ice crystals are formed, separated and washed with fresh water to free them of the saline water entrained in between them. The entire system is thermally insulated so as to minimize heat gains or 'cold losses'. As applied to demineralization, both direct and indirect freezing processes are of recent development. The common refrigerating equipments are used for the purpose. In direct freezing processes, water acts as its own refrigerant and in the indirect processes, a more volatile liquid, like butane, is used as a refrigerant, which comes in direct contact with saline water and the use of the conventional heat exchanger is dispensed with. In another process, propane forms a solid hydrate with water and the process is known as the hydrate process.

In the direct freezing process (Ashley & Bosworth, 1958) precooled and deaerated saline water is passed into a crystallizer or a freezing tower with very low pressure wherein rapid evaporation takes place. This leads to partial cooling of saline water, which ultimately freezes into a fine slush, which is washed free of saline water held in between the crystals. In the counter-current washer, ice rises up and a stream of wash water flows down. This method is very efficient and requires a small quantity of fresh water for washing. A large compressor is incorporated in the plant for maintaining a low pressure in the crystallizer. Instead of letting out the vapours into the atmosphere, they are withdrawn from the freezing tower, compressed and passed into the counter-current washer, wherein they are condensed into ice and the heat released melts the washed ice into pure water. The plant performance depends on the compressor design, which has to handle large volumes of water vapours across small pressure difference in the two chambers. Rotary fans and blowers are suitable for the job.

In the absorption refrigeration (Bosworth *et al.*, 1960) water vapours are absorbed in a hygroscopic solid or solution kept cold through a heat exchanger with melting ice from the washer. Fifty per cent by weight of lithium chloride solution, which has very low vapour pressure at 15°C, is used to absorb vapours from the freezing tower. During absorption, heat is released and utilized to melt ice. Cold fresh water in turn is employed to maintain the absorption solution at 15°C. To maintain the salt concentration in solution constant, a part of the solution is withdrawn and pumped to a regenerator provided with steam coils, in which it is boiled. After concentrating, it is returned to the absorption chamber. Vapours formed during melted ice. Solar energy may be employed for concentration.

To overcome the drawbacks of low vapour pressure and the handling of large volumes of water vapours in a vacuum-tight plant, the indirect freezing process use a refrigerant (Weigandt, 1958) with very high vapour pressure at the freezing temperature and low miscibility with water. Butane boils at $-0{\cdot}5$°C. Liquid butane and saline water are introduced into a freezer maintained at a pressure at which butane boils off and water is frozen into ice. Butane vapours are compressed to slightly higher pressure than atmospheric and passed into the ice water, when ice melts and butane vapours are condensed into a liquid. On account of difference in densities, butane and fresh water are separated into two layers. Butane is recirculated. A second compressor is used to compress a part of the butane and is required for adjusting the heat leak into the system, which is thus continuously maintained at the required low temperature. Fresh water, obtained from these processes of freezing, contains about 500 ppm of salt, which is just the maximum salinity limit recommended by the U.S. Public Health Service for drinking water (Spiegler, 1962). The actual power consumption in these processes roughly indicates the cold losses and the overall efficiency of the plant. For obtaining the actual value, pilot plants have to be run and the results extrapolated to larger units. These freezing processes are presently under development and their investment cost is uncertain and may be higher than that for flash distillation.

As stated earlier, propane forms a solid hydrate containing 17 molecules of water, though liquid propane dissolves only a light amount of water. Some laboratory scale experiments and preliminary engineering studies have been undertaken. In operation the method is similar to the butane freezing process. Instead of an ice-saline water slurry, a hydrate-saline water slurry would move up the ice washer and then to the melting vessel, where propane vapour condenses to liquid phase and ice melts into water. The former is recycled and the latter is withdrawn. Though the cold losses would be considerably reduced on account of its working at a somewhat higher temperature, yet the equipment has to withstand higher pressures. The use of Freon-31 as a hydrate former is under investigation.

Ion exchange — Complete removal of salts from water by ion exchange (Kunin, 1958) was made possible nearly 30 years ago and is now a routine process for water treatment in industries requiring the use of mineral free water and for the operation of high pressure boilers. The quantity of chemicals consumed is proportional to the amounts of salts removed from water. It is competitive with other processes of demineralization only for low salinity brackish water.

In operation, saline water is passed through a column packed with solid cation exchanger, which is an organic acid and exchanges hydrogen ions with the positive ions of the saline water. On entry into the column, the top layers of resin exchange most of the hydrogen ions. With movement down the column it comes into contact with fresh resin and more of the positive ions are exchanged. However, when water leaves the column at the bottom, the positive ions are completely replaced by hydrogen ions and the water is acidic. Sodium, calcium and magnesium ions of the saline water are replaced by hydrogen ions. It is then passed into another column containing an anion exchange resin, which exchanges all negative ions against hydroxyl ions. OH' and $H^{\cdot}$ ions combine to form water.

To regenerate these resins into the active form, moderately concentrated solutions of acid and hydroxide are passed through these columns. After regeneration, the resins are rinsed and are active for reuse.

In softening process, only the cations exchange occurs, but in demineralization both cations and anions are exchanged. The construction of the columns in the two cases is similar but in demineralization effective corrosion protection coatings are provided to withstand acid solution circulation. In actual practice, nearly 70 per cent of the total capacity of the ion exchange resin is used before regeneration. For each kg of salt removed nearly 1·5 kg each of pure acid and base are needed. As large amounts of chemicals are necessary for regeneration of the resin, the treatment of highly saline water or sea water becomes uneconomical. For this process to be economically feasible, inexpensive regenerants must be used and a considerable portion of the regenerants must be recovered. It has only been used in special cases, such as the supply of drinking water for the town of Eilat on Red Sea. During World War II, the Permutit Company developed a sea-water desalting kit for the production of small amounts of drinking water for pilots shot down and stranded in life rafts. The ion exchange resin containing silver ions is compressed into briquettes, which also contain a swelling clay, silver oxide and activated carbon. The briquettes and sea water come in contact in a plastic bag in which the ion exchange and precipitation take place. Though the treated water still contains large quantities of the salt, yet it is fit for emergency use. These kits are being successfully used for advance parties in the Sahara.

Electrodialysis (Wilson, 1960)—In this process the highly ioned salts are removed from water by electrical forces and concentrated in separate compartments or cells. Electrodialysis units consist of a number of narrow cells, which are separated by alternating cation and anion permeable membranes, which are prepared from ion exchange materials and possess selective action. The edd cells have electrodes for passing electric current through the entire unit. When current is passed, positive ions travel in one direction and negative ions in the opposite direction. In the central cell both types of ions pass through the permeable membranes due to their selective action. Salt concentration in the cells on either side increases and is maximum in the end cells, in which are also present the reaction products of electrodes with salt solution due to passage of electric current. In other words, nearly half the cells contain partly demineralized water and the rest carry enriched brine. In practice, ten to hundreds of cells are installed between one pair of electrodes.

The ion selective membranes are the most sensitive part of the cell units and determine the cost of the plant. They are fouled by scale deposition or interaction with the salts in solution. Even the most durable ones require occasional replacement. Attempts are being made to produce suitable membranes and many types are available on the market.

The amount of electric current required is in proportion to the amount of salt to be removed and varies with the salinity of the water to be treated. As large salt depleted layers are formed near the membrane faces in the dilute compartment that offer great electrical resistance, it is customary to pump water continuously through the cell. Plastic spacer provided between the membranes helps to ensure good mixing within the cell. For processing moderately brackish waters, plants of different sizes including that for a family use, can be obtained.

If the cost of the membranes and equipment can be sufficiently reduced, this process may become economically feasible for desalting of sea water. Currently attention is focussed on the reduction of polarization and scaling, energy requirements, etc.

Solvent extraction—Certain organic solvents can extract more or less pure water from saline water in one temperature range and release it at a different temperature. For example, triethyl amine dissolves nearly 30 per cent by weight of water at 20°C and retains only 2·5 per cent at 50°C. Saline water, when brought in equilibrium with this solvent at 20°C, separates into two layers on being heated to 50°C. However, water layer still contains nearly 3 per cent of the solvent, which is stripped off with steam in a column in which water and steam flow countercurrently. Such units have only been run on the bench scale. The solvent also extracts some salts and the separation is not complete. Another solvent is phenol. For its removal from water, a second solvent, benzene, is used. However, so far, secondary and tertiary amines with 5 and 6 carbon atoms have been found to be the best solvents.

Miscellaneous—The reverse osmosis system of desalination depends on the use of pressure greater than osmotic pressure of sea water to force fresh water at ambient temperature through a selective membrane rejecting the dissolved salts. In addition to pore size and shape, the role played by membrane structure, method of its fabrication and the transport mechanism have not been understood so far.

Combination plants: Since the cost of energy in the various desalination processes is a major fraction of the cost of water produced by different processes, efforts have been made to reduce the energy required through increasing the effectiveness of the processes. Distillation by evaporation has so far given the best results. What is required is low-pressure steam, which can be produced by heat from either a conventional thermal plant (coal, oil or gas) or a nuclear reactor. Low-pressure steam might be available on a surplus basis from chemical plants and can also be obtained by expanding high-pressure steam in a turbine.

The possibility of obtaining very cheap heat energy from extremely large nuclear reactors and using it in distillers of simple design and relatively high efficiency has been indicated. Further reductions in the fuel cost were to be derived from the simultaneous generation of electric power. Keeping this in view, preliminary study of a desalting plant to supply the water needs of the Florida Keys has indicated that a combination of nuclear electric power generation plant and sea water demineralization plant would provide fresh water at an economically competitive price. A 10 million gpd multi-stage flash distillation plant in combination with a 50 MW nuclear electric power plant is envisaged to be built. Another study to supply fresh water to Tijuana, Mexico, contemplates a 72 million gpd desalting plant, built in units of 12 million gallon capacity, to be integrated with the recently built steam electric plant at Rosarito.

In Soviet Russia (OSW, 1964) six scientific research institutes are presently working on desalting and are operating several pilot plant installations. A desalting plant of 1·5 million gallon a day capacity supplies fresh water to 20,000 inhabitants of Shevchenko, a new city on the arid east shore of the Caspian sea. Heat from a conventional power installation is employed to desalt sea water. However, a duel purpose plant desalting sea water and generating electric power with nuclear energy is under construction here.

American experts are also studying the possibilities of setting up a similarly large plant near Jedda, Saudi Arabia, to be fuelled by oil or natural gas.

TABLE 1: Typical large distillation plants

	Location	*Total installed capacity, gpd.*	*Type*	*Manufacturer*
1.	Kuwait (Persian Gulf)	2,500,000	Submerged tube	Weir & Westinghouse
2.	Kuwait (Persian Gulf)	2,500,000	Flash	Westinghouse
3.	Kuwait (Persian Gulf)	375,000	Submerged tube	Richardson, Westgarth
4.	Qatar	1,800,000	Flash	Richardson, Westgarth
5.	Aruba (Caribbean)	3,500,000	Submerged tube	G. & J. Weir
6.	Curaco (Caribbean)	1,000,000	Submerged tube	G. & J. Weir
7.	Nassau, Bahamas	1,200,000	Submerged tube	G. & J. Weir
8.	Venezuela	1,750,000	Flash	Buckeley & Taylor
9.	Taranto, Italy	1,200,000	Flash	Aqua-Chem Inc.
10.	Elath, Israel	1,000,000	Flash	Baldwin-Lina-Hamilton
11.	Chocolate Bayou, Tex.	750,000	Flash	Westinghouse
12.	Isle of Guernsey	600,000	Flash	Wier
13.	Bermuda (Hotel Service)	48,000	Flash	Griscom-Russell
14.	Kingley Air Force Base (Bermuda)	225,000	Vapour Compression	Cleaver-Brooks
15.	Dharan Air Force Base (Arabia)	200,000	Vapour compression	Cleaver-Brooks
16.	Pacific Gas & Electric (Morro Bay, Calif.)	150,000	Submerged tube	Lumus Company
17.	Gibraltar	200,000	Flash and vapour compression	Cleaver-Brooks
18.	Virgin Islands (U.S. Government)	275,000	Flash	Cleaver-Brooks
19.	Southern California Edison (Oxnard, Calif.)	100,000	Flash	Cleaver-Brooks
20.	Aircraft Carriers (U.S.) (each)	200,000	Flash	All manufacturers
21.	Destroyers (each)	32,000	Flash	All manufacturers
22.	Freeport, Texas (OSW Demonstration plant)	1,000,000	Long tube-vertical	Chicago Bridge & Iron
23.	San Diego, Calif. (OSW Demonstration plant)	1,000,000	Flash	Westinghouse
24.	Roswell, New Mexico. (OSW Demonstration plant)	1,000,000	Forced circulation vapour-compression	Chicago Bridge and Iron

@Based on the information given in 1960, 1961 and 1962 Saline Water Conversion Reports.

TABLE 2: Present status of saline water demineralization demonstration plants in U.S.A.

	1	2	3	4	5
1. Process selected	Distillation, falling film, 12-effect	Distillation, flash 36-stage	Distillation, vapour compression	Electrodialysis 4-stage in series	Electrodialysis, 6-stage, 3 in parale and 2 in series
2. Capacity, gallon per day	1,000,000	1,000,000	1,000,000	250,000	650,000
3. Location of plant	Freeport, Tex	San Diege, Calif.	Roswell, New Mexico	Webster, South Dakota	Buckeye, Arizona
4. Architect-engineer firm	W.L. Badger Assoc.	Fluro Corp.	Catalytical Construction Co.	Bureau Reclamation	*
5. Date of starting operation	May 31, 1961	March 5, 1962	July 1, 1963	March 8, 1962	December, 1962
6. Source of raw water	Sea water	Sea water	Brackish well water	Brackish well water	Brackish well water
7. Process equipment manufacturer	Chicago Bridge & Iron Co.	Westinghouse Electric	Chicago Bridge & Iron Co.	Asahi Chemical Industry Co. Ltd. Japan	Ionics Inc.
8. Total plant cost	$ 12,000,000	$ 1,640,660	$ 1,800,000	$ 433,470	$ 297,741
9. Cost per 1,000 gallons	$ 1·64	$ 1·64	*	$ 1·18	*
10. Cost per 1,000 gallons (normalized plant)	$ 1·51	$ 1·16	*	$ 0·80	*

@Based on the information given on page 102 and 152 of the 1962 and 1963 Saline Water Conversion Reports, Office of Saline Water, respectively.
*Not yet available.

TABLE 3: Pilot plants under construction at the Research & Development Test Station, Wrightsville Beach, North Carolina*

	1	2	3	4	5	6
1. Process selected	Thin film	Thin film (Marine unit)	Hydrate process	Direct contact freezing	Direct contact freezing	Vapour reheat distillation with liquid-liquid heat exchange
2. Capacity, gallons per day	37,000	7,000	20,000	15,000	200,000	40,000
3. Architect-engineer	General Electric Co.	Naval Experiment Station	Sweet Water Development Co.	Struthers Scientific & International Corp.	Struthers Scientific & International Corp.	FMC Corp.
4. Source of raw water	Sea water	Sea water	Sea water	Sea water	Sea water	Sea water

*Based on the information given on page 143 of the 1963 Saline Water Conversion Report, OSW, (1964).

The UAR, Libya and Tunisia have also shown interest in saline water conversion to meet fresh water scarcity. The International Atomic Energy Agency (IAEA) is doing its best to persuade developing nations with large arid stretches to give the method a trial. The size of the nuclear reactor, which is so important to cost, is the main snag at the present moment. For a large size reactor, there may not be sufficient demand for power in an arid area in an underdeveloped country to make use of the power generated. IAEA, U.S. and Israeli scientists are also discussing plans for saline water conversion with the help of nuclear reactors. A possible cooperation between U.S.A. and Soviet experts in this connection are being explored. These are some of the trends, in which future world commercial plants may be built so as to produce water at still lower costs to be comparable with its cost from the conventional sources (in India Rs 1·00 or $ 0·2).

In Table 1 are given details of some typical large distillation plants presently installed throughout the world. Though over a dozen conversion processes were considered by the Office of Saline Water, U.S. Department of the Interior, yet only five of the most advanced and potentially promising processes were recommended for construction. The details available for these plants are listed in Table 2. Pilot plants under construction at the Research and Development Test Station, Wrightsville Beach, North Carolina, are listed in Table 3. It will be noticed that the cost per thousand gallons of fresh water from the existing demonstration plants is higher than $ 1, but the estimated cost of production from these plants, when normalized, would be reduced to nearly $ 1 as compared to estimated cost from the combination plants with nuclear energy being $ 0·18. However, certain experts believe that the cost ultimately may be lowered to $ 0.2 (OSW, 1964).

The demineralization of saline water is of great interest to India and the Rajasthan region offers vast scope for experimentation. The conditions here are almost ideal from the point of view of solar energy utilization, for the region has bright sunshine for most part of the year and the sun angle is high. The laboratory scale experiments on demineralization of brackish water conducted at the National Physical Laboratory, New Delhi (Khanna, 1962) could be extended by installing a number of solar stills of larger area that would convert brackish water of the region into potable water. These larger stills could be installed at the Central Arid Zone Research Institute, Jodhpur and work undertaken to study the cleaning problems and to evaluate the life of still components under actual working conditions. However, large sums of money are involved and it would need UN Special Fund assistance to supplement the Indian funds.

Secondly, it is contemplated to set up nuclear reactors for electric power generation in different parts of the country. It would be worthwhile to examine the possibilities of integrating these power generators with the multi-stage flash distillation plant for demineralization of brackish or sea water.

The help received from the progress reports of the Salt Water Conversion Project, University of California, Berkeley and the annual reports of the Office of Saline Water, U.S. Department of the Interior, Washington D.C. in writing the present paper is greatly acknowledged by the author.

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DISCUSSION

P. G. Adyalkar: What is the significance of the inclination of the upper glass-plate to the efficiency of the still ?

M. L. Khanna: The inclination is so adjusted as to produce film condensation rather than drop condensation.

H. Tabor: In normal heat exchanges drop-wise condensation was preferred but for a solar still film-type was preferred as the drops interfere with the incoming solar energy and thus affect the still performance.

B. Ramamoorthy: What is the theoretical minimum of energy required for desalting sea water ?

M. L. Khanna: The theoretical minimum of energy required for desalting sea water of salinity 34·3% at 25°C is 0·70 Kw hr/m^2 or 2·65 Kw hr per 1,000 H-S. gallons.

DEMINERALIZATION OF BRACKISH WATER[1]

by
R. NATARAJAN

INTRODUCTION

THE availability of potable water in the arid and semi-arid regions is scarce. Of particular interest to us is the semi-arid type of regions in Rajasthan where most of the water available is saltish, the total dissolved solids being over 2000 ppm (Taylor, 1952) which is higher than the normal permissible limits for drinking water (U.S.P.H.S., 1946). Even though, in certain regions, local people live on salt contents much higher than the permissible limit of 1000 ppm of total dissolved solids (Nordell, 1961), this cannot in any case exceed beyond 2000 to 3000 ppm. Therefore, there is a positive need for finding out a suitable method for removal of salt from such water rather than importing potable water from long distances. Keeping this in view and also the possibilities of utilizing sea water as a source of potable water in the coastal regions where good drinking water is not available, work is in progress in various countries on removal of salt from water. The methods that have received major attention in this regard are mostly based on evaporation, chemical treatment, freezing and electrodialysis. In this paper is presented a short resume of the work being carried out in various parts of the world; and lines of approach adopted in the Defence Laboratory, Jodhpur, to evolve suitable methods based on indigenous resources is also included.

DETAILS OF VARIOUS DESALTING PROCESSES

Evaporation Methods

There are a number of methods based on the principle of evaporation, among which the multiple effect distillation (Badger *et al.*, 1961), flash distillation (Howe, 1962), vapour compression (Campobasso, 1948), wiped film evaporation (Howe, 1961) and the solar distillation (Grune *et al.*, 1960) are the important methods from the point of view of large scale production of potable water.

In the multiple effect distillation process, steam derived from boiling brine in the first stage is condensed in the second stage where it is allowed to give up its latent heat to boil more salt water and so on. In this process the maximum efficiency coupled with economy can be achieved by employing about six stages, even though, theoretically about 17 stages are possible (Gilliland, 1955). The major difficulty in this process, however, is scale formation in the equipments and consequent heat losses.

In the flash distillation process, the sea water is heated and fed into chambers kept under reduced pressure. Here the vapour releases and is condensed in coils passing through cold sea water where the latent heat of cooling is reutilized for heating purposes. This process even though avoids much of scale formation, as the temperature employed is low, involves treatment of large volumes of vapour.

In vapour compression distillation, the steam from boiling brine is compressed so as to raise its temperature. This superheated steam is used to heat further quantities of sea water during which process it condenses. The concentrated brine as well as the condensate are passed in a double pipe heat exchanger so as to heat the feed water nearly to its boiling point. This process is highly efficient from the point of view of fuel economy but involves considerably higher costs of installation. Scale formation and corrosion of the equipments due to the hot brine are also of considerable significance.

In the wiped film evaporator developed by the GEC, the salt water is distributed as a film of about one thousandth of an inch thick inside a vertical copper tube by means of a rotating wiper and is heated by a steam jacket. The vapour produced is drawn of from the top and the brine from the bottom. It is claimed that this process prevents much of scale formation. The process is still under bench scale/small scale models.

Utilization of solar energy for the purpose of distillation eliminates the cost of fuel. However, the diffuse nature of solar energy makes necessary the use of large areas. Even though a number of domestic solar stills have been developed, large scale employment has not been made due to scale formation, vapour losses due to leakages and the cost of installation.

A number of domestic desalination units (Cadwallader, 1962) are available employing most of the above principles.

The latest approach in distillation processes which promises to be of considerable significance with regard to economy and fuel consumption is that based on nuclear energy (Committee Report, 1963).

1. Contribution from the Defence Laboratory, Jodhpur.

Chemical Methods

The important methods based on chemical treatment for the purification of salt water include the ion exchange process, solvent extraction, and the formation of hydrate crystals. Among these, the ion exchange method is the oldest and widely applied in the industry for softening of water. The permutit process of softening water using the naturally occurring zeolites is well known. The use, however, of ion exchangers for producing drinking water is of recent origin, after the advent of the synthetic ion exchangers particularly of the polystyrene type. In the ion exchange process two types of resins are employed viz. a cation exchanger which removes the basic group yielding H^+ ions, and an anion exchanger which removes the acidic group yielding the OH^- ions with the net result that the salts are completely removed. These resins could also be mixed and employed as a mixed bed resin process for particular purposes. The capacity of the resins to exchange ions is not indefinite and these need regeneration after exhaustion, which in turn involve use of acid and alkali. This cost of regeneration is generally high. Attempts are, therefore, being made to reduce the same (Gilliland, 1955).

The ion exchange process is ideally suited for waters containing about 1000 ppm of t.d.s. which may be extended up to 2500 ppm successfully (Yoseph, 1956). In the case of water containing higher salt contents it may not be economical to employ this process on large scale.

For production of small quantities of drinking water for the purpose of employment by individual stranded persons, where the cost is not a criterion, a kit based on silver barium zeolites has been developed (Lane *et al.*, 1946). Here silver and barium ions get exchanged with sodium, potassium, calcium and magnesium ions present in sea water to yield insoluble silver chloride and barium sulphate. Pure water is obtained on removal of the treated resin along with the precipitates. In this process the removal of salts is, therefore, effected in a single operation.

The solvent extraction process is in the development stage. Here, the extraction of pure water from saline solvent is achieved by use of organic solvents. For example N-ethyl-n-butyl amine has been found to extract about 30 per cent water at 30°C and to retain about 13 per cent at the separation temperature of 75°C. This process because of its simplicity of operation appears promising (Jenkins, 1961; Chem. Engg. News, 1963).

In the hydrate process, low molecular weight hydrocarbons such as propane (Knox *et al.*, 1961) at low temperature yield clathrate crystals having 17 moles of water. These crystals could be separated and washed to yield water having a salt content less than 500 ppm. This process is still in the initial development stage.

Freezing Methods

The removal of salt from sea water by freezing and separating it in the form of ice is an attractive alternative method to distillation since it involves only about one seventh of the energy required for evaporation. Also this process reduces corrosion, scaling, etc. of equipments due to the low operating temperature. Some of the processes involving the freezing principle include (i) freeze-evaporation process where the salt water is first chilled in chambers under high vacuum followed by separation of washed ice crystals and melting the same, and (ii) refrigerant cooling method (Karnofsky, 1961) in which the sea water is partially frozen to a slush by direct contact with boiling butane at a pressure slightly below the atmospheric pressure when the water supplies the heat of vapourization with consequent freezing. Ice is separated and melted by a reverse process. All these processes even though attractive, involve formation and separation of ice crystals from brine during which process it gets highly contaminated with salt.

Electrodialysis

The electrodialysis method consists of electrolyzing the salt water in an electrolysis cell comprising of alternate cation and anion exchange membranes making into a series of compartments in which the water passing through alternate membrane pairs is depleted of salt while that passing through the other sets of membrane pairs is enriched in salt. A number of ion exchange membranes of homogenous and heterogenous types have been developed and their performance studied on large scale units (Wilson, 1960). The basic requirements of the membranes to be employed include high electrical conductivity, low permeability to the passage of water itself, high selectivity to the respective ions, good mechanical strengeh, and chemical stability to impurities like Fe, H_2S, etc. which are likely to be present in the water to be treated and also the products of electrolysis like chlorine and sodium hydroxide obtained at the anode and cathode compartments respectively. Even though the membranes obtained are not entirely satisfactory with regard to all the above requirements, considerable progress has been made in employing this method on wide scale. This process, however, will not be economical for waters containing more than about 10,000 ppm t.d.s.

Other Methods

Among the various other methods under consideration for the desalting of water, mention must be made of the process based on reverse osmosis (Gilliland, 1955; Jenkins, 1961).

Osmosis involves the passage of water through a semipermeable membrane from dilute to a strong solution of salt, as a consequence of which osmotic pressure is created. The reverse osmosis involves the application of a pressure greater than the osmotic pressure to the concentrated salt solution in such a cell so as to make water flow in the opposite direction, viz. from the stronger to the weaker solution. This is similar to the processes involved in intake/excretion of many electrolytes in the living cell. Even though this basic principle is very elegant, so far no suitable membrane with sufficient mechanical strength and permselectivity has been developed.*

Present Work

Keeping in view the availability of basic materials in the country, three different approaches have been made with regard to desalting of water. For the purposes of use in emergency, a desalting kit (Natarajan *et al.*) based on the silver salt of an indigenous polystyrene cation exchanger (Govindan *et al.* 1963) has been developed. Work on ion exchange column method using the indigenous cation exchanger and an anion exchanger based on melamine and hexamine (Krishnaswami *et al.*, 1962) is in progress for use with brackish water containing salts of the order of 2500 ppm. Efforts are also underway to develop a suitable anion exchanger based on either polystyrene, melamine or urea. Further, heterogenous type of membranes of both cation and anion exchange types using dialyser paper have been prepared and are under study for use in electrodialysis process.

*In the recent past membranes based on cellulose acetate have been found to be fairly satisfactory.

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DOMESTIC USE (SOLAR ENERGY)

SOLAR ENERGY SURVEY[1]

by

H. TABOR

BACKGROUND

THE general state of the art in solar energy research and utilization up to 1960, in particular in relation to arid zone problems, was summarized at the UNESCO Arid Zone Conference in Paris in that year and reported in the conference proceedings. In 1961, at the U.N. Conference on New Sources of Energy in Rome, more than a hundred papers were given covering different aspects of solar energy research and application.

The 1960 and 1961 conferences brought us to a stage which may be roughly summarized as follows:

(a) Much work was being done in solar energy research for space applications: Most of it had little significance for terrestrial applications due to the different economics and technical requirements.

(b) Solar furnaces had been developed to quite a high degree but their application, like the space applications, was relevant only to highly sophisticated technological communities.

(c) For the "down to earth" applications for solar energy, research was underway in a number of centres but it had to be admitted that, apart from water heating, the amount of useful application was disappointingly small. The total amount of water being distilled in the world by solar energy was less than the capacity of the smallest municipal water works. There were no records of more than a handful of solar pumping units in actual use — and virtually no production of such units. Several models of solar cookers had been developed but the total number of such cookers in use in the world was probably less than a hundred*. Several proposals had been made for solar refrigerators but there were less than ten (reported) experimental units working. A few solar heaters and/or cooled solar houses had been designed and built but almost exclusively in highly developed countries. A very small number of experiments in solar drying for agriculture had been reported.

This state of affairs existed, not because of a shortage of good scientists and engineers — indeed some first class scientific work had appeared in the solar energy literature — but because of basic factors related to solar energy and to the potential users of this energy. Solar energy, being diffuse, called for large devices, resulting in high capital cost. The potential users in the developing nations were mostly low-income groups. The consequence of these two factors was that no commercial companies were involved in any solar research and development (other than water heaters, solar cells and space applications) and that research development was conducted by universities and government laboratories. No commercial company had been moved to try to exploit the very large potential field for solar refrigerators in the hot, non-electrified regions of the world.

In the last three years, the situation has not changed a great deal but there are a few breaks in the clouds which are discussed below:

BASIC CHANGES

Of the two factors governing solar energy exploitation i.e. the amount of energy and the amount of capital available, not much can be done about the first. However, there are signs that the developing countries can raise capital for programmes if these can prove that they will benefit the economy. Thus, if there is more courage in development of commercially useful solar devices, the chances of their being used are better now than a few years back. On the other hand, the developing countries are now better able to discriminate between the various paths to economic and social progress so that any scheme, solar or any other, must present a convincing case.

PRESENT STATUS

(a) *Materials:* Rather less progress has been recorded in this aspect than one might have expected. The best transparent plastic — polyvinyl fluoride (Tedlar) — announced a few years ago, is still rather expensive and the manufacturer (*du Pont*) actually ceased promotion for solar applications and concentrated on its other uses having more favourable markets. Also, the aluminized version of this plastic was found to be unstable.

The use of selective black surfaces for improving the efficiency of solar absorbers has grown. A

1. Contribution from National Physical Laboratory of Israel.
* Excluding "picnic" cookers in the U. S.

completely commercial plant for producing such surfaces on galvanized iron sheets up to 1×2 m was set up in Israel and produces many thousands of units per year. In Australia, selective blackening on copper sheets is being used on a small scale and one or two other centres have reported on the use of such surfaces for experimental collectors*.

(b) *Solar Radiation Measurement:* Most of the instruments for solar energy recording were rather expensive. Recently, it has been shown that solar cells can, under certain circumstances, be used with reasonable accuracy. A simple unit called a Sol-A-Meter is sold commercially in the United States and the Brace Institute recently reported on the use of solar cells with an ampere-hour meter for integration. These developments in low-cost equipment should encourage a wider network of measuring stations.

(c) *Solar cookers:* This area has remained virtually stationary. Although, in this country (India), the solar cooker would be of great importance to national development if it prevented or reduced the burning of dung and agricultural wastes as fuels — when they should be used as fertilizers — yet it does not seem to have caught on, because of price, or social custom or both. Since reasonable designs are *in existence, the problem is one of organization,* not of science.

(d) *Solar distillation:* No breakthroughs have been reported in this area. But steady progress along classical lines is reported from some centres. The CSIRO in Australia have applied ingenious engineering principles to making a conventional "ridge" type still (using glass covers) which looks as though it will be the best to date but they have not yet published details of costs and performance. The University of Arizona is experimenting with stills using plastic covers and external condensation. A plastic covered still was recently installed in Symi in the Dodecanese Islands. Most of the stills reported are single-effect types (to reduce complexity in construction) and the outputs are in the region of 0·1 gallon per day sq. ft. Since the cost of constructing a sq. ft of any kind of still cannot be reduced indefinitely, this system will never produce really cheap water. But where, as in Symi, any other fresh water is extremely expensive the solar distiller has its place. If, in any arid zone, one can decide how much the local community can afford to pay for fresh water, then the viability of solar distillers — in today's state of development — is at once determined.

(e) *Refrigeration and air-conditioning:* The Rome Conference had indicated that air conditioning, solar or electrical, was probably beyond the means of most developing areas. The prognosis for refrigerators, particularly at the village level, seemed better. In the last three years, some work has been reported but it hardly changes the picture from the technical and scientific point of view. What is still required is a market study of what is needed in a given area and a courageous commercial organization to produce for that area.

Australia is a rather special case of a (largely) underdeveloped country but having a population with a high standard of living. Air-conditioning is virtually a necessity to get the population to move to the underdeveloped arid areas in the centre of the continent. Consequently, the Australians are doing interesting work in solar air-conditioning that will probably be of benefit to other arid areas in due course.

(f) *Water heaters:* These are already successful in many parts of the world and their use is growing in communities in a middle stage of development*. They compete (in sunny areas) with electrical water heating, except where the electricity cost is extremely low and will usually compete with low efficiency oil heaters. However, on an industrial scale, they cannot — as yet — compete with large efficient oil-fired heaters. If this is true for water heating, it is even more true for steam production, where the solar collector is less efficient due to the higher operating temperature.

(g) *Air heaters:* Some progress is reported in air heaters (used for agricultural drying). One difficulty in many agricultural applications is that the season of use is short so that the capital investment per annual BTU is high.

(h) *Power supplies:* (i) *Micro-power:* The solar cell is still the standard method of producing from sunshine very small quantities of power — say, up to a few watts. There has been substantially no drop in the very high price of silicon solar cells, which leads to a capital cost of about \$ 100 per (peak) watt output. (This brings the cost of electricity to about \$ 7 per kWh in a sunny region).

However, there is a good chance of progress here. Work is proceeding on other types of cells —referred to as large-area cells — which, unlike silicon, are not based on single crystals. These use materials, such as cadmium sulphide, telluride or selenide or gallium arsenide. Such cells have lower conversion efficiencies than silicon cells, but where area or weight are not important the only criterion is the cost per watt. It may be expected that solar-cell power will fall in cost by one or even two orders of magnitude in the next few years. Such cells can play an important part in powering communications systems (radio, telephones) in non-electrified areas, thereby greatly assisting the social and economic development of such areas. It is unlikely that they will be cheap enough to permit operation of mechanical equipment. Although there is much

*Selective surfaces have special significance in collectors used in outer space and a good deal of basic research has been carried out in this field.

*Very highly developed communities are often too densely populated to permit solar heaters: very poor communities cannot afford *any* form of domestic water heater.

research required in thermoelectric energy converters, the practicability for simple terrestrial applications is in doubt. The high temperatures call for heliostatic concentrating mirrors and efficiencies are still very poor.

(ii) *Small power supplies* (In the range of a fraction of a horsepower to several horse-power): In 1955, an Italian company demonstrated a solar pumping unit operated by flat plate collectors. This was a piston engine using sulphur-dioxide as the working third. A few such units were made and sold but it appears that their measured power output was only a small fraction of the nominal power rating.

Recently a Swiss company has announced a similar unit. It has not been possible to obtain full details or a photograph of the unit though the description is reminiscent of the Italian unit. The power output is given in water pumped, not in horse-power, and is very small. Thus, the Type O model will pump 500 to 1000 litres per hour at depths up to 50 m. If we take 500 litres at 50 m this corresponds to 1/10 H.P. pump work. Allowing for pump and transmission losses the shaft power output is probably double this. At a cost of US $ 2000*, this is close to $ 10,000 per installed horse-power.

At the U.N. Conference in Rome in 1961, the National Physical Laboratory of Israel demonstrated a 5 H.P. solar-operated vapour turbine. The model was experimental with many practical problems still to be solved, but it proved the basic principles behind its conception. In the last three years, the laboratory has concentrated on converting the crude demonstration turbo-generator into a practical prototype. In June of this year, the first such prototype — rated at 600 watts — was completed. It is hermetically sealed, has only one moving part (the rotor) and requires no maintenance of any kind. In theory, it should — like as a modern sealed refrigerator unit— work for many years.

Perhaps the most encouraging fact is that a manufacturer has been found who will take the prototype and produce it on a commercial basis. The units can be built in any size from 150 watts to 4 kw. The first models to be made will be 200 watts, 600 watts and 4 kW. (The smallest size is intended for the operation of communications equipment). It is of interest to note that the expected high reliability, long life and freedom from maintenance have prompted the use of such units with fuels instead of solar energy where independence of weather conditions — and of the cleanliness of the collectors — is essential.

The first batch of commercial units will be available in about 6 to 8 months, after which the manufacturer will plan his production schedule, which, of course, affects the price, on the demand. It is not possible to give prices at this time but a first estimate is that the 4-kW unit will cost $ 3000 plus the cost of collectors, at present estimated at about $ 5000. (For smaller installations the cost of the collectors falls proportionately but the turbo-generator less so). Both the price of the turbo-generator and that of the collectors will fall as the market increases.

Although $ 2000 per kW is a high price, there are many cases where it is viable. One example is given in Section 4 of this paper.

(iii) *Large power units*: As reported in previous conferences, the solar pond appears to be the only approach to really large-area solar-energy exploitation that has any reasonable chance of success. Work on the solar pond concept has been stepped up in the last 3 to 4 years though the final answers will only be forthcoming in about two years time. The slow progress has not been primarily due to lack of funds but because, after completion of the laboratory studies, the experiments have to be carried out in the field on a scale that is not too small to hide the effects being studied. Such experiments take a long time to construct and are bound by the annual cycle of solar radiation and seasonal weather. Because the solar pond may have some special interest in this part of the world — on account of its possible use in salt production — I will devote a few minutes to this interesting subject. It will be recalled that a solar pond is a mass of water having a black bottom acting as a large area solar collector. To increase the heat retention efficiency, convection in the pond is suppressed by impressing a density gradient with the highest density at the bottom. This is achieved by using highly saline water at the bottom and water of decreasing salinity as one goes upwards. It may be shown that, with an adequate gradient, convection does not occur even though the bottom may approach the boiling point. (Temperatures up to 94°C have been recorded with near ambient temperature at the top of the pond). The slow diffusion of salt upwards is compensated by adding salt or concentrated solution at the bottom and washing at the top. The heat may be extracted by decanting the hot solution at the bottom. Hydrodynamic theory shows that this is possible — without causing mixing of the upper portion of the pond — because a density gradient exists.

As a collector for low-temperature heat, the solar pond should be an order of magnitude cheaper per unit area than the conventional solar collector used for water heating since no metal, plastics* or glass are used in its construction. As such, the pond would produce low-temperature calories at a fraction of the price of calories produced from fuel. It is

*This includes the cost of the pump. There is a Type I model of double the pumping capacity: this costs $ 3,000.

*A lining may be necessary on land which cannot be made substantially impermeable.

thus possible to consider power production using low temperature turbines, despite the inevitable low Carnot efficiencies. Depending on the investment needed in constructing the pond and its plumbing, the cost of power produced from a pond of, say, 1 sq. km in size would be somewhere between 1 and 2 U.S. cents per kWh the pond of this size having an installed capacity of about 5000 kW. Although 2 cents is not competitive with large central power stations, it is competitive with small diesel stations. Thus, for the supply of blocks of electric power — in the range, say, 500 to 5000 kW — the solar pond would be attractive. From what is known today, the local requirement for such ponds are flat, preferably impermeable ground, a local supply of cheap salt or, better, a supply of sea water and an adequate amount of sunshine. (Areas near the equator will provide a more uniform output during the year than those at high latitudes with their reduced solar incidence in winter. Thus a calculation under Israel conditions (at latitude 32°) showed the mid-summer output at about four times the mid-winter output*). Thus the best sites are those near the sea that might be suitable for salt production.

Because a solar pond is, potentially, a source of very cheap low-temperature calories, it has applications for processes requiring large amounts of such heat. An example of interest, particularly in this country, is salt production.

In the standard method of making salt by solar evaporation, water is run into large pans and is concentrated in stages by evaporation until the last pans are virtually dry. Three points are to be noted. The utilization of solar energy is inefficient because, in some pans, the bottom is white or light-coloured so that only the infra-red and part of the visible solar radiation is absorbed and also because, as the brine becomes more concentrated, the vapour pressure of water falls and higher evaporation temperatures are needed, leading to larger heat losses to the atmosphere. The second point, related to this question of vapour pressure is that, in humid regions, it is impossible to produce salt unless the last stages of concentration are carried out in fuel-fired evaporators. Thirdly, solar salt production is not possible in areas where rainfall would interfere with the evaporation cycle.

The solar pond used for salt production makes the process almost independent of the weather (provided there is enough solar radiation) and also uses the sunshine more efficiently. This is because: (a) the evaporation process is carried out in a closed evaporator supplied with heat from the bottom of the pond, and (b) the surface of the pond is always near ambient temperature so that heat losses are small. A paper study conducted at the Arid Zone Research Institute in Beersheba showed that, for local conditions, the yield of salt for a plant of given area should be about doubled by using the solar pond. Of course, the cost of constructing solar ponds and maintaining their correct operation is higher than for simple evaporation pans but the 'harvesting' from a closed evaporator is easier than from large open pans. There is also every likelihood that the salt obtained from the evaporator will be refined, since the conditions of crystallization are controllable, whereas the salt-pan salt is crude and for most applications has to be refined.

*Daily variations of sunshine are hardly noticed in a solar pond because of the large thermal capacity of the pond and the ground underneath).

APPLICATION AND ECONOMICS

The present status, as described above, has intentionally omitted developments primarily of academic interest or of interest in space technology. It is seen that, other than the possible use of solar cells for micro-power requirements, all the other applications are based upon solar energy as heat at moderate temperatures. It follows, therefore, that solar energy utilization is attractive when, and only when, the alternative supplies of heat are more expensive than the total of interest, amortization and maintenance costs of solar collectors. Even where the solar collector can show, on paper, a lower cost per unit of energy, conventional fuels may still be preferred either because of lack of available capital, or, in some cases, because of conservatism. Discontinuity and lack of control over yield are further objections.

The cost of solar heat in sunny areas varies somewhat from place to place because of differences in sunshine and in local manufacturing facilities. But the cost of fuel varies much more; a factor of five or more can be found between the cost of liquid fuels in remote interior areas and the same fuels at the seabord.

We will consider two examples, of interest to arid zones, which I hope will give encouragement to persons interested in the development of such areas.

In the rapporteur's summary on solar cooling and refrigeration at the U.N. Rome Conference, it was pointed out that, for an arbitrarily chosen set of conditions — which are probably not far from real conditions — a solar absorption refrigerator would compete with a conventional fuel-operated unit if the fuel cost is more than $ 28 a ton. As this is about twice the seabord price of fuel, it is at once seen that many arid zones would find the solar refrigerator worthwhile. However, it was assumed that some additional development work would have to be done by an adventurous manufacturer. (One difficulty in finding such a manufacturer is that, at least initially, he would have to be international, supplying the small markets of many countries: tariffs and import restrictions in some countries would inhibit his activities and hence his willingness to enter the business. Nevertheless, I am confident that there will be progress in refrigeration for food-stuffs and medicaments using solar energy).

The second example deals with water pumping. This is probably the greatest initial energy need for arid zones. A colleague of mine recently visited the Republic of Niger, large areas of which are very dry, at least for eight months of the year. Water can be found at depths of from 45 to 80 m. He was given the following information from careful records kept by the Public Works Dept., concerning a group of ten pumping stations of 20 H.P. capacity*. The stations operated between 170 and 240 days a year or 1200 to 2800 hours a year. The total water pumped for the ten stations was just under 300,000 cu. m per year, and the cost of the water came out at 66 US cents per cu m. The cost of maintaining each station i.e. supplying fuel, oil, spare parts and maintenance but not including amortization on the equipments was approx. $ 10,000 per year (which represents 33 cents per cu. m). It would appear that amortization, overheads and other items come to a further $ 10,000, thus leading to the water cost of 66 cents per cu. m.

*There are two diesel units at each station each of 30 H.P. the 50 per cent overrating being necessary for mechanical reasons.

These costs are rather frightening to those trying to make the desert bloom, but they are an encouragement to the solar scientists. If a solar pump — as indicated in paragraph 3h(ii) above — costs around $ 1300 per horse-power, and requires no fuel and negligible maintenance other than that associated with the pumps, then the pay-off time is three years, assuming 20 H.P. and $ 10,000 a year saving in running costs.

Summarizing, we see that some progress is being made in developing practical ways of using solar energy, mainly as heat at moderate temperatures (or power derived from this heat) and that the economic viability must be checked in each case and for each site. Some applications are already viable in certain areas; as research and development proceed, the areas of viability will be increased.

DISCUSSION

R. L. Datta: How far the work on "solar pond" has proceeded ?

H. Tabor: Report from the Negev Institute in Israel, indicates that some work was being done in Chile though mostly of a theoretical nature.

SPACE HEATING BY SOLAR ENERGY[1]

by

J. P. Gupta and D. Krishnamurti

INTRODUCTION

In regions situated at high latitudes, the ambient temperature is quite low, thereby making the heating of living space essential. Usually this is achieved by resorting to the use of suitable fuels e.g. wood, coal, oil, etc. Besides the above conventional method, investigations carried out elsewhere have shown that solar energy can also be used for heating living space. In far away regions (e.g. Ladakh) conventional fuels are scarce and no hydroelectric power is usually available. Besides, the transportation of fuel from distance places is laborious and expensive owing to the uneven terrain of these areas. Since solar energy is abundantly available in high altitude regions, it was decided to develop a suitable equipment for heating the living space by sun. The present paper reports the results of investigations (on a full scale model of a room) carried out at Defence Laboratory, Jodhpur, for heating living space by solar energy.

GENERAL CONSIDERATIONS OF TECHNIQUE

A conventional solar space heating system mainly constitutes a flat plate solar collector, heat storage bin and a suitable device for circulating the heat transfer fluid. The flat plate solar collector is essentially a blackened metallic surface which is covered with one or more transparent sheets of glass or plastic for trapping the incident solar radiation and backed with suitable thermal insulation for reducing the thermal losses. The solar radiation transmitted through the transparent cover is absorbed by the black surface but the heat radiation emitted by latter is absorbed by the glass cover due to its opacity in infra-red. The heat absorbed by the blackened surface is taken up by the medium of air or water which is allowed to flow beneath the blackened surface. For solar heating in winter, the flat plate solar collector is generally made to face towards south (in the Northern hemisphere) at an angle of about 15° plus the latitude so that maximum solar radiation is incident.

The storage of heat is most essential to meet the heating requirements during night and cloudy weather. Heat is stored by circulating the heat transfer fluid from the solar collector through the storage medium during the sunny period. The stored heat is recovered back during the sunless period and transferred to the living space. Usual types of heat storage media are pebbles, hydrated salts e.g. Glauber's salt ($Na_2SO_4.10.H_2O$) and water. For air as heat transfer fluid, pebbles and hydrated salts are preferred for storing heat. Water is a good heat storage medium due to its large thermal capacity. It can simultaneously be used for transferring heat from solar collector to the heat storage bin. In the latter case, water in a storage tank, is heated during the day by circulating it through the solar collector. Automatic circulation of water is possible by thermosiphon action if the storage tank is placed at a higher level than the solar collector. Very often, hot water from the storage tank is circulated through finned types of radiators and living space is heated by blowing room air over these radiators. Space heating has also been affected by circulating hot water through radiant heating panels located in the room. Living space is heated by radiation and convection of heat from these panels.

Obviously all the above mentioned methods require pumps, blowers, etc. for the forced circulation of the heated fluid and hence electric power is needed to operate them. Since solar space heating is often required at places where electric power is not available, it is desirable to devise a solar space heating system without resorting to the forced circulation of the heated fluid. Experiments have been conducted at Defence Laboratory, Jodhpur, keeping this fact in view.

EXPERIMENTAL DETAILS

In the present method water is used for both the transfer of heat as well as heat storage. Solar collectors are placed on the ground outside the southern wall of the room to be heated in an inclined positions facing the sun. Water is stored inside the room in a metallic tank which occupies practically the entire southern wall and is placed at a higher level than the solar collectors so that thermosiphon circulation of water is possible. The cold water is fed to the solar collector from the bottom of the storage tank and hot water from the solar collector enters the tank at about 2/3 of the

1. Contribution from Defence Laboratory, Jodhpur.

height of the tank. This is to ensure uniform heating of the major portion of water in the storage tank and at the same time to provide additional head for the flow of water. Water in the storage tank is heated by circulation through the solar collector during the day. The living space is heated by natural convective and radiative heat losses from the surface of the storage tank which faces the room. The other five surfaces of the storage tank are insulated for reducing radiation and conduction losses. The details of the experimental chamber, solar collector and the storage tank are given below.

Experimental Chamber — It is the living room of the experimental hut. It has the dimensions 12 ft (length) × 9 ft (width) × 8 ft (height) from inside. The walls which are made of 1½ ft thick stone are plastered with 1 in. thick mud on both sides. The inside of the walls is insulated with 1½ in. thick jute insulation board. The U-factor (Thermal conductance) of the walls is 0·13 Btu/hr/°F. The roof which is supported by 5 in. thick wooden ballies (spaced 12 in. centre to centre) consists of 1 in. thick wooden planks and 2 in. of mud roofing. The space between the ballies is loosely filled with jute felt. The average U-factor for the ceiling is 0·11 Btu/sq. ft/hr/°F. The room is so built that the length coincides with the East-West direction. There is a door 6×3 ft on the northern side and a window 3×2½ ft on the eastern side. There is also an adjoining room (6 ft long) on the western side which is used for keeping necessary measuring equipment. A door of size 6×2½ ft opens between the two rooms. A certain amount of ventilation is also provided in the room.

Solar Collector: The solar collector consists of two corrugated G.I. sheets which are riveted and sealed together in mirror-image position. Two headers (1½ in. dia.) are provided for the inlet of cold water at the lower end and outlet of hot water at the upper end. The inlet and outlet for water are achieved through G.I. pipe pieces (¾ in. dia.) which are attached to the two headers in opposite directions to avoid short circuiting of water in the solar collector. The upper sheet is painted black to a matt finish. This assembly is mounted in a wooden box and insulation of 4 in. thick saw dust or glass wool is provided at the back and sides of the heat absorbing element. A single sheet of transparent window glass is used to frame the black surface, keeping an air gap of 2 in. between the two. In the present studies four such solar collectors have been used and each of them has an absorbing surface area of 17·5 sq. ft. All the four solar collectors are connected to a pair of storage tanks (described below) in two parallel circuits. As mentioned earlier, the solar collectors are mounted facing south and making an angle of 40° with the horizontal.

Storage tank — 16 gauge galvanized iron sheets have been used in the fabrication of two storage tanks, each of dimensions 5 ft 2 in. (length) × 4 in. (thickness) × 4 ft (height). Both the storage tanks are placed on a stone platform along the southern wall inside the room at a height of 2½ ft. The spacing between the two tanks is one foot and insulation of 4 in. thick loosely filled rock-wool is provided behind them. Suitable arrangement is made in the storage tank so that it stands the hydraulic pressure. The capacity of the two tanks is 86 gallons and the total capacity of the whole system is 110 gallons. The storage tanks and insulation occupy about 4 per cent of the total volume of the experimental chamber.

RESULTS AND DISCUSSION

The investigations regarding the performance of the equipment were carried out during the winter of 1963-64. The temperature inside the experimental chamber was recorded at a height of 5 ft and at a distance of 3 ft from the storage tank. Besides, temperatures at various points of the system and the room were also recorded. However, details and discussion regarding these results will not be given here owing to the limitations of space. The following are the salient features of the results which have emerged from these studies.

The temperature of the experimental chamber for January 1964 was recorded continuously. The observations at intervals of 6 hours, i.e. at 0530, 1130, 1730 and 2330 hours, along with the atmospheric temperatures were recorded. There was a significant and continuous rise in temperature of the experimental chamber above the ambient most of the time.

It was observed that the rise in temperature during the night was much more than that during the day. A maximum rise in temperature above the ambient temperature of 1°C was found to be 20°C. It is also clear that the thermal capacity of the system was sufficiently large so that heat was retained in the room even after two days of cloudy and overcast weather.

The average rise in temperature of the experimental chamber was 13°C above the average ambient temperature of 10·2°C on 23rd January 1964 for an incident solar intensity 660 calories/sq. cm/day (i.e. 2450 Btu/sq. ft/day) on the inclined black surface. The overall efficiency of the heating system was found to be about 40 per cent for these figures by taking into consideration the transmission and ventilation heat losses and also the heat absorbed in the structure of the room during the intermittent heating cycle.

It was found that except in the vicinity of the storage tank, the temperature distribution inside the room was practically uniform.

Besides the salient features mentioned above, the following observations are noteworthy.

On most of the clear days the atmospheric temperature reaches its maximum value between 1500 and 1600 hours and a minimum between 0700 and 0800 hours. Fall in the atmospheric temperature is very rapid immediately after sunset while rise is rapid after sunrise. The fluctuations in water temperature correspond more or less to the variations in atmospheric temperature. In general the temperature of water in storage tank is minimum before sunrise and the maximum value is attained between 1600 and 1700 hours i.e. about an hour after the peak value of the atmospheric temperature. This time lag is accountable as due to the finite time required for thermosiphon circulation.

Variations in the temperature of solar heated room are practically smooth and continuous. Its temperature is generally maximum at about 1800 hours and the minimum value occurs between 1000 and 1100 hours next day. Thus the variation in chamber temperature lags behind the variation in atmospheric temperature by about three hours. This is explicable as due to the finite time required for the heated water to flow into the storage tank and subsequently to heat the experimental chamber by radiation and convection processes.

Before concluding, it is remarked that the present experiments have been conducted under clear sky conditions. If cloudy and overcast weather were to persist for a long time auxiliary heating would be required. Subsequent to the presentation of the paper at this symposium, a similar equipment was installed at high altitudes to heat an insulated room made of sundried bricks. The size of the solar heating equipment and the experimental room were similar to those reported in this paper. It had been possible to recover about 60,000 to 70,000 Btu (about 15,000 to 17,500 K cal) of heat from sun at an over-all efficiency of about 40 to 45 per cent.

CONCLUSION

The present investigations show that utilization of solar energy for space heating is a feasible proposition even without resorting to the forced circulation of the heated fluid. It can supplement the huge amount of fuel required for heating the living space at high altitudes.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to Dr. V. Ranganathan, Deputy Chief Scientist, Research & Development Organization, Ministry of Defence and to Dr. H. Nath, Director, Defence Laboratory, Jodhpur for their keen interest in these studies. The assistance of Shri R. K. Chopra and M. V. Gupta in recording observations is also acknowledged with thanks.

DISCUSSION

H. Tabor: Was there ventilation in the test chamber; also if a second unheated chamber was used as a control? How many BTU were delivered to the Chamber?

J. P. Gupta: There was normal ventillation at the top. Second unheated chamber as a control was not available in the present studies. 48000 BTU per day were delivered to the room heated by solar energy.

H. Nath: In regard to success of practical application of solar energy for domestic and other needs, the socio-economic conditions in this part of the country were not an inhibiting factor as long as it could be proved that the gadgets were of definite value to them.

SOLAR COOKING[1]

by

B. M. L. SAKSENA, T. D. VARMA, V. P. GUPTA, D. C. JHA, P. CHANDRA & S. K. KHURANA

INTRODUCTION

THE problem of using the sun's energy is very fascinating, when one considers the virtual inexhaustbility of its source and the tremendous power of the radiant flux received by the earth. The power received in a year by the earth from the sun is equivalent to 58×10^{16} kilowatthours which is 20,000 times greater than that produced by all the sources of power being used at the present time. For centuries scientists have been engaged in harnessing solar energy for various uses of man. Cooking with the help of solar energy has been the most interesting field of research in this direction. The first solar cooker was designed and used as far back as 1860.

The solar cookers developed uptil now essentially belong to two types, the distinction being primarily in the manner in which concentration is achieved and the degree to which it is used.

The focussing type cooker uses a reflector to concentrate direct beam solar energy on to the vessel in which the food is cooked. All the cookers developed on this principle have generally parabolic reflector surfaces. In a few cases spherical and even cylindro-parabolic reflectors have been used. A solar cooker using parabolic reflector of spun aluminium was designed by Ghai *et al.* (1953). Stam (1961) has used aluminium foil on concrete or plaster base of spherical shape to concentrate rays. Duffie *et al.* (1961) developed paraboloid reflectors of aluminized 'mylar' plastic film on polystyrene shell, while parabolic umbrella type cookers have been designed by Lof & Fester (1961) using aluminized 'mylar' film.

The oven type cooker is an insulated box with a transparent window on the side exposed to the sun and employs external/internal plane reflectors to concentrate the energy. Pioneer worker in the design of such cookers is Maria Telkes (1959). Abou-Hussein (1961) has developed one such cooker using polished aluminium sheets as internal flat plane reflector.

Prata (1961) has, however, developed a cooker which is a combination of the two types, i.e. a reflector-cum-oven type. It has a nickel plated aluminium sheet, parabolic-cylindrical reflector and an insulated cylindrical oven.

1. Contribution from Defence Science Laboratory, Delhi.

With the reflector type cookers, a high degree of concentration is achieved, but the cooking vessel loses much of the heat by convection and rediation to the surroundings, specially when it is windy on account of its being exposed. The oven type cookers are costlier and heavier, and have a low degree of concentration. However, they keep the cooking vessel protected from ambient conditions and also allow the food to remain hot for some hours after it is cooked. The effective cooking power of the above mentioned cookers varies from 0·15 to 0·5 kW. The cooking time in all cases is longer than that required over a woodfire or a kerosine burner.

D.S.L. SOLAR COOKER

This solar cooker has been designed to incorporate the advantages of both the types. In this, a concentrator consisting of multiple plane mirrors has been used to converge solar rays over a wide area of the cooking vessel. Heat losses from the vessel are minimized by placing it in a thermally insulated enclosure.

The concentrator consists of 42 plane glass mirrors of size 8×8 inches each, arranged in a spherical configuration. Its focal length is 20 ft. The size of the focal spot is approximately 10×10 inches. The concentrator is mounted on a stand fitted with four castors to give it lateral and rotatory movements required for following the azimuthal motion of the sun. There is also a tilting arrangement for zenith adjustment. Similar concentrators were used by Khanna *et al.* (1959) for concentrating palm juice.

The oven is a double-walled rectangular box of aluminium with a glass window. The space between the two walls is filled with glass wool to prevent conduction of heat. The glass window allows solar rays to pass into the oven while preventing re-radiation from the hot interior. Inside the oven a mirror is placed at 45° to the vertical to reflect the concentrated rays vertically upwards. The oven, being closed, prevents the wind from coming in contact with the cooking vessel and thus avoids heat losses.

Concentration Ratio and Temperature — Theoretically, the concentration ratio of the concentrator should be 42, but in actual experiments it comes out to be 26-27. The temperature at the focus of the

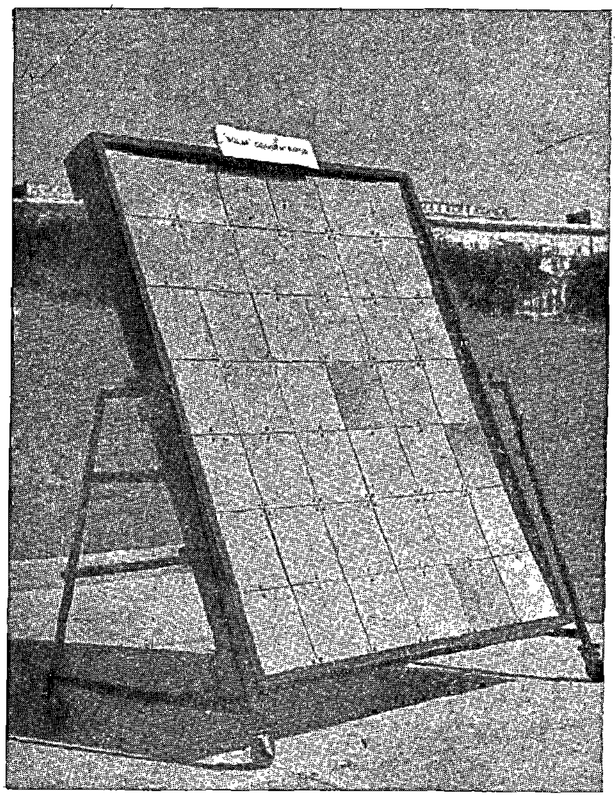

Fig. 1 — Concentrator

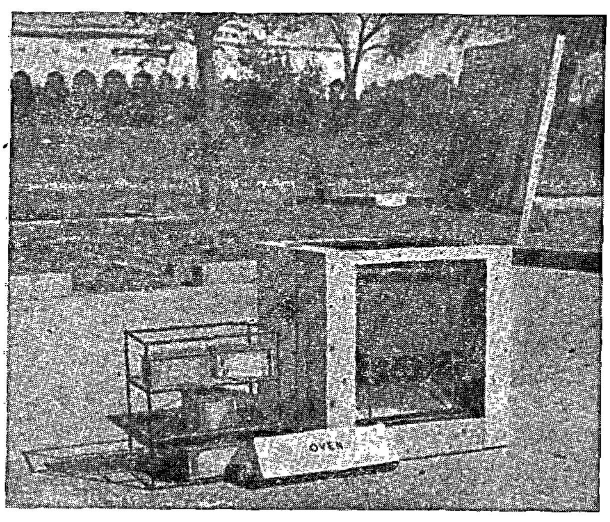

Fig. 2 — Oven with cooking vesse land arrangement for baking bread

concentrator has been found to be between 250°C and 300°C varying with the intensity of solar radiation. The temperature inside the oven ranges from 200°C to 250°C.

Heat Output — The heat output of the cooker, as estimated from the rise in temperature of water, was found to be 8,000 to 9,000 cals/min. at Delhi during the month of March 63. At Leh, it was approximately 10,000 cals/min. during the months of May-June 63.

Trials in Plains and at High Altitudes — The cooker was given extensive trials at Delhi and at Leh. Almost all types of cooking processes, viz. boiling, frying, baking, roasting, etc., were tried with success. The trials were conducted for several months at different hours of the day. The environmental parameters of the two places are given in Table 1.

TABLE 1: Environmental parameters of places where the cooker was used

	Delhi	*Leh*
Altitude, ft.	Approx. 700 ft. above M.S.L.	Approx. 11,500 ft. above M.S.L.
Pressure, mb.	970 to 995	650 to 675
B.P. of water, °C	100 (approx.)	88 (approx.)
Initial temperature of water during trials	20°C	8 to 10°C

Typical results of the trials conducted and cooking times for various foodstuffs taken in Delhi and at Leh, are given in Table 2.

Effect of Ambient Conditions on Cooking Time at High Altitudes — The ambient conditions have a considerable effect on the time required for cooking any foodstuffs. This is more pronounced at high altitudes and the following are the main influencing factors:

(i) The initial temperature of water, which is the main medium for cooking most of the foodstuffs, is very low at Leh. It goes down to even below 0°C during winter. Hence the heat required for cooking is more and as such the cooking time is considerably increased.

(ii) The ambient temperature being very low, the conduction losses from the oven, though highly insulated, are more.

(iii) The boiling point of water at Leh is approximately 88°C and hence no food except rice and potato is well cooked at this temperature. Other foods take a long time to cook.

(iv) Because boiling point is low and cooking time is considerable, a good portion of water is evaporated before cooking is complete. Therefore the quantity of water required for cooking a certain quantity of food is much more.

TABLE 2: Comparison between cooking times at Delhi and Leh

Sl. No.	Materials cooked	Delhi		Leh		
		Quantity (Lbs)	Cooking time (min) without extra pressure	Quantity Lbs	Cooking time without extra pressure (min)	Cooking time with 5 Lbs extra pressure (min)
1.	Dal Arhar	4	70	4	140	—
2.	Bread	3	35	2	60	—
3.	Meat	4	120	2	180	120
4.	Rice	5	60	4	60	—
5.	Rice	5	70	4	65	—
6.	Dal Arhar	2	60	2	135	65
7.	Potato	4	65	4	75	60
8.	Dal Moong	2	50	2	120	45

DISCUSSION

To overcome the difficulty of low boiling point of water at Leh, cooking was done under an extra pressure of 5 lb/sq. in. It was found that cooking time is reduced considerably and that no extra amount of water is needed. It is interesting to note that the difference between the atmospheric pressures of Delhi and Leh is only 5 lb/sq. in. and with the application of 5 lb/sq. in. extra pressure, a comparision of the times taken for cooking the same food at the two places at the same time final temperature is possible.

A comparison of cooking times shows that when cooking is done without extra pressure, the time taken for cooking all foods except rice and potato is much more at Leh than at Delhi. This, as stated above, is attributed to low boiling point of water (88°C). Once 5 lb/sq. in. extra pressure is applied to bring the B.P. to about 100°C, the cooking time is almost the same for the two places. The losses due to low temperature of water and atmosphere at Leh, are compensated to some extent by the higher intensity of solar radiation at high altitudes.

Advantages—The concentrator of the cooker employs plane mirrors which are cheap and easily available. The heat energy concentrated at the focus is transmitted into a thermally insulated oven where there is little chance of its being lost to the surroundings. The area of the focal spot is about 10×10 in. and hence heat is available over a considerable portion of the cooking vessel, resulting in rapid and uniform cooking. The cooker is capable of cooking an amount of food sufficient for 10-12 persons. Baking and roasting are also possible with this cooker. The time taken for cooking various dishes compares well with that taken with cookers developed elsewhere. The oven retains the food cooked in the afternoon in warm condition for consumption at night.

Disadvantages and suggestions — The glass mirrors are fragile, hence care has to be exercised in adjusting the mirrors. Substitution of these by metallic or plastic mirrors can obviate this difficulty. The present unit is not very compact due to the large focal length of the concentrator. Use of plane mirrors of smaller size can reduce the focal length. This will also increase the temperature at the focus which is not very high at present. It requires manual adjustment of the concentrator in following the sun. Some automatic mechanical device can be used for this purpose but it will increase the cost of the system.

The cooker can be very useful at high altitudes where there is a shortage of fuel. In its present form, it may not be acceptable to the masses. However, if modifications on the lines suggested above are made, the cooker will become very popular.

ACKNOWLEDGEMENT

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DISCUSSION

P. G. Adyalkar: What will be the cost of a solar cooker for an average family of 5 persons preparing 3 essential dishes? Can *Chappathis* (or Pan Cakes) be prepared on the solar cooker?

M. L. Khanna: About Rs. 250/-. *Chappattis* cannot be made but bread can be baked in a case.

A. B. Zafar: Do you have data to show if solar cooking improves or deteriorates the nutritive value of the food?

H. Tabor: There should be no diminution in the nutritive value of the cooked food.

M. L. Khanna: At the worst, there may be over-baking in the outer-layers, which, however, could be regulated by suitable adjustment of the cooker.

ELECTRICAL GENERATOR (WIND POWER)

UTILIZATION OF WIND POWER IN ARID AND SEMI-ARID AREAS IN INDIA[1]

by

S. P. VENKITESHWARAN & K. R. SIVARAMAN

INTRODUCTION

ENERGY is a very important requirement for the development and improvement of the living conditions of the community in any area. In parts of the country which face shortage or absence of natural resources like coal, oil, etc., the production and supply of energy required for attaining the material wellbeing presents important problems regarding the fuel required for developing this power. The supply of fuels like coal, oil, etc. to drive machines, involves payment both for the fuel itself and for its transport. In an area remote from the main sources of supply, the cost is often prohibitively high due to the high cost of energy transmission in small amounts. The capital and operating costs of small prime movers are high in such localities. Hence, there is need to consider the exploitation of local energy resources such as, wind power, solar energy, etc. which are free and inexhaustible by their nature.

The basic need in the arid zone of Rajasthan, which is characterized by vast tracts of desert land, is the supply of drinking water to its human population and cattle wealth. In this region, the sub-soil water is brackish and unfit for drinking and it has, therefore, to be obtained from borings at depths ranging from 40 to about 100 ft. According to a project report of the Rajasthan Government, Proposal for Rural Water Supply, " drinking water facilities constituted a formidable problem in our arid areas. It is a foremost and inescapable duty of any Government to see that at least hygienic drinking water is available to all its citizens. It is not an uncommon sight in the arid areas of the State to see men and women walking many miles with pots for some drinking water."

ENERGY REQUIREMENTS

The primary requirement of energy in arid zones is for supplying drinking water and also electricity to small communities. Although no accurate estimate can be given of the quantities of water required, a fair assessment made by listing the probable energy consumptions and power needs of the community on the one hand, and computing the output the wind-driven plants may yield at different places on the other, will help to know whether the energy requirements could be met by them.

WIND SPEED DATA

The first requisite in estimating the potentialities of a place for wind power utilization is a knowledge of the wind speeds prevailing in the arid zones. The annual average wind speeds for 22 stations in Rajasthan obtained from the India Meteorological Department were plotted to know wind regime. Although this gives an idea of the distribution of wind speeds, in general, for assessing the output of a windmill, hourly values of wind speeds are desirable. Hourly values of wiid speed recorded by the pressure tube anemograph (installed by the India Meteorological Department) are available only for Jodhpur and Jaipur in Rajasthan. These have been used to plot the velocity duration curve for these two places. The velocity duration curve gives the number of hours for which wind speeds of a particular value and above are attained in a year. It can be seen that a windmill working at wind speeds above 8 km. p.h. can deliver power for about 4900 hours in a year at Jodhpur and for about 3500 hours at Jaipur.

WATER PUMPING WINDMILLS

The National Aeronautical Laboratory has designed and developed two types of water pumping windmills, designated WP-1 and WP-2. The WP-2 windmill is suited for regions of moderate wind speeds and is of the direct acting type. The WP-1 type is suited for windier regions and is of the gear type.

The WP-2 windmill starts working at wind speeds of 6 to 8 km.p.h. The head mechanism, which carries the wind wheel or rotor and tailvane, mounted on a four-post steel tower 30 ft high, directly operates a pump with a stroke of 5 in. The pump is of the reciprocating type and is installed either with a 6 in. or a 4 in. cylinder depending

1. Contribution from National Aeronautical Laboratory, Bangalore.

on the height through which water has to be lifted. The rotor which is of the multibladed type has a diameter of 16 ft and carries 12 blades. The tower and rotor are designed to withstand wind stresses up to 100 m.p.h.

The power output P in kW of a windmill is given by the relation

$$P = 12{\cdot}6 \times 10^{-6}\, AV^3 \times C_p$$

where A is the swept area in sq. metres, V the wind speed in km.p.h., and C_p the overall power coefficient.

The large size of the swept area of the rotor and the angle of setting of the blades make the WP-2 windmill start working even at 6-8 km.p.h., and enable a reasonable yield at these wind speeds. To estimate the power output and the quantity of water pumped in one year, the mean hourly wind speeds at that place are required over a year. From the hourly values of wind speed, the number of hours in a day when the wind speed equalled or exceeded particular values were computed. Using these values, the quantity of water pumped through a total head of 10 metres by a WP-2 windmill of swept area 4·88 sq. metres (corresponding to a rotor of 16 feet diameter) and of assumed constant overall efficiency of 12 per cent was calculated day by day for Jodhpur and Jaipur. It is assumed that the windmill starts pumping at 8 km.p.h. and gives the full output at 25 km. p.h. It is also assumed that for higher wind speeds the full output is maintained but not exceeded. The outputs of water that can be pumped at Pali, Ajmer and Gadra Road were also computed on the basis of the daily mean wind speeds obtained by the Wind Power Division of the National Aeronautical Laboratory. It is realized that the estimate of output based on the daily mean wind speeds will give a rather low estimate, but in the absence of hourly data, this gives an idea of the water output. The monthly output is obtained by adding outputs for all the days in the month. The results are given in Table 1.

PUMPING PERIODS AND RESERVOIR CAPACITY

When pumping water is the sole object of the windmill, provision must be made for its continuous supply, either directly from the windmill pump or from a reservoir where water is stored during peak pumping periods. To decide upon the reservoir capacity sufficient to hold water for one or two days' requirement, the windmill output throughout the year must be studied closely with reference to the rate of consumption of water on a day-to-day basis, since it may not be practicable to provide storage of excess water pumped during the windier months to cover the needs during dull months. However, it should be the aim, at least in arid areas, to store enough water to cover two to three days' needs as an emergency, since even during the months when the pumping rate is high, there may be one or two days of calm spells in between. There are no rigid criteria regarding the size of the tank, this being judged by a compromise of factors, such as the output of the windmill, the water drawn for daily requirements and finally the cost of the tank, which adds to the capital cost of the installation. Since we are considering only the day-to-day requirements, the mean daily output derived from the monthly

TABLE 1: Estimated monthly and mean daily quantities of water pumped by WP-2 windmll (in kilolitres)

(The mean daily output derived from the monthly output is given within bracket)

Sl. No.	*Station*	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annl.*
1.	Jodhpur	881 (29)	852 (28)	1163 (39)	1218 (41)	2456 (82)	3384 (113)	2666 (89)	1777 (59)	1023 (34)	395 (13)	537 (18)	742 (25)	17094
2.	Jaipur	552 (18)	567 (19)	969 (32)	936 (31)	2057 (68)	2435 (81)	1406 (47)	771 (26)	929 (31)	389 (13)	188 (6)	474 (16)	11672
3.	Gadra Road	760 (25)	631 (21)	1721 (57)	2434 (81)	6310 (210)	11610 (387)	10162 (339)	3420 (114)	1282 (43)	272 (9)	79 (3)	118 (4)	38799
4.	Pali	420 (14)	238 (8)	596 (20)	1370 (46)	9817 (327)	14295 (476)	1985 (66)	2845 (95)	1282 (43)	480 (16)	48 (2)	134 (4)	33511
5.	Ajmer	252 (8)	48 (2)	797 (27)	2582 (86)	10771 (359)	9243 (308)	2342 (78)	1589 (53)	1714 (57)	154 (51)	47 (2)	216 (7)	29750

Wind Speed Data:
1. Based on anemograph data 1958-60
2. Based on anemograph data 1958-60
3. Based on daily means 1955 & 1956
4. Based on daily means 1956
5. Based on daily means 1956

quantities of water pumped can be taken to represent the water pumped per day on an average. These are given in Table 1. It can be seen that at Jodhpur, except in the months of October and November, the mean daily output during the year is over 25 kl. If the average requirement of water for a family of four persons is taken as 900 litres per day, the windmill can supply the daily needs of 28 such families for nearly the whole year. The size of the tank in all the five Stations under discussion, which is sufficient to hold a day's water requirement can be taken as 25 kl. (5500 gal.). Although the tank may not be full for one or two months in a year, it can store water for supply during any part of the day for the rest of the year when the output is much more than 25 kl.

OPERATING COST OF WP-2 WINDMILL

The common practice in India is to use bullocks (or camels) for pumping water. The bullocks cost something like Rs 700/- per pair, their life is about 5 years, they need at least one man to drive them and each of them may eat about 10 tons of fooder per annum and one has to grow crops to feed the bullocks.

The factors to be considered in estimating the cost of operation of a windmill are the interest and depreciation on the capital costs of the windmill installation and the annual recurring charges. This will also depend upon the life of the plant; the life of some of the major parts will be very much longer than that of other components. On an average the interest and depreciation on the capital may be taken as 10%. Those parts that require replacement due to wear will be included in the maintenance costs. As wind is free, the only recurring cost is for maintenance.

Cost without water tank

Cost of windmill	Rs 3,200
Installation costs (including foundation pipes, labour, etc.)	Rs 500
	Rs 3,700
Interest, depreciation, @ 10 per cent per annum	Rs 370
Annual Maintenance	Rs 50
Total cost of operation for one year	Rs 420
Annual output of a WP-2 windmill at Jodhpur	17100 kl.
Cost of pumping 5 kl. (about 1100 gl.) of water at Jodhpur *through a total head of 10 metres*	$\frac{420\times5\times100}{17100}$ or 12 nP

This does not take into account the transportation cost of windmill parts.

COST WITH WATER TANK

The cost of a masonary tank can be assumed to be Rs. 800 for every 5 kl. capacity. For a 25 kl. capacity tank, the cost will be Rs 4,000 and the annual interest and depreciation for the windmill and the water tank taken together at the rate of 10 per cent per annum will be Rs 820. These tanks will be erected at a height of about 10-15 ft above the ground. The costs of pumpnig 5 kl. of water through a total head of 10 metres with a water tank of 25 kl. capacity and without a tank have been calculated and are given in Table 2.

TABLE 2: Estimated cost of pumping 5 kl. of water by windmill

Station	*Annual output in kl.*	*Cost of pumping 5 kl. of Water by WP-2 windmill through a head of 10 metres*	
		without storage tank	*With storage tank of capacity 25 kl.*
		nP	nP
Jodhpur	17094	12	24
Jaipur	11672	18	35
Gadra Road	38799	5	11
Pali	33511	6	12
Ajmer	29750	7	14

It is interesting to compare these costs with the corresponding costs when a diesel engine and a pump are used for pumping water. A 2 hp diesel engine will be required to pump about 10 kl. of water per hour (2200 gal. per hour) through a total head of 10 metres and it will consume about 1 pint of diesel oil per hour. The cost of pumping 5 kl. of water through 10 metres head can be worked out as follows:

Cost of Diesel engine, pump, including installation costs	Rs 2,500
Interest, depreciation & maintenance at 20 per cent per annum	Rs 500
Cost of fuel, assuming that the engine is worked for 3650 hrs. in a year, at Rs 5/- per 10 hrs. working	Rs 1,825
Total annual costs of operation	Rs 2,325
Cost per 5 kl. pumped	32 nP.

*From Table 2, it is seen that the cost of pump*ing by a diesel engine at different places in Rajasthan is 2 to 5 times that by the windmill without storage tank; the cost of pumping by a windmill with a storage tank is also less than with a diesel pump.

In some regions in Rajasthan, the surface water is usually brackish and fresh water is available only at depths of about 80-100 ft. In this case, the output will be in inverse proportion to the values in Table 1 and the cost of pumping 5 kl. of water will be high by the same proportion, but this can be justified by the utility of the windmill in these areas. At Jodhpur for example, the annual output will be about 7125 kl. when the total water head is 80 ft.

MONTHLY VARIATION OF WIND AND RAINFALL IN RAJASTHAN

It is of interest to compare the monthly quantities of water pumped by the windmill with the corresponding monthly rainfall for the four stations, Jodhpur, Jaipur, Pali and Ajmer. It is seen that maximum wind speed and hence the maximum water pumped by the windmill is during the months of April, May, June and July when the rainfall is low. This has been observed at many other stations also in India. In arid regions particularly, the windmill will serve a very useful purpose as it gives its effective output during these crucial months.

OTHER USES OF WIND POWER

Another type of windmill which could be used for pumping water is the one using a crown and pinion arrangement in the head mechanism and capable of being used to drive a centrifugal type of pump. This type of windmill may be able to raise water only up to a height of about 10 ft. Its rate of pumping is, however, high (as much as 130 gal. per minute at wind speeds 25-30 km.p.h.) and it will be quite suitable for pumping brine into salt crystallizers where the height of pumping is usually within 10 ft. Trials with a prototype of this windmill are being carried out in the Laboratory. In addition to pumping water, wind power could be employed for a variety of purposes like corn grinding, cutting fodder, etc.

WIND ELECTRIC GENERATORS

Wind electric generators could be used in farms for irrigation or supply of electricity for lighting, etc. for a small community. When used for lighting, the generators must be used along with storage batteries that serve as a standby, to ensure a constant supply.

When one considers the possibilities of wind power in any region one has to obtain information from the Meteorological Service on the prevailing direction of the wind, its average value every year, its variation from month to month, etc. All this is important and useful, but may serve only as a guide and not replaced a wind survey to decide on favourable sites. While there may be no choice in the case of the water-pumping windmills which have to be located near the well, the most favourable site in the locality can be chosen in the case of the wind electric generators. The reason is that wind power is proportional to the cube of the wind speed, so that if one can find a site with an average wind speed of even one or two miles per hour higher than that in the area round about, then there can be an increase in the annual output of energy by 30 to over 50 per cent. Therefore, wind measurements at specially selected sites are important when starting wind power investigations for the generaion of electricity.

The wind speed data required for estimating the output of wind electric generators are hourly values, since the power characteristics of the generators vary with wind speeds and a constant value for efficiency cannot be assumed for the entire operating range. From the hourly values of wind speeds, the number of hours in a year during which each of the wind speeds are attained are determined. Then the contribution to the power developed by the plant, by each of these wind speeds blowing for the durations obtained above are summed up to obtain the annual output of the generator. In calculating the power output as above, the characteristics of the generator, such as out-in-speed, rated speed, variation of power coefficient with wind speeds have to be taken into account.

The annual energy output of six types of generators fabricated by different countries and of different capacities have been estimated for Jodhpur and Jaipur for which hourly wind speeds are available. The details of the generators are given in Table 3.

The monthly distribution of the energy output and the annual energy output worked out are given in Tables 4 and 5. It can be seen from the Tables that (i) the estimated energy output increase with the rated power up to generator capacity of 7·5 kW, and decreases later, (ii) the total energy output of the Dowsett Holdings generator inspite of the higher rated power, is less than that of Allgaier 7·5 kW generator. This is because Dowsett Holdings has a rated speed above the most prevailing wind speeds in Jaipur and Jodhpur, and hence delivers little power in the lower wind speed range.

OPERATING COST OF WIND ELECTRIC GENERATORS

There are only two factors to be considered on the question of economics. One is the cost of the machine on which depend the annual capital charges

TABLE 3: Details of Wind Electric Generators Studied

Machine details	*Dowsett holdings* (25*kW*)	*Allgaier* (7·5 *kW*)	*WVG-5* (5·5 *kW*)	*WVG-2* (2·5 *kW*)	*WV-2* 2 *kW*)	*KSV-800* (0·85 *kW*)
Manufacturer	Dowsett Holdings Limited, Tallington, Stamford, Lincs, U.K.	Allgaier-Werke Uchingen Wurtt, Germany		Elektro, G.m. b.H., St. Gallerstrasse, 27, Winterthur/2H Switzerland		
Diameter of wind rotor, metres	12·2	10	5·0	3·8	3·5	3·0
Cut-in-Speed, km.p.h.	20	16	8	6	5	4
Assumed rated speed, km.p.h.	61	37	41	40	38	32

TABLE 4: Estimated monthly and annual energy output of 6 wind electric generators at Jodhpur (In kWh)

	Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Elektro KSV-800 (0·85 kW)	21	13	33	28	67	101	78	45	26	10	13	17	452
Elektro WV-2(2kW)	38	38	55	47	97	137	109	67	42	20	26	32	708
Elektro WVG-2 (2·5 kW)	43	44	66	55	118	172	135	86	51	22	28	37	857
Elektro WVG-5 (5·5 kW)	67	69	108	91	217	319	251	149	86	30	40	54	1481
Allgaier (7·5 kW)	38	62	148	116	350	548	411	171	99	23	22	21	2009
Dowsett Holdings (25 kW)	14	38	125	76	231	412	293	86	54	10	7	5	1351

TABLE 5: Estimated monthly and annual energy output of 6 wind electric generators at Jaipur (In kWh)

	Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Elektro KSV-800 (0·85 kW)	14	15	28	26	61	64	42	20	20	10	5	11	320
Elektro WV-2(2 kW)	27	26	46	40	97	98	67	36	39	20	10	21	527
Elektro WVG-2 (2·5 kW)	29	28	55	51	118	120	81	39	46	21	8	23	619
Elektro WVG-5 (5·5 kW)	42	45	94	86	214	218	145	63	76	30	9	35	1057
Allgaier (7·5 kW)	30	32	139	114	388	389	231	62	95	36	4	25	1545
Dowsett Holdings (25 kW)	19	14	115	87	348	355	202	38	53	20	3	9	1263

for interest, depreciation and maintenance. The other is the annual output of energy (per kW), that one can get from the machine when installed at a suitable site. Whether it is for generation of electricity or simply water pumping, an important question is the amount of wind available at the place.

To compare the operating costs of the different wind electric generators, the output of energy per kW installed capacity has to be worked out, as the annual energy output depends on the range of operation of the generator and it may so happen that two generators with almost the same capacity may yield different energy outputs at the same place because of the difference in their operating range. The values of energy output per kW installed capacity for the six generators are given in Table 6. The energy output per kW installed capacity for each generator being known, the cost per unit of energy can be worked out, knowing the capital cost of the plant, installation charges, etc.

According to the particulars supplied by the manufacturers of the Electro generators, the capital

TABLE 6: Annual energy output (kWh) per kilo watt of installed capacity and cost per kilowatt hour of energy (Rupees) of the generators at Jodhpur and Jaipur.

	Annual energy output (kWh) per kilowatt of installed capacity		*Cost per kWh of energy (in rupees)*	
	Jodhpur	*Jaipur*	*Jodhpur*	*Jaipur*
Electro KSV-800 (0·85 kW)	532	376	0·68	0·96
Electro WV-2 (2 kW)	354	264	0·68	0·91
Electro WVG-2 (2·5 kW)	343	248	0·70	0·97
Electro WVG-5 (5·5 kW)	269	192	0·67	0·94
Allgaier (7·5 kW)	268	206	0·90	1·17
Dowsett Holdings (25 kW)	54	51	4·44	4·75

cost, including freight and installation charges of the KSV-800 type of generator works out to about Rs 3000 per kW of installed capacity, that of WV-2 and WVG-2 types to about Rs 2000 per kW and that of WVG-5 to about Rs. 1500 per kW. The cost per kW of the Dowsett Holdings and the Allgaier machines is of the order of Rs 2000. The cost of transportation and installation and other incidental charges are also included. Taking the above values and assuming the annual depreciation, maintenance and interest to be 12 per cent of the capital cost, the cost per kWh of energy has been calculated for each Station and is given in Table 6. Of all the generators considered, the 7·5 kW Allgaier generator yields the maximum energy both at Jodhpur and Jaipur. However, the cost per kWh for the generators in the range 2-5 kW is found lowest.

All the wind electric generators considered above except Dowsett Holdings (25 kW) and Allgaier (7·5 kW) generators are of the D.C. type, and hence energy can be stored in batteries. The operating costs obtained above exclude the cost of batteries. If the generator is required to supply power for lighting and domestic use, it is necessary to have a set of batteries as a stand-by source of power supply, in which case the cost per kWh energy will be approximately double the cost without batteries. This again can be justified by the utility of wind electric generators in arid zones where there are no alternate cheaper sources of energy.

A 6 kW, 220 Volts D.C. Allgaier generator was worked during 1960-62 in Khapat Agricultural Farm at Porbandar, to drive three 2 hp motors pumping water for irrigation. Since Porbandar is very windy, the generator could be worked whenever required without storage batteries. The cost of pumping 5 kl. of water was nearby 12 nP., whereas the cost of pumping by a 10 hp Diesel engine working side by side with the generator was 35 nP.

The design and fabrication of wind electric generators is being taken on hand at the National Aeronautical Laboratory. The industry in India has yet to be developed for the fabrication of d.c. generators and motors. Meanwhile, attempts have been made to construct wind electric generators for battery charging with motor car generators. These will be very useful at places without electricity to charge car batteries.

Experiments are also being carried out on the performance of Dunlite Wind Electric Generators (1·5 kW, 110 Volts) obtained from Australia to study their design features. These generators are of the high speed type and start delivering power at wind speeds above 20 kmp. h. and gives full output at about 40 (km.ph.)

CONCLUSION

There is no doubt that utilization of wind power has immense scope in arid and semi-arid zones in India. Installation of windmills for pumping water for domestic purposes and minor irrigation, grinding corn, cutting fodder, etc. and medium capacity wind electric generators to supply power in these areas, which are under-developed for want of fossil fuels and hydro power, would make a substantial contribution towards development and prosperity of these areas. While it may take some more time for fabricating wind electric generators indigenously, direct water pumping windmills, which have been fabricated and tested to withstand the weather conditions in India, can be profitably used in the arid zones for supplying water.

PAPERS DISCUSSED AT THE PLENARY SESSION

AERIAL PHOTO-INTERPRETATION FOR SURVEY OF NATURAL RESOURCES[1]

by

P. C. RAHEJA[2]

GENERAL

FROM the aspect of efficient use of resources the crucial problem of the arid zone is one of the human and livestock ecology. The potential requirement of the livestock and the people are constantly on the increase. The basic and biotic resource surveys have to ensure that they provide essential information for future sustained development to establish a natural equilibrium between production and the needs of the people. In the north-western arid zone there is a strong disequilibrium between current deteriorating resources and the high density of livestock and human population. Therefore, reconnaissance surveys of basic resources is of limited value. Detailed surveys of these resources are of vital importance to develop them to their optimum potential.

SURVEY TECHNIQUES

General — The aerial photographs available for preliminary examination of photo patterns to demarcate landforms, hydrological features, geological formations, land use patterns, and vegetation characteristics are on two scales, 1:40,000 and 1:25,000. These photographs are sometimes further treated in the laboratory to make the images more legible. In these surveys vertical photographs are used both at the interpretation and mapping stages so that survey techniques are orientated accordingly.

PRELIMINARY INVESTIGATIONS

Climatology — There are a number of meteorological observatories and rainfall gauging stations in the region which were established 40-50 years ago. The data of the standard normals of temperature, humidity, wind speed, rainfall and evaporation from all these stations are compiled. Besides, the values are picked up from the respective isopleth maps. The figures of daily rainfall data are also collected for the study of run-off characteristics, the nature and length of the precipitation and drought spells. The data of crop yield are collected from the revenue records of the tract for studying the climate-vegetation and the relative effectiveness of rainfall from the aspect of recharge of aquifers and potential evapo-transpiration.

Geomorphology — The vertical aerial photographs are studied initially to differentiate landscape characteristic from the aspect of land forms, erosion hazards, slope characteristics, sand dune dynamics, land units and land systems based upon the watershed characteristics. Each stereo-pair is examined under the stereoscope to study the photo-images of different geomorphic features which vary in tone, shade, form and distortion characteristics of the different types of plains (flood plains, and erosional plains); drainage characteristics; frequency and distribution of dunes; outcrops and nature of their weathering; basins and depressions where the dunes occupy an extensive area and have buried deep the original land surface so that the latter no longer affect the life on the surface, the dune surface is distinguished as a new surface and is as such demarcated on the photographs. These all are annotated, and are complemented by photogrammetric measurements of heights and detection of slope direction. Each land form produced by the similar geomorphic processes and in identical stages are grouped together and delineated on the aerial photographs. In addition to this one of the typical tributary drainage system is selected in which a set of query points are fixed from the headwaters to the confluence with the trunk stream along the valley for study of drainage basin characteristics and for size distribution of fluvial detritus. These points are also marked on the photographs.

Geology — The geological survey is conducted firstly in relation to ground water potential; secondly development of present day landscape; and thirdly, geological deposits of local importance. From the aerial photographs surface geology is studied. The outcrops are demarcated on the photos. Besides, lithological types are differentiate from various shades, tones and tints. The study of petro-fabrics is also facilitated by differentiating photo-patterns examined under the stereoscope. The features differentiated are joint patterns, frac-

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Director of the Institute.

tures, foliations, etc., which give clue to the diastrophism evident at different points in the survey area and for delineating the areas of recharge, direction and movement of ground water. The photo-patterns also indicate the extent of irrigated areas from different sources of water supply. For these studies the photographs are spread on the table and differentiating photo-patterns indicating different features are mapped on the base map. Simultaneously query points are fixed on the aerial photos of the area in selected typical photo-patterns. Annotated record of the features is taken down for comparison in the field. Each pattern is sampled twice to ensure validity of correct interpretation.

Hydrology — The stereoscopic view, particularly through a binocular attachment, facilitates the study of topography, drainage lines; waste lands; erosional features etc. in different types of identical land patterns; irrigated land patterns with wells and water storage structures with or without water. The terrain characteristics and drainage patterns reveal the nature and availability of ground water. Normally light textured soils and well drained soils show up light in tone in the photographs, while the poorly drained and fine textured soils show dark tone in the aerial photos (Frost, 1953). The erosional features on the photographs throw considerable light on soil patterns and rainfall run-off relationship. The irrigated land patterns stand out distinctly under the stereoscope than the rain-fed cultivated land patterns. The former show differentiating characters which give clues to the extent of utilization and quality of water from the well from which irrigation is practised. Identification of drainage lines and demarcation of catchments from the aerial photographs together with information on slope and nature of the terrain greatly help to formulate proposals of surface water storage. The study of individual aerial photographs under the stereoscope in advance of field work survey provides valuable information in planning for the traverse.

Based upon the stereoscope investigations a note is prepared indicating the proposed traverse route linking the query points and the detailed observations to be recorded. The query points are fixed after a close study of the different groups of patterns under the stereoscope. These query points cover all the distinctive patterns so that they are adequately sampled. At least one query point for each type of photo-pattern is considered essential.

Pedology — In the first instance all available information in the form of Survey of India toposheets, geological reports and other relevant data on cultivation pattern, soil survey records of any portion of the proposed survey area are collected. A systematic study of aerial photos is then taken up under the stereoscope to study the variability of the topographical features of the terrain and simultaneously establish a preliminary relationship between aerial photo-pattern and the primary data collected from the reports. The examination of the stereo-pairs in the laboratory enables a delineation of the genetic types of soils formed in different land units. Special examination of stereo-pairs is necessary to observe photo-pattern discontinuities to distinguish the soil covers within a genetic type of soil boundary. In this work previous experience gained in the field is most helpful in recognizing various differentiating features. The identification of the boundaries of soil series and soil types is usually difficult at this stage from the study of aerial photographs, but soil phases are readily distinguishable. As soil phase has a great significance in land use planning, therefore, each genetic type of soil is distinguished on the basis of phase variability; slope class, erosion class, stoniness, drainage characteristics, etc., shown up by tonal variability, which are taken as criteria for fixing query points. After preliminary delineation of boundaries the query points which distinguish soil covers within the variable photo-patterns, are marked on the photographs to sample them during the course of the land traverse.

Land use — Studies on land use are conducted in two parts: (i) study of cultivated lands, and (ii) study of uncultivated lands. The aerial photographs of the proposed survey area are spread and laid out as a mosaic to get an overall view of the area. Distinct photo-patterns such as those of hills, river beds, village common grazing lands, and other uncultivated areas, readily discerned under a stereoscope, are marked out with chinagraph pencil. Patterns, which have similar tone and texture, are given common symbols. The boundaries are then transferred to a base map, prepared from Survey of India topo-sheets on the scale 1: 126,720. As the survey maps were prepared in 1930, the changes that have recently occurred are noted on the aerial photographs.

The query points for study of land use patterns are selected in typical photo-patterns. As the total number of distinguishable photo-patterns is not very large, at least each pattern is sampled twice. The number of samplings or query points is increased, whenever the quality of the photographs is not up to the mark or whenever biotic influences show up as distinct textural or tonal variations.

Vegetation — One of the principal criteria for studies on vegetation is the homogeneity of a stand, on which so much emphasis is placed by the continental school of Phyto-Sociologist. This is easily accomplished by selecting query points in those photo-patterns where the density and cover of vegetation is uniform as in some of the village grazing lands, where although free grazing is permitted, lopping and cutting of trees is not practised by common law and natural vegetation is preserved to a considerable extent. The vegetation has also a relationship to land form. Similarly the drainage patterns have a strong relation to type of vegetation. Finally, soil phases show up distinguishable photo-patterns of vegetation. These are also demarcated. All the vegetation patterns are then grouped in relation to land form, drainage patterns and soil phases and on their basis a few query points are marked on the photographs.

Cartography — The photo-runs are laid down in the laboratory to determine the north line. This is compared with large scale topographical maps supplied by Survey of India. Whenever the scale of photographs, the focal length and height of flight are not given, then scales are determined and recorded on the photographs with the help of a rotometer in relation to linear measurements between the two well defined points of the topo-sheets and their corresponding points on the photographs. In general, a number of readings are recorded. In case, the variation is considerable the scale is checked in the field.

By consulting the toposheets, principal features such as roads, canals, and other important land features are marked on the photographs to facilitate survey work which is extremely helpful in planning traverse through the query points. Besides, the ground control points, at least two on each photograph, are given with reference to S.O.I. topographical maps. These prove extremely helpful in the field for accurate mapping work and delineation of boundaries of land units and land systems. Whenever the photographs lack in ground control points, secondary ground control points are selected and plotted from the S.O.I. maps and their coordinates are worked out. The exact locations are vèrified by means of plane table survey.

Base maps for the field survey parties are cartographed from the available large scale S.O.I. toposheets for recording details and incorporating field data. The field boundaries marked on the photographs are transferred to the base maps. The maps are prepared for each of Community Development Block. The boundaries of the villages in the Development Block are shown in the map after consulting cadestral survey maps or Community Development Block maps. The coverage of the area of the aerial photographs, showing the overlapping portions including their number and flight direction, are also drawn on the base map. The scale of the base map is 1: 126,720. These are drawn on modified polyconic projections.

FIELD SURVEYS

When all the specialists have completed photo-interpretation and compiled their notes, a combined discussion is held to summarize the information and draw up a list of agreed query points which will provide correlated information to all the specialists. Based upon these query points one or more traverses are fixed to permit their examination *in situ*. In a Development Block consisting of 60-75 villages, having approximately a human population from 60-100 thousand persons, three to four traverses suffice to cover all the query points. Each traverse comprises of 12-15 query points which it is possible to examine in a period of 4-5 days.

The field party generally consists of the Ecologist, the Hydrologist, the Geomorphologist and the Soil Scientist. Sometime the Geologist also accompanies the party. The field work is conducted for 4 to 6 days at a time, operating from a base camp. Jeeps with four wheel drive are the vehicles commonly employed in view of the terrain and absence of metalled roads. The cart roads and unmetalled roads are quite common in the area. During traverses between query points the distance is navigated entirely with aerial photographs and notes are recorded. The mileage of the vehicle is noted at regular interbals on the air photos and in the field note books as these data are very useful for final interpretation. Besides studying in detail at the query points, the vehicles stop for short intervals at subsidiary check points to note unusual features of terrain; vegetation cover; soil profile; catchment characteristics; hydrological features; geological materials; etc. The control points marked on each of the photographs are compared in the field with reference to outcrops, stream bifurcation, road crossings and railway bridges for preparation of planimetric maps.

INTERPRETATION AND MAPPING

Interpretation — In the initial stages there was attempt to recognize and delineate " Land Systems " " Land Units " as mapped by the Division of Land Research and Regional Survey, Commonwealth Scientific and Industrial Research Organization, Australia (Christian, 1958). Preliminary study of the aerial photos of Western Rajasthan, however, did not reveal such units as the land use has been very intensive by extending over a long period. This concept appears to be valid where an extensive watershed which is more or less virgin is into account. The detailed photo-interpretation studies indicated that photo-patterns mostly reflected the long standing agricultural and non-agricultural use areas with distinguishing features from the aspect of geology, geomorphology, soils, land use, hydrology, vegetation and habitations. Therefore, land units are delineated on the basis of recurring patterns of land use in the cultivated areas and other patterns depicting the influence of biotic factors in unculturable areas. These land use patterns can be reconciled with recurring variations in topography, parent materials, soils and vegetation. As such they justify an integrated approach. On the whole the land use classification corresponds to the U.S.D.A. " Land Capability Classification ", as modified and adopted by the All India Soil &

Land Use Survey. Thus in the present approach, not only are lands classified on a ecological system of the Australian concept (Stewart, 1953) but at the same time, a practical utilitarian classification is adopted which can be effectively utilized to harness the resources of the land by the special staff of the Development Block.

The field survey data are partly plotted in the field and partly in the laboratory. The value of the field records is reassessed after further examination of aerial photographs in relation to observations recorded at the query points. In case of doubt another traverse is arranged to check up on the spot unexplained variations which cannot be properly composed and corrected by photo-interpretation based upon inductive or deductive processes. The interpretation is extended to areas not covered by ground survey by detailed stereoscopic examination of individual pairs of photographs. The boundaries are redrawn or corrected wherever necessary after final interpretation.

Map compilation and preparation of map manuscripts: — After editing, the data are compiled into a map manuscript by assembling and adjusting the data. This is then processed through following heads:

(a) Preparation of fair mapping and colour guides.
(b) Arrangement of marginal data on the map format.
(c) Removal of the unnecessary details from the map to facilitate expression.
(d) Laying down lettering specification for the maps.
(e) Selection of cartographic devices and colour.

The compiled map manuscript is copied and reproduced in non-photographic colours on dimensionally stable drawing sheets.

Then the fair mapping is drawn which inculdes the line work to prescribed standards, the blocking of areas for tint screens, the layout for placement of lettering, arrangements for inset maps, marginal notes, borders and legends.

The maps are then reproduced photographically and sent to the various specialists for respective interpretation work. The maps are reproduced mostly on the original scale and never reduced more than half of the original scale. For integrated land survey we prepare the following maps.

TABLE 1: Maps cartographed for integrated land survey

Particulars of maps	*Sources*	*Equipment used for compilation and rectification*	*Description of map*
1. Administrative map showing villages	1) S.O.I. topographical maps 2) C.D. Block maps 3) Data from census report 4) Data from administrative offices	1) Pantograph and 2) Procota drawing machine	Planimetric map transferred on modified polyconic projection
2. Landform map showing drainage patterns	1) Work map or base map 2) Aerial photographs with survey details 3) S.O.I. contour maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Overhead enlarger (Agfa verioscope)	Aerial line map drawn on base map; transferred on modified polyconic projection
3. Soil Map	1) Work map 2) Aerial photographs with survey details marked by survey parties 3) S.O.I. contour maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Aerial line map drawn on base map and on modified polyconic projection
4. Land use capability of agricultural and non-agricultural lands	1) Work map 2) Aerial photographs with survey details marked by survey parties 3) S.O.I. contour maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Aerial line map drawn on base map and on modified polyconic projection
5. Pasture potential areas	1) Work map 2) Aerial photographs with survey details marked by survey parties 3) S.O.I. contour maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Aerial line map drawn on base map and on modified polyconic projection
6. Geolithology and static water level	1) Work map 2) Aerial photographs with survey details marked by survey parties 3) S.O.I. contour maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Isopleth
7. Ground water exploitation zones and class of ground water	1) Work map 2) Analytical data	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Aerial line map on modified polyconic projection. Planimetric map transferred on modified polyconic projection

Continued

TABLE 1 — *Continued*

Particulars of map	*Sources*	*Equipment used for compilation and rectification*	*Description of map*
8. Ground water quality map and water contour map	1) Work map 2) Aerial photographs with survey details	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Aerial line map drawn on base map and on modified polyconic projection
9. Land system map	1) Work map 2) Aerial photographs 3) Land form, soil and vegetation maps	1) Procota drawing machine 2) Vertical sketchmaster 3) Proportional compass 4) Agfa verioscope	Composite aerial line map drawn on base map and on modified polyconic projection
10. Three dimensional maps	1) S.O.I. maps 2) Aerial photographs	On two and three perspectives by means of vertical and horizontal profiles	Block diagrams

As soon as the maps are finalized a report of the detailed survey of physical resources of climate, land, soils, water potential, minerals, pastures, forestry and agriculture is drawn up based upon the observations recorded in the field and the interpretation of aerial photos. This survey report forms the basis for future planning and development of the natural resources.

SUMMARY

For detailed reconnaissance survey of natural resources aerial photographs available in two scales, 1:40,000 and 1:25,000 are used for laboratory analysis. The fields of study involved are climatology, geomorphology, geology, hydrology, pedology, ecology and cartography. The photographs are interpreted to delineate land forms, drainage patterns, erosional surface, catchments, geohydrological features, ground water potential zones, water quality, soil series, soil types, land use patterns and study the pasture types and pasture potential, forest types and firewood and timber potential and cropping patterns in the cultivated lands. Each of the specialist draws up a list of query points. For correlation the specialists discuss their interpretation of the aerial photograph data with reference to query points and draw up a traverse. In the field the interpreted data are checked up by actual survey. Sometimes two to three surveys are necessary for delineating boundaries and determination of the potential of resources on the base map. Based upon the laboratory photo-interpretation and field surveys maps prepared consist of administrative units; land forms showing drainage and erosional surface patterns, soil type and land use capability; pasture potential, ground water potential, ground water quality and so on. On the basis of these maps a report of natural resources is compiled for future planning and development.

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DISCUSSION

C. S. Christian: Different natural resources include land, soil, plants, trees and water. Different part of land surface will have different characteristics and different land use. The different land patterns may have varying land uses such as agriculture, forestry, pasture, fishery, mineral exploitation, underground or surface water, etc. Thus there may be different kinds of problems in these different land patterns.

Aerial photographs represent the landscape of the region in term of black and white and intermediate shades and by careful interpretation the different physiographic patterns can be identified and demarcated. The various land types within a land pattern can further be identified and delineated. Sometimes the features or characteristics are not seen on the photograph but have to be identified by inference or anology. In other cases the identification is done by corollary, that is by observing the photographs and subsequently examining in the field. All these processes have to be resorted to in order to make a complete assessment of natural resources in an area. For utilization of these natural resources further steps are necessary in the form of agronomic experiments, crop trials, detailed forest inventory, water gauging, trial boring for underground water, etc. Aerial photograph is one of the many tools in survey and it does not show everything.

C. Voûte: Aerial photography can be used in the assessment of hydrological resources by identifying the water bearing rocks, aquifers and other geological structures, catchment areas and their drainage patterns. Taking these into consideration the exact spots for boring could be fixed. Air photos could also be used for exploitation of natural resources for engineering purposes, such as rocks and clays for building materials, slope stabilization and location of useful minerals.

P. C. Raheja: Aerial photographs are used at the Central Arid Zone Research Institute, Jodhpur for assessment of natural resources in the arid regions of Rajasthan. The procedure followed for such survey and the interpretation of the photographs for identification of various geomorphic units, soil units, vegetation and potential water resources has been standardized. By such integrated surveys it is possible to develop land transformation plans for the different development units.

S. Pandey: With the help of aerial photographs geomorphic studies of the Central Luni River basin are being conducted very quickly by deduction and induction methods and different land patterns such as land forms, drainage patterns, vegetation, erosion patterns, textural types, cultural patterns, etc., have been delineated. By detailed studies of the drainage channels in the watershed and from other characteristics identified in the air photos of scale 1 : 40,000 and 1 : 30,000, it has been possible to draw up plans for soil and water conservation in the arid tracts. By use of the aerial photographs geomorphic maps can be prepared more quickly than by actual ground survey alone.

S. P. Chatterjee: Aerial photographs have proved very useful tool for land survey in arid regions of Rajasthan. These photographs, which are supplied by the Survey of India, are not easily made available to Universities and other non-Government Organizations. It is desirable that such Institutes, which need these photographs for research and training purposes, should be able to procure these without difficulty.

J. Dresch: The aerial photographs should be easily made available to all Institutes who would like to use them for research and developmental work. Coloured aerial photography may be introduced in this Country as these have proved very useful in other countries.

S. P. Raychaudhuri: The present air photographs of scale 1 : 40,000 are very small for land survey in intensely cultivated areas where the land holdings are very small. The Planning Commission of the Government of India has already decided that henceforth all aerial photographs will be in the uniform scale of 1 : 15,000 which may be very helpful for all tyees of detailed survey.

A. K. Sen: The base maps for coordinated land survey are Standardized in the Cartographic Laboratory of the Central Arid Zone Research Institute. The initial base maps are prepared from Survey of India toposheets. On these maps the coverage of the aerial photographs with their overlaps, number, flight direction, etc., are indicated. Physiographic aspects, identified in the photographs, are transferred to these maps by means of radial line plotting or vertical sketchmaster. Such base maps are of immense help in transferring the boundaries of the mapping units on to the maps.

B. B. Roy: Very soon a large number of Organizations in India will take to aerial photography for survey of natural resources and this will require a large number of trained personnel. Adequate provision should, therefore, be made for training in photogrammetry.

C. S. Christian: The Government of India be moved so that aerial photographs may be made available to Institutes which are engaged in research and training in photogrammetry. At present black and white air photographs may continue to be used but use of coloured photographs in due course may be taken up.

RESOURCE ANALYSIS AND PLANNING FOR DEVELOPMENT[1]

by

P. C. RAHEJA[2]

INTRODUCTION

THE primary function of integrated surveys is to collate information on physical and human resources for efficient utilization to develop them to the maximum potential. As land, water, vegetation and livestock are the principal resources of settled population, a proper inventory and assessment enable the planners to develop them in a systematic manner. Christian and Stewart (1952) have given a very comprehensive definition of *land*. It consists of climate, soils, vegetation, water resources, geology and landscape of the tract or region. The development of deteriorated or under-developed resources into more productive use of them in their terminology would mean *Land Transformation*. This has been defined by Munshi (1962) " The utilization of land on a rational basis so that the available resources of land, water and livestock are developed to the maximum potential and the population is assured a decent standard of living. There exists a state of balance between rainfall, soils, crops, trees, animals and man ". Accordingly in the integrated surveys initiated by the Institute the objective has been to develop *Land Transformation* plans of the units which have been demarcated administeratively for execution of development plans for the region. For such an inventory an area of about 11,000 sq. km. was taken up for reconnaissance survey in 1961. After reconnaissance survey, detailed survey based on aerial photographs has been initiated of the five Development Blocks in the region which form the Central Section of Luni River Watershed. The prominent features of Siwana Development Block, of which the report has been compiled are summarized in the succeeding text.

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Director of the Institute.

RESOURCE FEATURES

Physiography—The regional elevation of the Siwana Block area is 170 m above m.s.l. A number of low hills are scattered around Siwana town which attain an altitude of 1000 m above mean sea level. These hills are characterized by steep and precipitous slope. Apart from the Luni River in the northern part of the Block, there is no organized drainage system. Radial ephemeral drainage channels emanating from the hills form a net work and carry water to the river. Some of these are choked with blown sand. Similarly foot hills are also covered by blown sands which have been stabilized by native vegetation. Due to stream flashes some of them are badly dissected and deeply gullied.

Climate—The mean annual rainfall varies from 300 to 350 mm decreasing from south-west to north-east. The coefficient of rainfall is 56 per cent. For the Siwana town the normal rainfall is 344 mm. Nearly 90 per cent of the precipitation occurs during the south west monsoon season. The distribution of duration and intensity of the spells of wet periods are given below:

TABLE 1

Duration in days	*No. of rainfall spells in mm*						*Total spells*	*Expected spell per year*	*Intensity per spell mm/day*
	<25	25-50	50-75	75-100	100-125	>125			
1.	109	26	9	3	0	1	148	3·1	2·0
2.	22	20	14	5	2	2	65	1·4	2·0
3.	9	16	8	5	2	2	42	0·9	1·8
4.	4	3	8	4	1	1	21	0·4	1·6
5.	1	4	1	3	1	6	16	0·3	2·3
6.	0	1	2	2	2	0	7	0·1	1·3
7.	1	1	1	1	3	9	16	0·3	—
Total spells	146	71	43	23	11	21	315	—	—
Expected spell/year	3·0	1·5	0·9	0·9	0·2	0·4			

The number of wet spells decreases with increase in their duration. The intensity of spells is not correlated to duration of rainfall. The spells of longer duration provide significant rainfall over the Block. The wet periods in which rainfall exceeds 25 mm provide some run off. These number, on the average, 3·5 per rainy season. Significant run off is provided when rainfall exceeds 50 mm and these number 3·0 per rainy season. The conservation of this run off water and its utilization for agricultural and other purposes would be a significant contribution to water potential of the Block.

January is the coldest month in the winter period. The mean maximum and minimum temperatures are 25°C and 9°C respectively. Frosts occur on very rare occasions but cold waves are experienced. May is the hottest month in the summer season. Dust storms and dry hot winds occur frequently. The monsoon sets in the beginning of July when humidity increases considerably and temperatures fall, the withdrawal of monsoon form Siwana Block normally takes place by middle of September. The evaporation is 2600 mm per annum. Evaporation is the maximum during May which amounts to 440 mm.

pre-requisite. Rainfall data of 48 years were analysed and are reported below:

TABLE 2: *Commencement data for Kharif crops*

Commencement date	*No. of years*	*Commencement date*	*No. of year*
1-15th June	2	1-15 August	5
16-30th June	4	16-31 August	2
1-15th July	9	1-15 Sept.	1
16-31st July	7		

Thus the percentage number of years with true commencement of rainfall is 63. The average length of the period of adequate rainfall in Siwana Block is seven weeks with a standard deviation of four weeks. The estimated growing period are likely to be 12 ± 4 weeks. The percentage number of years in the past when estimated growing period in Siwana Block exceeded 12, 14 and 16 weeks, were 44, 27 and 13 respectively. The indices of efficiency of rainfall were determined and the data are summarized as under:

TABLE 3: Rainfall efficiency in different periods of crop growth during the *Kharif* season

Particulars	*Average No. of months*	*Month-wise distribution of number of years*					
		May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
I_4 Enough to initiate growth	$1{\cdot}48 \pm 0{\cdot}8$	1	3	36	35	13	1
I_8 Maintain growth under low transpiration rate	$0{\cdot}82 \pm 0{\cdot}7$	0	1	18	26	4	0
I_{12} Maintain growth under medium transpiration rate	$0{\cdot}48 \pm 0{\cdot}6$	0	0	9	17	3	0
I_{16} Maintain growth under high transpiration rate	$0{\cdot}28 \pm 0{\cdot}4$	0	0	2	14	1	0

The temperatures during the greater part of the growing season of monsoon crops are moderate with minimum diurnal variation. Bulk of the area under crops is unirrigated. Consequently by far, the incidence of rainfall is the most important climatic factor which influences crop growth. To estimate when adequate moisture conditions for safe crop establishment first occur, a total rainfall of 50 mm in one week was adopted as the criteria of adequate rainfall for germination of crops. This week should be followed by a 20-day period with a minimum total rainfall of 55 mm, otherwise the season is regarded as having a false start. In such a case a new start is considered to be an essential

The month in large number of years suitable for maintaining growth under medium and high transpiration is August.

Ground water potential and utilization — The principal formations of Siwana Block are Younger alluvium of Quaternary, Older alluvium and " gruss " of Pleistocene and Malani volcanics, Siwana granite and Jalore granite of Palaeozoic (Lower Vindhyan) periods. Structurally the region has intermontane valleys and inter-montane basins developed due to igneous and volcanic rocks. These valleys and basins are the water potential zones. The volcanics and the crystalline rocks which cover a large proportion of the area are not good water bearing rocks except in the joint and fructured planes.

The blown sand deposit and Younger alluvium tracts have more of Class II type of ground water while Older alluvium has more of Class III to Class V types. Similar is the position regarding Malani volcanics, Siwana granite and Jalore granite. The ground water exploitation areas are (a) near Luni River, (b) intermontane valleys and basins and (c) stabilized sand dune areas. The data for degree of exploitation of ground waters for irrigation are summarized as under:

TABLE 4: Annual consumption of ground water and ground water resources and percentage of reserves consumed

Zone	*Water for livestock and human population*		*Water requirement of crops million litres*	*Total ground water consumed million litres*	*Depth of water table. Metres*
	No. of days	*Water needs million litres*			
Over-exploited	245	169	4447	4616	18
Sparsely exploited	275	220	2935	3154	12
Under-exploited	185	851	178702	179553	35
Un-exploited	100	80	nil	80	12

In the over-exploited zone the recharge rate is very slow. The area covered is 5·3 per cent of the Block area. The index of ground water exploitation has increased by 7 points in the past 5 years. The sparsely exploited zone covers 1·5 per cent area. The ground water depth varies from 6·1 to 18·3 metres. The increase in index of ground water exploitation for irrigation during the past five years has increased by 12 points. The wells cannot stand much more draft and extension of irrigation would prove harmful. Under-exploited zone covers an area of 29·0 per cent of the Block. The wells can withstand increased draft. The index of ground water exploitation for irrigation and other purposes has increased by 20 and 13 points during the preceeding 5 years. The un-exploited zone covers an area of 62·2 per cent. The depth of ground water varies from 6·1 to 24·4 metres below ground level. Most of the wells are meant to meet the requirements of human and livestock population. During the past five years the index of exploitation has increased by 38 points. Thus 69·9 per cent of the total cultivated comprises of unexploited or under exploited zone. Nearly 50 per cent of the irrigated areas is in the over-exploited or sparsely exploited zones. Of all the villages 17·8 per cent depend on ground water, 18·9 per cent on surface water and 62·2 per cent on both surface and ground water.

LAND CAPABILITY CLASSES

(i) *Class I lands*—The lands are fit for intensive cropping and can be put under arable, crop vegetables and orchard trees. They have high potential fertility, they are level, well drained, free from any undesirable factors. The extent of area in the Block is 350 hectares.

The cropping pattern comprises of wheat in winter season followed by fodder Sorghum in monsoon season. As irrigation water is available, commercial crops like fruit trees of citrus, guava and vegetables can be grown to bring in more return on investment. The use of fertilizers and green manuring would upgrade production by 20-30 per cent.

(ii) *Class II lands*—The lands are nearly level, very gently slopping, freely drained with coarse to medium textured soil of 1-2 metres depth overlying freely drained sands. With proper management these lands are capable of giving good crop yields. These are subject to slight wind erosion hazard. Good quality ground water is available in the area for irrigation but the quantity is not sufficient to cover the entire area. The area of this class of lands is 4,400 hectares in the Block. These occur along river levees; deep valley fills; sheet wash deposits; and large interdune areas.

Mostly these are single crop areas. Wherever irrigation facilities exist wheat is grown which often is followed by Sorghum, for fodder. In some areas chillies and onions are cultivated. There is scope for taking to fruit culture and raising of market garden crops near urban areas. Where irrigation is available fodder production can be taken up to supplement the cattle fodder which is normally scarce during the season.

There is scope for increasing irrigation facilities. The use of fertilizers should be stepped up. In the hummocky and highly wind blown land, provision of wind breaks and strip cropping would prove helpful.

(iii) *Class III lands*—These lands suffer from several limitation such as (i) moderate to high susceptibility to erosion and needing protection under cultivation; (ii) nearly level lands with poor natural drainage (iii) salinity hazard; and (iv) shallow soils with poor moisture holding capacity. Class III lands occupy 93,000 hectares in the Block. The characteristics of various sub-classes are given below:

TABLE 5: Land characters, extent, present utilization and potential utilization of subclasses of Class III lands

Symbol	*Land characters*	*Extent hectares*	*Present utilization*	*Potential utilization*
IIIe O	Generally level, well drained with moderately deep soil; ground waters saline	5,800	Single cropped lands, principal crops are *millet, moth, bean guar*, no irrigation	To step up production promote use of organic manures and fertilizers
IIIe M	Nearly level to gently sloping and occasionally moderately sloping, freely drained soil; soil depth 50-100 cm; moderate to high wind erosion hazard; low hummocks 40-60 cm. high; fence line hummocks 1·5 m. high; ground water salinity medium	42,700	Single cropped lands; grow *millet, sesame* and *cluster bean* crops; fallow periods 1-3 years	Limiting factors drought and wind erosion hazard; planting grasses in fallow lands of over 2 years duration check wind erosion; permanent buffergrass strips in highly wind eroded areas where biotic activity is strong; discourage soil cultivation after short showers; heavy manuring, penning of sheep and fertilizer application to step up production
III W	Nearly flat lands with moderate to severe drainage impedence and low to medium salinity hazard; ground water highly saline and unfit for irrigation	3,300	Water stagnates during monsoon season, on drying land cropped under wheat; seldom *millet* crop grown on this land	Improvement of drainage essential improved water storage to enable production of market crops and fruit trees; tillage and use of acidic fertilizer increase production
III S	Level lands fairly well drained but with shallow to moderate soil depth; hard cemented kankar pan restricts root penetration; ground water saline	2,200	Crops grown are millet, cluster bean and sesamum	Breaking of hard pan and application of fertilizers can step up production

(iv) *Class IV lands*: These comprise moderately sloping to steep lands flanked with dunes and suffer from severe wind erosion hazard. The total area covered is 50,300 hectares. These are single cropped lands. The main crop is millet. Occasionally *Moth* bean is grown in patches. In between the millet crops the land is left fallow for 3-5 years.

The sand dunes can be divided into the following sub-classes.

TABLE 6: Characteristics of sub-classes of class IV land

Sub class	*Height of dune*	*Type of land*
IV $e/_1$	<10 meters	Moderately sloping land on dune flanks with low dune intensity
IV $e/_2$	10-20 meters	Strongly sloping lands on dune flanks with medium dune intensity
IV $e/_3$	>20 meters	Steep lands on dune flanks with high dune intensity

The dune slopes need special protection against wind erosion. The sub-classes IV e_2 and IV e_3 should not be cultivated and should be cordoned off to restrict biotic activity for regeneration of natural vegetation. In sub-class IV e_1 there is need for buffer grass strips, which would minimize wind erosion and increase production.

(v) *Pasture types and range management*: In the Siwana Block the uncultivated lands include the following:

TABLE 7

Sl. No	*Group*	*Area hectares*	*Percentage of total area of Block*
1.	Waste land fit for cultivation	4,533	2·2
2.	Waste land unfit for cultivation	23,306	11·6
3.	Grazing lands including orans	5,112	3·3
4.	Thui forest (in foot hills)	9,240	4·5
5.	Moderately dense forest (orans)	5,338	2·5
6.	Thorny shrubs and weed	10,870	5·3
		58,419	29·4

Thus about 30 per cent of the area of the block is partially utilized but its potential can be substantially raised by introduction of perennial species of grasses, fast growing shrub and tree species and regulating livestock grazing and exploitation for firewood and timber.

The uncultivated lands of the Block belong to land capability classes III to VIII. The class III lands are used for open grazing. The per cent density of trees is *Prosopis spicigera*-1·8; *Capparis decidua*-2; and *Z. nummularia*-19·7 percent. The ground cover consists chiefly of *Eleusine compressa* and *Dactyloctenium sindicum*. The grass cover is about 4 percent. The production of forage can be substantially increased by reseeding *Cenchrus* spp. The area of Class III lands is 3037 hectares. Class IV lands are mostly overgrazed common lands with strong wind erosion hazard. The plant cover is less than 3 per cent. In flat sandy lands seeding with *Cenchrus* spp. and in slightly saline low lying lands *D. annulatum* are suggested to increase forage production. Class V lands consist of saline (2,796 ha); stony (4,032 ha) and hummocky (1,983 ha). These are unculturable waste lands. Class VI lands are mostly dissected sand which cover 7437 hectares. The ground cover consists of *Aristida* spp, *Desmostachya bipinata* and *P. turgidum* which have low pasture potential. Stony and gravelly foothills which have sparce low scrub vegetation are Class VII lands and occupy 9,852 hectares. The pasture type is *Aristida adscensionis-Oropentium thomaeum — Tragus biflorus*. The grass cover is hardly 1 per cent. Class VIII lands consist of hills and saline *Ranns*. They occupy 22,753 hectare. Of these 875 hectares are under protection of Forest Department.

The population of livestock maintained is very large. The pasture resources can only be developed by regulated grazing based upon carrying capacity basis. In Classes III and IV reseeding is feasible and should be taken up. In other areas rotational grazing should be practised to increase regeneration of palatable perennial pasture species.

(vi) *Socio-economic*: Siwana Block has 89 villages. The population is 76,234 persons. Assuming the rate of increase to be the same as for the Census period 1951-61, the population will substantially increase. Household is the unit of production and consumption. The average size of the household is 5·7 of which 4·3 comprise the head, his wife, sons and daughters and rest 1·4 are dependents. Four-tenths of the population is dependent on others, the dependency is greater among females than male members of the family. 85·5 per cent of the population is engaged in agriculture and 5·6 per cent in animal husbandry. The other sources of livelihood are the traditional caste occupations like carpentary, blacksmithy, tanning and leather work, pottery and weaving which are followed as subsidiary occupations by the members of the concerned castes to meet the needs of the rural population.

The average size of the holding is 10·1 hectares which is fragmented into 3·03 parcels. 24·6 per cent (50,384 hectares) of the area is uncultivable. The net area sown in 1960-61 was 45·4 per cent (92,924 hectares). The irrigated area formed 2·5 per cent (5205 hectares). Subsistence type of farming is practised. The area distribution under crops is given below in Table 8.

Most of winter area was irrigated by wells in different villages. Besides 252 hectares were cropped under spring season crops principally the fodder crops (228 hectares acre) of sorghum and berseem. The miscellaneous crops in the winter season consisted of rape and mustard; onions, garlic and other vegetables; and cummin (*Zira*). The miscellaneous crops in the monsoon season comprised of *Sesamum*; *Phaseolus* pulses and sorghum for fodder. Thus in summer three-fourth of the area and in winter almost nine tenths of the area were under food crops.

The production of food is estimated at the present rate and the consumption by the increased population in 1966 and 1976 have been detailed in Table 9.

TABLE 8: Area under various crops in 1960-61

Particulars	*Summer*				*Winter*		
	Millet	*Millet + Moth bean*	*Cluster bean*	*Misc.*	*Wheat*	*Oats*	*Misc.*
Area in hectares	52,690	12,163	13,831	9,473	2,459	257	351
Percentage	59·8	13·7	15·7	10·8	87·5	5·3	7·2

TABLE 9: Food requirements of the people in 1961, 1966 and 1976

Particulars	*Consumption per adult per day gram*	*Consumption in 1961 by 65,561 adults/annum*	*Consumption in 1966 by 75,647 adults (tons)*	*Consumption in 1976 by 99,855 adults (tons)*
Cereals	397·6	9,514·47	10,978·20	14,491·3
Pulses	56	1,359·21	1,563·31	2,070·2
Milk	54·4	10,873·69	12,546·51	16,561·5
Non-leafy vegetables	11·6	27,184·21	31,366·27	41,403·9
Green leafy vegetables	56·8	13,592·11	15,683·14	20,701·9
Sugar and jaggery	56·8	13,592·11	15,683·14	20,701·9
Fats and oils	14·2	339·80	392·10	517·5

The estimated production of crops in 1961, 1966, 1976 on the assumed basis that increase in production would occur at the rate of 2 per cent per annum from 1961 to 1966 and at the rate of 3 per cent per annum in the period 1966 to 1976. The data indicate that the cereal production is adequate to meet the requirements of the growing population but diet will continue to be deficient in vegetables, animal and vegetable protein, fats and oils and sugar and jaggery.

Next to land, livestock is the most important asset of the farmer. The total livestock population in 1960-61 was 2,33,509 of which goats and sheep constituted 69·0 per cent of the total adult population, 51·2 per cent are drought animals. On the average the household has 1·75 bullocks, 2·72 cows and cow young; 0·80 buffaloes and he-buffaloe young; 5·32 sheep; 6·26 goats and 0·32 camels. The density of adult units per 100 grazing hectare units is 303. Most of the livestock produce goes to meet the requirements of the family. At the optimum level of feeding the requirements of feeds and fodders have been estimated and given in Table 10 below:

TABLE 10: Estimated forage and feed requirements of livestock

Food requirements per adult animal	*Requirements in 1961 of 86,735 adult stock (tons)*	*Requirements in 1966 of 92,156 adult stock (tons)*	*Requirements in 1976 of 1,02,998 adult stock (tons)*
Green fodder @ 16 kg straw bhusa	5,06,532·40	5,38,192·50	6,01,509·05
and hay @ 4·54 kg	1,43,729·70	1,52,716·00	1,70,677·65
Concentrate feed @ 0·91 Kg	28,809·45	30,612·55	34,211·45
Salt @ 0·03 kg	949·74	1,009·11	1,127·83

The comparison of the fodder and feed availability resources (Table 11) and the optimum requirements for the stock indicate that the optimum requirements of food and forage far exceed their availability in the area. The animals are not given any mineral salts to supplement the feed. In consequence there is very high deficit in the mineral feeds of the animals. This requires considerable effort to improve the situation to provide adequate quantity of forage and feeds to the livestock.

LAND TRANSFORMATION PLAN

General—The inventory of resources by study of physiography, climatology, geology, pedology, ecology and sociology have indicated that these resources can be substantially developed not only to meet the essential requirements of the human and livestock population but production can be stepped upto raise the standard of the people.

TABLE 11: Estimated availability of forage, hay, concentrate feeds

Particulars	*Availability of feeds in various periods*		
	1961	1966	1976
Green fodder-Monsoon season	13,059·20	14,365·12	18,674·64
Green fodder-Winter season	423·00	465·30	604·90
Dry stock-bajra (1 : 6)	58,913·64	64,805·00	84,246·50
Dry stock of bajra + moth (1 : 4)	7,687·05	8,455·70	10,992·41
Hay of Guar (1 : 5)	11,618·05	12,779·85	16,613·80
Wheat bhusa (1 : 2)	7,947·30	8,742·03	11,364·64
Barley bhusa (1 : 2)	597·52	657·27	854·45
Hay from fallow and banjar area of 61,193 @ 165 kg/ha	10,096·84	11,106·52	14,438·48
Grazing of green forage from fallow and banjar area @ 165 kg/ha	10,096·84	11,106·52	14,438·48
Top feed hay from 61,193 hect. of fallow and banjar land @ 55 kg/ha	3,365·62	3,702·18	4,812·83
Green grass grazing from 2,178 hect. of forest area @ 1,000 kg/ha	2,178·00	2,395·80	3,114·54
Green grass grazing from 2,178 hect. of forest area @ 1,000 kg/ha	2,178·00	2,395·80	3,114·54
Top feed hay from 2,178 hect. of forest area @ 275 kg/ha	598·95	658·85	856·51
Green forage grazing from 8,202 hect. of permanent and other grazing land @ 1,000 kg/ha	8,202·00	9,022·20	11,728·86
Top feed hay from 8,202 hact. of permanent and other grazing land @ 55 kg/ha	451·1	496·22	645·09
Green forage grazing from 4,156 hect. of hills @ 165 kg/ha	685·74	754·31	980·60
Green forage from 26,294 hect. of usar and barren land @ 500 kg/ha	13,147·00	14,461·70	18,800·02
Top feed hay from 26,294 hect. of usar and barren land @ 27·5 kg/ha	723·08	795·39	1,034·01

Hydrological cycle—The major crops grown in the area show a very high deficit in their water requirements. In the monsoon season it is approximately 13,000 hectare metres and in the winter season it is 1600 hectare meters. The winter deficit is met by irrigation from the wells. It is necessary to evolve efficient rainfall conservation practices to meet the deficit during monsoon.

Most of the water required for human consumption, livestock and washing is conserved in storage tanks and village ponds. There are in all 1759 wells in this block. Ground water in 56 villages covering 624 sq. km are now under-exploited which could be developed for better utilization. While the domestic requirements of the household could thus be met, water required for crop production cannot be made up from the available sources. Therefore, improved varieties of crops like Millet-R.S.K. cluster bean-Plasana; and Castor-C H. 6 which require less water and have short growing season are recommended for the tract.

Nutrient cycle— The fertility status of the soils is low due to low organic content resulting in low crop production and uneconomical utilization of water. Fertility of the soil could be increased by use of organic manures and fertilizers. The conservation of dung and pen manure and returning them to land is very essential. Dung from the livestock should be adequate to apply to the land at the rate of 2-3 tonns/ha. In the next 10 years at least 50-60 per cent of the area should have dressing of P_2O_5 and N at 20 kg/ha. for pulses and cereals, respectively.

Food situation—There will be a surplus of cereals in this area while pulses will be in short supply between 1961-76. To balance the diet, it is necessary to step up production of pulses by bringing 25 per cent of fallow land under *Phaseolus* spp. and cowpeas.

A high proportion of the population supplements its diet by milk and milk products and 40 per cent depends on animal proteins. This area is surplus in milk supply up to 1966 while in 1976 it runs into deficit. Improvement of stock is possible by providing sufficient torage mineral flour; stock water, concentrates, vaterinary aid and breeds with pedigree bulls. While sheep and goat population will be sufficient to provide mutton requirements, there is need for developing poultry farming. Sugar and *Jaggery* will continue to be imported.

Forage and feed situation — There is extreme shortage of forage hay, *Bhusa* and concentrates to the extent of 24,818 metric tons. For this purpose planting of 8 lakh trees of *Prosopis spicigera* and *Acacia arabica* may yield 30 kg of fodder per tree. The present production of 1000 kg of forage per hectare should be stepped up to 2000 kg per hectare by good range management practices. Simultaneous checking of growth of livestock population is essential.

Intensive agricultural programme— In broad outlines indications have been given for programme of intensification. It should aim at 40 per cent increase in production by use of improved seeds, implements, manures and fertilizers, pesticides, soil conservation practices. The programme of development must take an intensive shape before the results will be achieved.

SUMMARY

An intentory of natural resources of Siwana Block in Western Rajasthan has been prepared based upon survey of resources by aerial photo-interpretation. On the basis of assessment of present utilization of resources and the improved farming and range management practices the Land Transformation programme to increase production for meeting the requirements of increasing human population has been drawn up. The study has indicated that by optimum use of natural resources the food, cash and increased standard of living requirements can be met up to 1976. The lines of improvements in agriculture and animal husbandry have been outlined.

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PRODUCTIVITY OF ARID LAND FOR FARMING AND ANIMAL HUSBANDRY[1]

by

P. C. RAHEJA & D. K. MISRA[2]

INTRODUCTION

ABOUT one-third of the world's land surface form arid zones. Arid and semi arid zones together account for two third of the land surface. In this country also one third of the area is subjected to the characteristic features of aridity. The rainfall is deficient and erratic. The potential evapo-transpiration exceeds precipitation. Besides, arid zones are characterized by intense, high diurnal variation of temperatures, extreme seasonal variation in climate, light soils and both animals and human beings are subjected to water scarcity conditions.

In common parlance there is only one desert area of the country, that is the Rajasthan desert. In recent years the terminology has changed and the world's deserts have been declassified on the basis of aridity index. The three arid regions of India are Northern Arid Zone (Ladhakh — Gilgit tract) which cover an area of 1,28,750 sq. km, North-western Arid Zone which includes South-eastern Punjab (Ferozpur, Sangrur, Rohtak, Hissar, Mohindergarh and Gurgaon districts); Western Rajasthan (Shri Ganganagar, Bikaner, Jaisalmer, Barmer, Jalore, Pali, Jodhpur, Nagaur, Sikar, Jhunjhunu and Churu districts) and Western Gujarat (Kutch and Jamnagar) of which the area is 2,95,000 sq. km and Southern Arid Zone comprising Rayal Sema tract (Bellari, Kaddapadh, Anantpur and Chital Durg) covering an area of 53,895 sq. km.

PROBLEMS OF ARIDITY

Soil moisture deficit and atmospheric aridity: In these regions, the lack of rainfall is one aspect but the erratic nature is another aspect with all the associated ill effect. The agriculture and grass and forest tree suffer a very great setback due to ill distributed rainfall. In some years there are early rains providing a chance to the vegetation to germinate early, but a long spell drought thereafter kills early sprouted seedling. In other year's there may not be any early rains. The late rains are commonly not of much benefit to the vegetation. These factors put together hamper the agriculture and grassland very much. The high evapo-transpiration rate reduces the rate of plant production. Due to irregular and erratic rainfall in several years there is very short growing season. In consequence the seed setting in crops, and grasses is very much reduced. In pasturelands this severely affects subsequent regeneration of species. Under such varying agro-climatic conditions, it is most important to have suitable varieties for this tract, which are adaptable to the high aridity, low soil moisture level and short duration of growth of plants. The research work in this direction has been practically very little. The present task is to select drought resistance, low water requirement and high yielding varieties of the crops cultivated in the region. The scope of evolving new varieties through cross breeding with desired characters is thus obvious.

Wind erosion: As a consequence of high degree of aridity the wind begin to gain speed in from February and this speed continues to increase till June. During these months, the vegetation is completely dry and soil moisture in the upper soil surface is very low. The transport of soil particles by saltation and surface creep is very large. These processes are largely responsible for the formation of sand dunes and hummocks. The lighter particles are transported over long distances and deposited as loss. In Western Rajasthan approximately 80,000 sq. miles area is faced with the problem of wind erosion. This high degree of wind erosion presents a very serious problem in arable farming. When a profile of typical desert soil is cut open around Jodhpur, it is observed that there is no horizen distribution and the whole profile has only sand deposit. These soils have 89·0 per cent sand, 5 per cent silt and 5·5 per cent of clay. The status of nitrogen and phosphate is also very poor.

Flash erosion: In some localities there is tremendous water erosion problem in the light gravelly soil as these soils have no structure. With a shower of 12-25 mm. rain the formation of rills takes place and they soon form gullies. In gravelly plain areas of Bikaner often large gullies are formed with 40 mm. rainfall. The rolling topography of land surface in the wind blown sand deposited areas is most susceptible to water erosion.

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. Director and Agronomist respectively.

Uptake of nutrients: Due to limitations of soil moisture, usually the uptake of nutrients by crops and grasses is reduced. In case of early rains in the month of July the vegetation gets an early start and is able to make some headway, and absorption of nutrients is slightly better than in period of either late rains or practically no rains. Therefore, the response to application of fertilizers is generally low and inconsistent.

SOCIO-ECONOMIC SITUATION

General: The agricultural production in the extremely arid regions is much less per unit area. This quantity creates shortage of food for the urgent needs of the local population. In the scarcity years, this problem is further aggravated. Immediate attention has to be paid to make trends meet with respect to food and improve the living standard.

The population pressure in this arid zone varies from 7 to 300 persons per sq. mile. The people have over exploited the resources and stresses on the resources are becoming greater day by day. The nomadic tribes, who have little interest in conserving the resources, have contributed further to the over exploitation of native vegetation. The consequences are the use of marginal lands for agriculture, establishment of less useful species of plants, degradation of cultivated areas by encroaching sands and expanding area under salinity. The commulative effect of those processes has manifested in significant reduction in water resources. The climate also tends to be dry. With the result that this region has become more arid and less productive.

It is exiomatic that as aridity increases and grazing and stock water resources dwindle people take to nomadism. In the past nomads furnished requirements of the settled population and had an economic function to perform. With the opening up of interland by transport they have ceased to perform this vital function and their visits are most unwelcome.

Nomadism: The nomadic tribes have an approximate population of 2·5 lakhs. Some of these tribes are anti-social. They carry infectious diseases of human being and livestock. Unless these tribes are economically settled, all efforts at rehabilitation of resources of vegetation may not be of much avail. This is a regional problem and can not be solved on a state level as nomads move from one state to another without check and hinderance.

Illiteracy: The poor standard of living and illiteracy go hand in hand. Due to low income, uncertain and unassured economic conditions, the individual initiative is very much reduced. There is high degree of illiteracy in the arid zones. The old traditional customs and strong caste feelings and their bondage is still prevalent in these regions. There is more attachment to the caste groupism and kinship. The feudal system also had broken the backbone of the people of this region. Due to high degree of indebtedness the land owners have mortgaged their holdings.

Health hygiene and housing: Diseases present in the desert areas are peculiar to them and are different from those of humid and semi-humid areas. Two of the most serious diseases are Tracoma and Guinea-worm. People still live in very unhygienic conditions. Their houses are mostly '*Kachha*' structures where sand piles day after day. They are insanitary and some of them have poor ventilation. Improvement in all these sphere is desirable to increase the efficiency of work and standard of living.

Lot of evil social and economic customs are standing in the way of human progress. The natural environment, particularly dependence of bulk of the population on rainfall, engenders in them pessimism which retards initiative. Factionalism has strong roots in the villages of the desert areas. These have to be overcome to create a social order of a progressive nature.

LIMITATIONS IN ARABLE FARMING

(i) *Weed control*: The extent of competition offered by weeds to crop under arid and semi arid conditions is more critical due to special limitations of moisture and plant nutrients. Loss of water through weeds estimated at Sholapur during 1941-42 indicated that the transpiration coefficients were 556 for *Inchaemum pilosum*, 813 for *Cynodon dactylon*, 1104 for *Tepluosia purpurea* and 1402 for *Tridax procumbens* while it was 430 only for *Jowar* (Kaul and Raheja, 1952).

The most dominant weed species of the arid zone are *Tephrosia purpurea*, *Pulcaria wightiana*, *Tribulus terrestris*, *Indigofera cordifolia* and *Convolvulus pluricanlis*. The root system of these species is very deep and these offer a very great competition to the crop plants.

(ii) *Soil structure*: The Arid Zone soils hardly have any structures. Small amount of organic matter and poor precipitation results in very quick decomposition of organic residues. As sands constitutes 85 to 93 percent of soil fraction, the desert sandy soils have no structure. As such their soil water aeration environment is not condusive to high rate of production.

(iii) *Low fertility status*: The total nitrogen and phosphorus content in these soils is 0·01 and 0·04 per cent. This is very low fertility status of the arid zone soils. The constant cropping on agricultural land without the return of nutrients to this soil leaving them exhausted. There is an immediate need to take measure to build up the soil fertility.

(iv) *Pests and diseases*: There is immeasurable amount of damage done to desert crops and grasslands. One single invasion of locust or an epidemic of crop diseases completely destroys the crops. The locust damage is very common and the locust swarms come over to western parts of Rajasthan from Middle East. More scientifically planned efforts are required to tackle this problem. Attack of termites to crops is very significant. The virus diseases in legume crops cause great loss and lower the crop yields to a very great extent. New techniques and insecticides are to be used to control these diseases.

(v) *Saline waters for irrigations*: Besides the soil salinity a still greater problem is of saline waters for irrigation in this region. The sweet soils become saline by use of saline waters. As a consequence, the crop yields are appreciably reduced.

(vi) *Cash crops*: The present system of cultivation in desert regions is based on subsistence farming. Farmers like to grow grain crops required by them for their own consumption. They do not produce cash crops which will improve their economic condition. Although there is a great need of fodder production, yet very little efforts have been made to increase fodder cultivation. In the lean periods many times the cattle have to go hungry or half-fed. Increased fodder production will increase the animal production.

(vii) *Interrelation between agriculture and animal husbandry*: The total livestock population in western Rajasthan is 13·87 million of which 55% consists of sheep and goat and rest are largely bovine stock. In terms of adult livestock 6·35 million are maintained on the grass area of 19·83 million hectares, or one adult stock on 3 hectares. With 44 per cent of area under crops, the population of livestock is extremely high on grazing resources. In consequence, it takes 4½ years instead of two years to mature a heifer to drop a calf and milk, mutton and wool production are also very very low. In all probability the same position holds good in arid areas of the Punjab and Gujarat.

There should be close co-ordination between agricultural production and harnessing these resources to meet the shortage for meeting the animal demand. The increasing emphasis on fodder production, mixed farming, growing fodder and legume mixtures will maintain a balance between animal requirement and agricultural production.

FRESH APPROACH TO AGRICULTURE

(a) *Conservation of soil*: The successful farming in arid zone depends upon such agricultural practices as will reduce the chance of soil erosion to the minimum and provide conditions of soil and water conservation and improvement of soil fertility. Amongst the conservation farming practices suitable for arid regions where wind erosion is a great menance, stubble mulch farming and wind strip cropping are of high significance.

(b). *Stubble muclh farming*: The stubble mulch farming is practiced in dry land conditions, where evaporation of moisture from the soil and soil blowing present serious problems, which retards water run off, decreases soil erosion and increases water infiltration during intense rains. The practice of using crop residues as stubble mulch on grain fields began in the U.S.A. as early as 1910 (Carter and McDole, 1942). Stubble mulch farming is regarded as one of the most significant contributions to dry land agriculture where wind erosion is serious (Lowdermilk., W.C. 1953). In the mid west dust bowl of United States, large scale mechanized stubble mulch farming is practiced as a measure of protection to the cultivated farm land from wind erosion. The stubble mulch farming is a step towards maximum efficiency of rainfall utilization (Duley, *et al*, 1939). A crop residue of 5 to 20 million tons per hectare has proved beneficial for sandy soils to prevent blowing (Misra, 1960).

The study of stubble mulching with crop residue of *Pannisetum typhoides* (Bajra) in the desert soils of western Rajasthan was initiated at Jodhpur in 1958. The crop stubble of different sized including 15·0, 30·0, 45·0 cm size and whole stalk stubble were maintained. No crop stubble was left in control plots. The minimum soil loss due to wind erosion was noted in case of whole stubble i.e. 761·1 kg/ha followed by 45 cm stubble 949·9 kg/ha. The soil loss in smaller stubble plots was 1116·5 and 1491·3 kg/ha in 30 and 15 cm stubble plots respectively. Maximum amount of soil 2087·8 kg/ha was blown from control plots.

(c) *Wind strip cropping*: In the wind strip cropping investigations, the perennial protective strips consisted of *Lasiurus sindicus* and *Ricinus communis* established at right angle to the general direction of the prevailing winds to reduce the impact and threshold velocity of the wind to minimize wind erosion. In between the protective strips the field is cultivated and crops are rotated. Average crop yields of 484·4 kg/ha of *Phaseolus radiatus* and 372 kg/ha of *Phaseolus aconitifolius* were obtained from protected plots as compared to 272·0 kg. and 256·9 kg per hectare of *Phaseolus radiatus* and *Phaseolus acontifolius* respectively from non-protected plots. In addition to the grain yield in the protected plots the yield of *Ricinus communis* at the rate of 746·5 kg/ha and 1650·0 kg/ha of dry matter of *Lasiurus sindicus* were obtained. These preliminary observations show that the intervening crop strips yield higher return than the strips where such protection has not been afforded to the grass strips, (*Bhimaya et al.* 1958).

Soil moisture studies at every 3 m. distance on the leeward side of protective strip at 15 cm and 22·5 cm depth indicated 0·5 to 1·5 per cent higher soil moisture control in protected cropped land as compared to unprotected land at these depths respectively.

(d) *Water conservation*: In the rainfall areas, the conservation of every drop of moisture is essential, *Kharif* crop are grown under *barani* conditions and for growing *Rabi* crop under dry conditions, this moisture has to be conserved. The first step required for the purpose is to make bunds at reasonable intervals to retain the water and not to allow any run off. The repeated cultivations have to be done to keep the land free from weeds and also to allow full absorption of moisture. A gram crop (*Cicer arietinum*) was taken yielding 780 kg of grain per hectare at Pali Research Farm of this Institute. The bunds for conserving the soil moisture were constructed at a discourse of 100 metres apart in the soil having 1·5 per cent slope. These bunds proved to be quite successful in conserving the moisture.

(e) *Pest control*: The pests namely termite (*Anacanthotermes macroicephelus*) are very hazardous for crops like ground nuts, cotton and vegetable crops. The crop yields are reduced by 40-60 per cent if the termite attack is in epidemic form. It has been indicated by various experiments at this Institute that a dose of 30 kg/ha of BHC (5%) has been quite effective in controlling the termite. The use of pesticides like older, folidol and eldrine have proved very effective in pest control.

(f) *Change from subsistence to commercial farming*: The arable farming at present is centred round food grain production. Every household maintains a pair of bullocks for seasonable cultivation. The size of holding varies from 10 to 60 acres in different parts of the region. The level of production of food grains has not shown any improvement in the past 16 years. As the area under cultivation has not expanded as much as the population, the per capita availability of agricultural produce has become less than hitherto.

In order to improve the standard of living the arable farming needs orientation from subsistence to commercial farming. The experimental work at the Institute in the past 5 years has indicated that the area under castor, ground nut and guar for gum can be substantially increased to give high return to the farmers. The area under pulses can be extended by phosphate manuring with benefit to the soil by fixation of nitrogen. The yield of cereals can be stepped up by weed control, use of nitrogen and better utilization of rainwater. The practice of strip cropping can be introduced to stabilize soil against wind erosion. In soils of sufficient depth vegetable culture can be introduced with success.

Over the years a cropping pattern has developed in the arid irrigated areas of the country. This was patterned on the export of wheat, oil seeds and medium staple cotton to the United Kingdom. The country is in need of long and extra long staple cotton of which 3-4 lakh bales are imported annually. The irrigation water would be more profitably utilized if the proportion of area under cotton in relation to other crops could be raised. In S.W. California the grape vine industry has developed very successfully. The arid irrigated tracts can take to vine culture and this will develop an export market for grapes and resins. In Israel citrus production has stabilized the economy of that country as it is the chief export commodity. Similar industry can develop in this region. For bringing about this change economic adjustment, financial aid and more intensive orientation in cropping patterns is necessary.

(g) *Fodder crops*: The selection of suitable varieties of sorghum for fodder purposes indicated that *Merta* variety, Sojat Bawani and Sundhia Jowar were high yielding. The legumes, which can be grown with success with sorghum for fodder purposes in the desert regions are *Phaseolus aconitifolius*, *Ph. radiatus*, *Cymopsis tetragonoloba* and *Vigna cynensis*. The so enriched fodder in nutrients is very healthy fodder and substancially contribute towards the soil fertility. The growing of mixed fodder is also recommended from the crop rotation point of view.

(h) Six 2-course crop rotations were included in an experiment including, *Bajra-Bajra*, *Bajra-Jowar*, *Bajra-Moth*, *Bajra-Guar*, *Bajra-Green gram* and *Bajra-Fallow*. The observations for the past four years have indicated that the rotations of *Bajra-Guar* and *Bajra-Mung* have been very efficient, producing 11·06 quintals of *Bajra* and 5·44 quintal of Guar/ha and 10·035 dz/ha of Bajra and 8·68 dz/ha Mung. The rotations of *fallow-Bajra*, *Moth-Bajra*, *Bajra-Bajra* and *Bajra-Jowar* gave yields in the descending order. The best crop rotation which increased crop production to the extent of 17 per cent grain as compared to *Bajra* cultivation year after year in the desert soil.

(i) *Mixed cropping*: The practice of mixed cropping is very common in dry farmed areas, where usually cereals are mixed with pulse crops. The advantages consist in better growth of the associated non-legumes on poor soils and prevention of utter failure of the crop in regions of uncertain rainfall. It is more for insurance against deficiency of rains than for improving the quality of cereals or reducing the incidence of diseases that mixed cropping is practised. Considering the large area under mixed cropping, the investigation was planned and laid down in the field in 1959. The main plot treatments consisted of *Bajra* as cereal and its mixture with other four legumes, viz., *Vigna sinensis*, *Cymopsis tetragonoloba*, *Phaseolous radiatus* and *Phaseolous aconitifolius*. Methods of sowing were the sub-plot treatments. These consisted of inter-row sowing, one row of cereal and one row of legumes, two rows of cereal and one row of legumes, and one row of cereal, six rows of legumes and four rows of cereal and cross sowing. The experiment has been repeated for four years and mean values of results are presented. The seed mixture of *Bajra+Guar* gave the highest grain yield (Bajra — 8·36 dz/ha and Guar — 2·3 dz/ha) followed by *Bajra+Vigna sinensis* (Bajra — 7·84 dz/ha and Vigna sinensis —

1·37 dz/ha) and *Bajra+Phaseolus radiatus* (Bajra =7·27 dz/ha, Mung = 1·874 dz/ha). The control of *Bajra+P. aconitifolius* gave the lowest grain yield. Among sub-plot treatments of seeds ratios, normal seed rate of cereal, with ½ of legume gave the highest average yield.

(j) *Major nutrients*: A replicated trial was laid out in different parts of western Rajasthan to test the crop response to nitrogenous fertilizer. Another experiment having the treatments of NPK, singly in the doses of 16·8, 22·4 and 22·4 kg/ha and in combination was laid down at the Institute Farm, Jodhpur. These experiments have been repeated for two years and three years respectively. The grain yield results indicate an increase of 26 per cent in case of 22·4 kg/ha nitrogen over control. The increase in the NPK when assessed singly indicated that nitrogen and phosphate increased the grain yield by 18·0 per cent for individual factors for all the three years, while potassium showed that application of nitrogen and phosphate is essential for crop production in this region.

The response of trace elements on grain and straw yield of Bajra shows that the beneficial effect of Fe, Zn, Mg, and mixture of all trace elements had been well exhibited by increase in grain yield over control in each of the four years. The mean percentage increase in grain yield were 21·6, 18·0, 15·0 and 5·4 due to Fe, Zn, Mg, mixture of all trace elements and Mn respectively.

The stalk yield indicated favourable response to trace elements application in all the four years of experimentation. The mean percentage increase in stalk production for four years was 29·5, 27·4, 24·1, 21·0 due to Fe, Mg, Zn and Mn respectively stalk yield than control.

(k) Cultivation of grapes has been made with success in the areas of Sri Ganganagar and Hanuman garh. Grapes can be grown in abundance in the sandy areas with irrigation facilities has been proved beyond doubt. Several Varieties of grapes are being tried at this Institute for their performance and sweetness. Variety kandari an early maturing variety provides sweet berries and is a promising one. Some of the varieties namely Bhokhri, pusa and Kandari, and black prince have promise for this region. Pomegranate variety Saharanpuri has yielded very good sized fruits under Jodhpur conditions. Grape fruits and sweet lemon are yielding nice fruits in this Institute nursery at Jodhpur. Cultivation of melons on sand dunes in low rainfall regions like Bikaner has been done with good success. This is a technique which help in reducing wind erosion from sand dunes, produces poor man's vegetables and fruit for common man.

(l) *Animal production vis a vis arable farming*: Over 55 per cent of the wool production in India comes from this arid zone. There are about 10 breeds which are maintained by nomadic and local sheep owners. The ratio of sheep to goat is very high. It is in the neighbourhood of 3·0: 2·5 whereas desirable ratio is 6: 1. The goat cannot be entirely eliminated as she serves as foster mother and can more efficiently utilize the scrub vegetation. The cattle industry is based upon breeding for drought animals. The cow calf takes about 4½ years to mature into an adult animal. This is primarily due to heavy loss in body weight of young stock in the dry period. The dairy industry is non-existent. The survey in an area of 11,400 sq. km in the Luni basin showed that the livestock owned per household were 1·32 bullocks, 2·28 cows, 1·48 cow young stock, 0·38 buffaloe young stock, 6·48 sheep, 6·50 goats and 0·49 camel. The sale of livestock gave return of Rs. 45 and livestock produce Rs. 39 per household. The net income from other sources of livelihood principally cultivation was Rs 118 after meeting domestic requirements. Thus animal husbandry contributed substantial part of the total income. This can be substantially raised by proper animal management and rangeland improvement which forms the main source of livestock feed. By adequate protection to native rangelands coupled with controlled grazing increases range production by 100 per cent in 2 to 3 years time. Angle iron post with barbed wire is the most effective, best and cheapest fencing in the long run. Reseeding of native grasslands with suitable single perennial grass species improves the forage yield, the nutritive value of grasses and animal production substantially. Arrangement for supply of stock water on rangelands through underground water reservoirs (tankas) has proved to be the cheapest and most feasible means.

Thus situation can be remedied by starting wool production and marketing, sheep raising in selected areas, dairy industry in more suitably situated sites, mutton production on cooperative basis; and draft cattle industry in more favourable situations. The livestock industry is an absolutely unorganized affair and unless this is suitably regulated and properly controlled it will continue to remain at the subsistence level of production. Regulatory measures, financial assistance and cooperative marketing can turn it into commercial enterprise.

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PRODUCTIVITY OF ARID LANDS FOR FARMING AND ANIMAL HUSBANDRY[1]

by

B. B. Roy[2]

The arid region of India forming the western part of Rajasthan covers a total area of about 80,000 sq. miles. It is characterized by high temperature, low precipitation ranging between 5 to 20 inches (125 to 500 mm.) and high evaporation. The soil belongs to the desert soil group, being mechanically disintegrated and immature, sandy in texture, usually with appreciable salt content with significant amount of $CaCO_3$. The pH value varies between 7·0 and 9·0. All these conditions have given rise to serious handicap to productivity of the land for crop growth and animal husbandry. The main crops taken are *Bajra*, *Moong*, *Moth*, *Guar*, cotton and wheat and the yield is very much below average. The return from the land, whether, it is in the form of crop or animal produce, is therefore very low.

The main limitation in this region is the scarcity of water. The only river system is the Luni on the eastern part of this arid region which is dry for most of the year. The only source of water for raising crop is therefore the scanty rainfall which is very erratic and uncertain and the underground water. For any planning for development of water resources it is necessary to keep in mind the following points: (1) The water must be easily available on call, (2) it should be of sufficient quantity, (3) it should be of suitable quality and (4) the supply should be economical. It is very necessary therefore that a complete hydrological survey of this region be undertaken so that the potentiality of underground water resources for irrigation could be explored.

The vast region is subjected to severe wind erosion for most of the year. This is accentuated by bare soil cover, extensive cultivation and heavy over-grazing by cattle and livestock. Successful farming in the region depends upon such agricultural practices which will reduce the chances of soil erosion, provide for soil and water conservation and improve soil fertility. Agronomical practices which must be introduced so as to check the erosion include stubble mulching, wind strip cropping, suitable crop rotation and also mixed cropping. For effective conservation of moisture contour bunding is essential.

One of the major limiting factors for crop production in Western Rajasthan is the deficiency of plant nutrients in the soil. The soil is very deficient in organic matter resulting from quick oxidation due to high aridity and open soil texture. Nitrogen content also is very low and significant responses to application of nitrogen fertilizers on *Bajra*, wheat and other crops even under unirrigated condition have been observed by this Institute and also by others. Available phosphate content is generally low to medium and significant increase in yield resulting from application of phosphatic fertilizer has been obtained at this Institute and elsewhere. Potassium, however, is adequate in the soil and application of potash does not show any response. All these results point out that applications of nitrogen and phosphate are essential for crop production in this region.

Deficiency of some micro-nutrients has been observed in other arid lands of the world, as in California and Arizona in U.S.A. and in South Australia and application of these elements have given response to yield of crops and fruits. Systematic studies on the effect of micronutrients in Western Rajasthan have so far been few. Some work has been initiated by this Institute, but detailed studies on this line are very desirable. A large number of underground water samples analysed by us show high boron content and its toxic effect on crop needs investigation.

Large areas of Western Rajasthan have halomorphic soils and the high salinity and alkalinity are detrimental to normal crop growth. Investigations are needed to evolve suitable techniques for effective reclamation of such lands. With water as a limitation it may be necessary to introduce new varieties of salt tolerant crops adapted to saline condition.

The problems of arid and semi arid regions of this part of the country are identified as due to human and other biotic interference. It is essential that every piece of land must be used according to its capability or capacity. Vast areas which are suited only to permanent grasses or forest are at present under cultivation, which adds to deterioration of these and the adjoining lands. A careful land use capability survey of the entire area is therefore necessary so that such lands which come under Capability Classes V, VI and VII could be excluded from regular cultivation.

1. Contribution from the Division of Basic Resource Studies, Central Arid Zone Research Institute, Jodhpur.
2. Head of the Division.

The arid region of Rajasthan has very great scope for development of animal husbandry including dairy, sheep rearing and wool industry. Over grazing and over stocking, however, have been resulting in a serious problem and this must be avoided. Researches carried out at this Institute have shown that contour bunding and contour furrowing in pasture land in this region appreciably increases the moisture content of the soil and improves the yield of grass and this may be introduced. No studies have yet been made of the deficiency of any of the micronutrients in pasture lands of these areas and its effect on grazing animals. It is worthwhile carrying out a systematic study on this line.

Some of the major problems of the arid lands of Rajasthan which affect the productivity of crops and animal husbandry are enumerated above. Researches and investigation on these lines will go a long way in helping in stepping up crop and fodder yield and animal produce.

ANIMAL PRODUCTION IN ARID ZONE

by
G. C. TANEJA[1]

THE productivity of animals in arid areas is poor. The milk yield is low (Faulkner and Brown, 1953; Joshi and Phillips, 1963; Johnston, 1958) and the meat production whether it be by cattle, sheep, goat, swine or poultry (Faulkner and Brown, 1953; Warwick, 1958; Warren, 1939) is also low. There is reason to believe that work capacity of draft animals is also reduced. The animals may suffer from a decrease in fertility, semen quality, sperm production and slow development to reproductive maturity (Hammond, 1921; Ulberg, 1958) and increased calf mortality (Bonsma, 1950). The female reproduction may also be interferred. The lambing percentage is low and the weight of lamb is fairly small (Yeates, 1953). Developing embryos may be resorbed because of the high air temperature (Taneja, 1958a) and abortions may also frequently occur during advanced pregnancy (*see* Taneja 1958b for references).

Management plays an important role in animal production in arid areas. The grazing lands may be provided with shady trees so that during the intense heat, the animal may be able to seek shade. This will relieve the animal from some of the heat burden. Construction of sheds with suitable cooling roofs and errection of freely ventilated barns with wall protection against cold or sandy winds will be essential. Painting of shelters with paint which reflects sunlight, providing cool drinking water and sprinkling the animals with water, have shown to obviate the heat burden and improve productivity.

The aridity of environment cannot be changed to suit the animal, but only such animals shall have to be selected and bred that can thrive well under these environment. Therefore, the knowledge on the effects of various components of arid climate on animals are necessary. The arid climate may affect indirectly through nutrition and directly through changes in the behaviour and physiological functions of the animals.

NUTRITIONAL STRESS

Owing to the scarcity of food in the arid zones, animals often suffer from malnutrition. In many dry areas, water supplies are inadequate, making grazing control and fodder conservation difficult or impossible. Overstocking will be then a necessity leading to continuous overgrazing with a result of a denudation of plant cover and the domination of the coarse, nonpalatable and low feeding value plants over the perennial, edible rich grass. In the dry areas of Rajasthan it has been estimated that as much only 0·6 hectare per adult cattle unit are available whereas we require 12, 8, 4 and 3 hectare of poor, fair, good and excellent grazing land, respectively for each cattle unit (Ahuja, 1964).

The animals have to walk long distances in search for grazing or for water and this in turn makes additional demands on the amount of food stuffs required for body maintenance. Under these conditions of low nutritional level, animals exhibit deficiencies in protein and carbohydrates and may also suffer from anaemia, bone maladies and other disturbances due to the inadequate supplies of minerals and trace elements (Barrada and El-Itriby, 1964). The soil, in arid areas in India, are known to be deficient in molybdenum and cobalt.

Phosphorus deficiency is the most common mineral deficiency of livestock in the arid regions and this deficiency is commonly associated with soils deficient in available phosphorous. Where livestock do not receive good quality green roughage or pasture over extended period of time, vitamin A deficiencies may also result (Barrada and El-Itriby, 1964).

Feeds in arid and semi arid areas of India are poor in protein. It is also impracticable or uneconomical to upgrade the pastoral conditions to a level of high productivity, in particular during the hottest season. The protein contents of plants decrease drastically as they dry out in the hot season and such food is therefore of inferior nutritional value. The situation may be less disadvantageous that could otherwise be assumed in view of the fact that nitrogen compounds are sysntheized by the microbial flora of the rumen into protein which is subsequently digested and absorbed in the digestive tract. A better understanding of the conditions under which this occurs and the importance of the synthesis role of rumen flora may contribute importantly to animal husbandry in arid lands (Schmid-Nielsen, 1964).

SCANTY FEED, COMPETITION BY PESTS AND LIVESTOCK PRODUCTION

The natural low availability of feed is further affected by the pests as they compete with the livestock

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by consuming considerable amount of feed that can otherwise be available for livestock production.

There are two chief pests in this desert: locust and rodents. The devastating propensities of locust are well known. Amongst rodents also, the Indian desert gerbil, *Meriones hurrianae* is more effective due to its large number and occurrence in almost every type of habitat. It not only does great damage to germinating grasses but to their seeds also, thus leaving very low seed stock in the ranges which can regenerate during monsoon. It is observed that seeds of *Panicum antidotale, Dicanthium annulatum, Lasiurus sindicus* and *Cenchrus* species are relatively palatable to the desert gerbil. All these grasses are highly palatable to sheep. The rodent is, therefore a serious competitor to the livestock. Moreover, these rodents are a continuous source of soil erosion due to their tunnelling habit and thus indirectly lowering the feed production (Prakash, 1963).

The Desert Hare, *Lepus nigricollis* is also commonly found in this desert. Its number is not as large as that of the desert gerbil but they do appreciable damage to grasses and shrubs. Latter are used as top feed for the livestock. It is found to be particularly harmful to *Albizzia lebbek* due to its debarking activity of young plants which are grown in nurseries for transplantation in arid land for afforestation work. *Albizzia* is a very shady tree and can become a source of excellent shelter for the livestock.

Other wild animals occurring in this desert are the Gazelle, *Gazella gazella bennetti*; the Black Buck, *Antilope cervicapra* and Blue Bull, *Boselaphus tragocamelus*. All these artiodactyles are heavy feeders. During cropping season, they mainly depend upon crops but when the crops are not available to them, they depend on the natural vegetation including grasses thus consuming the feed which otherwise would have been available to livestock.

Another problem with which the Animal Production in this arid zone is faced is the occurrence of large number of goats in the desert. Goats have never-ending appetite and can consume almost every type of plant species including that which are useful for the soil binding, thereby increasing the soil drift hazard. It is high time that goat number should be regulated so that the feed can be utilized over more productive animals.

INADEQUATE SUPPLY OF DRINKING WATER

There is lack of water in arid lands. The rainfall is scanty and erratic and underground reserves are meagre. The animals therefore suffer from dehydration. Water is definately required by the animal for at least two different purposes: as an essential nutrient and component of the body and to assist the animal to reduce " heat load " by con ductive or evaporative cooling.

The information on the effects of water deprivation on productivity and work capacity is, however, lacking. One expects productivity such as milk production to be diminished and work performance to be reduced. Studies on camel have shown that these animals, instead of excreting urea in the urine, may adjust their kidney function so that a major part of the urea is being withheld from excretion. This is observed in the camel which is being subjected to dehydration. When water again becomes available, the urea enters the rumen, presumably via the saliva or *ruminal* secretion, and is re-synthesized into protein (Schmidt-Nielsen *et al*, 1957).

When the Merino is unable to obtain water during exposure to the sun in summer it continues to eat fro up to six days, although there is a considerable falling off in appetite after the second day. There is a sharp drop in weight of about 10 per cent within the first 24 hours at maximum temperatures of 36-38°C. From then on the weight loss is 3·5 per cent per day. At maximum temperatures around 40°C. or more there is a steady weight loss of 4·5 per cent per day (Macfarlane *et al*, 1956, 1961).

Sheep draws approximately half of the water used for urine formation and evaporative cooling from the extracellular space and the rest comes from gut and cell water. This may be contrasted with the behaviour of camel which loses water more slowly than sheep and draws it from gut and cell sources than from the plasma or extra cellular compartments. This should mean that there is less circulatory strain on the camel than in the sheep. It is remarkable, however, that sheep are able to maintain circulation when approximately half of the plasma water has been evaporated (Macfarlane, 1964).

There is considerable evidence that the use of water can be reduced by infrequent watering of livestock. If Zebu cattle are watered for one hour at intervals of two days, they drink 12 per cent less than if water is available all the time everyday. If the interval of watering is increased to three days, the water consumption is 31 per cent less (French, 1956). The first result of water restriction is probably to reduce a wasteful production of a relatively dilute urine. However, what effects may occur beyond this is unknown. Camels, when deprived of drinking water for extended periods of time, also reduce the use of water, the reduction approaching 50 per cent during the summer (Schmidt-Nielsen *et al*, 1956).

A reduction in frequency of watering may have a deleterious effect on the food intake and the condition of the animal. There is, however, some suggestion that these effects are not obligatory in all animals. For example, the camel continues intake of feed until a rather severe degree of dehydration has been reached.

It is possible that a carefully planned watering schedule may take advantage of the effcts described above. If the water supply is highly limited, or if the transportation cost for water is very high, such an approach may be necessary. If suitable breeds are selected and there is assurance that the undesirable effects of water restriction do not outweigh the advantages, it may be possible to resort to less frequent watering. The animals would then be able to spend a longer proportion of their time in grazing, and less time as well as less energy in walking to and from water (Schmidt-Nielsen, 1964). Evidently, this is a field where considerable attention should be given for further research.

THE DIRECT EFFECT OF HOT ARID CLIMATE

In the arid regions, air temperature is high and invariably exceeds skin temperature. Air humidity is low and this permits sun rays to pass through the atmosphere without any obstruction from clouds or moisture vapour in the air. This will be an added factor to further heating of both air and ground. Under these conditions one expects the vegetative cover to be sparse and the bare and dry ground strongly reflect solar radiation adding further heat to any surface exposed to the reflected rays. There is also great variation between day and night temperatures and between different seasons. This should mean that while considering the effect of heat on the well being of animal, the cooling effcts are also to be considered (Barrada and El-Itriby, 1964).

On the climatic elements which influence animals heat balance, radiation is the most effective. An animal in the field is exposed to the following important radiation exchanges with its surroundings as summarized by Lee (1953a).

1. Receipt of direct solar radiation, a part of which is reflected according to the colour and other properties of the coat and the reminder absorbed as heat.
2. Receipt of solar radiation reflected from the clouds and other particles in the sky, part of which is reflected from the coat in the same way as direct solar radiation.
3. Receipt of solar radiation reflected from the ground and other surrounding objects according to their properties, part of which is again reflected from the coat in the same way as direct solar radiation.
4. Exchange of " thermal " radiation with surrounding objects according to the relative temperatures of these objects and coat.
5. Loss of " thermal " radiation to the sky, which usually behaves as a body at lower temperature than the coat.

The heating effect of direct solar radiation is very well known. The percentage of incident solar radiation reflected from the terrain varies from 5 per cent for dark trees to 24-28 per cent for desert and 42 per cent for salt flats (Lee, 1953b). Both high incidence of solar radiation and high reflectivity of the terrain typically occur in conjunction with hot, dry conditions, whereas in the warm, humid environments, they are reduced. In the hot dry environments ground surface temperature may rise to 70°C, whereas in warm, humid enrivonment surface temperature may differ but little from air temperatures (Lee, 1953b). Under these conditions, any surface exposed to thermal radiation exchange with such ground will gain an appreciable amount of heat. Sky temperatures in a dry atmosphere may be appreciably cooler, especially if the air is relatively free from dust and permits the loss of important amounts of heat to it by radiation.

In this situation of high air temperatures and reflected solar radiation, the low air vapour pressure usually promotes heat loss from the body. Air movement through variable, promotes heat gain when air temperature is very high.

Animals maintained under these environments may show symptoms of over-heating which may lead to heat-stroke, dehydration, sunburn, and photo-sensitivity.

NATURAL SELECTION FOR ADAPTATION

Nature's help in the process of selection suited for the desert is going to be fairly small. Natural selection through droughts is likely to cull only aged animals that have already left the genes in the flock. Prof. Haldane calculated that natural selection may take around 300 generation to replace one gene loci. Therefore, only the artificial selection would be helpful in developing strains of animals that may be adapted to desert conditions.

BREED AND SPECIES DIFFERENCES IN RELATION TO STRESS OF ARID CLIMATE

The fact that the animals adapted to hot arid climate differ markedly from those in humid regions was recorded as early as 1858, when it was observed that the Zebu cattle of India, unlike European cattle, seek shade in the intense tropical sun (Lydekker, 1912). Kibler and Brody (1950) suggested that probably the Indian cattle have inherently lower basal metabolic rate than European cattle. Mullick and Kehar (1952) studied the seasonal variation in heat production of cattle and buffalo in India. These authors found that Indian cattle require 25 per cent less protein and about 20 per cent less calories for maintenance than the standards advocated by Morrison (1947).

Differences in coat colour have been associated with differences between breeds for their adaptation to different climatic region. Rhoad (1940) reported that cattle of lighter colour are more suited to hot arid climate since they reflect more of the rays of sun and therefore absorb less heat. Zebu cattle of Indian arid zone are of a relatively lighter colour as compared to European cattle and the differences in Indian cattle for their coat colour offer another source of variability for selection in relation to adaptation to arid climate.

Another factor which has been found as a cause of the differences in heat tolerance between Zebu and European cattle is the sweating rate. Taneja (1960) reported that Indian cattle have denser glands and the amount of secretion per unit area in Indian cattle is larger than that in the European cattle. Another area of research which should be taken up in near future is the study of breed differences in sweating rates in Indian cattle. The knowledge on this aspect will be helpful for making selection of Livestock for adaptation to arid climate.

INDICES FOR TOLERANCE TO ARID CLIMATE

Various methods have been used so far assessing the tolerance in livestock to arid climate. These indices are based on the rise of body temperature (Taneja, 1963). Actually no single measure of animal's response could be considered as an index of total response to total environment. Rhoad's index (Rhoad, 1944) has not been entirely satisfactory. Lee and Phillips (1948) suggested another index based on a short term exposure in the heat chamber that was also unsatisfactory. Obviously the development of a reliable method for indexing heat tolerance is dependent on a sound understanding of the physiological inter-relationships of the mechanism influencing on animals tolerance to heat. Of equal importance to the total animal responses is an adequate index of environment. This could be devised once the relative importance of climatic elements is determined. A useful approach is to link, experimentally in a climatic chamber, animal's responses such as rectal temperature, respiratory rate, respiratory volume, and evaporative loss to such important environmental elements as air temperature, vapour pressure and wind velocity in the form of multiple regression equations. Solar radiation may be included if the experiment is concluded in the field (Barrada, 1957). Parameters of the regression equations of both field and laboratory experiment should be compared.

GENETIC BASIS OF ADAPTION TO HOT ARID CLIMATE

Yeates (1955) assumed that if the differences between individuals with regard to rectal temperature have to be located, the animal must by subjected to atmospheric temperature. The results of Taneja, Negi and Satish Kumar (1964) have shown when the rise in rectal temperature is taken into consideration, the differences between sires are significant; thus allowing selection to be practised on the basis of sire differences. They estimated heritability of rectal temperature which varied from 19 to 20 per cent (19 per cent for morning temperature and 20 per cent for the differences between morning and noon temperature). Other workers, Seath (1947) and Gaalaas (1947a, b) reported heritability of 15 to 30 per cent. Considering these results there is a reason to believe that this character is heritable.

Seath (1947), and McDowell, Lee, Fohrman and Anderson (1953) reported the results of repeatability of body temperature of cattle. Seath (1947) tested Jersey and Helstain involving 52 cows by 7 sires in 1952 and 68 cows by 8 sires in 1945. In his data, 21 cows included in the study for both the years gave a repeatability of 0·37 for body temperature. Turner (1955) estimated the repeatability of body temperature as 0·45. McDowell, Lee, Fohrman and Anderson (1953) reported that the repeatability of body temperature was fairly high when data were analysed on seasonal basis. The estimate of repeatability for rectal temperature determined by Taneja, Negi and Satish Kumar (1964) for the morning observations was 0·31 and it was higher than the values estimated for the noon temperature or for the difference between morning and noon temperature.

BIOCHEMICAL POLYMORPHISM IN RELATION TO ADAPTATION

During the last 20 years, many facts illustrating the biochemical basis of genetic individuality have been added to the literature. Many of these aspects have been found to be of adaptive significance. The genetic basis of this kind of adaptation in sheep was reported by Evans *et al* (1956). The first paper indicated that there were two kinds of haemoglobin, the relatively fast haemoglobin A, and slower moving haemoglobin B, giving the three phenotype, A, B, and AB. The second paper suggested that these haemoglobin types were determined by two genes each responsible for the formation of one kind of haemoglobin. Later the distribution of these haemoglobin types in British breeds of sheep was investigated (Evans *et al*, 1957) and it became apparent that lowland breeds were predominately of haemoglobin type B, and the hill breeds were largely of haemoglobin type A.

Evans and Mounib (1957) observed that mountain and hill breeds, on the average, contain a greater percentage of HK (high potassium in the blood) animals than do the lowland breeds. Evans, Harris and Warren (1958) have shown that Northern European breeds are almost wholly HK type whereas the Australian Merino is almost exclusively of LK type (low potassium in the blood). A more valid comparison of our breed would be with that of the Australian Merino inhabiting nearly similar hot arid areas. The Marwari unlike Merino, is largely of HK type, the percentage of HK varying from 59 to 88 per cent (Taneja and Ghosh, 1965). This is, therefore, in complete contrast with the findings of Evans and Mounib (1957).

Further, if the differences in water metabolism of LK and HK types suggesting that LK animals may have more chance of survival in a relatively arid region than HK animals are considered (Evans, 1957) the proportion of LK animals in Marwari breed should be more than that of HK type. On the contrary, there are more HK than LK in the Marwari breed. Therefore, it is speculated that perhaps in the past there had been migration of flocks predominately of the HK type from the cold, mountaneous areas of Afghanistan to Rajasthan in India.

Two types of haemoglobin A and B are observed, in cattle, the B type is the fast moving one (Bangham, 1957). Bangham (1957) showed that cattle haemoglobins were controlled by two antosomal allelic genes fully expressed in heterozygot. The cattle B type haemoglobin has so far been found in 5 breeds (Jersey, Guernsey, South Devon, Brown Swiss and Sindhi). The association of the Bov. B gene with *Bos indicus* led Lehmann (1959) to examine the haemoglobins of the Indian Zebu; he found the gene frequencies of Bov. Hb A and B to be equal in the Gir cattle sampled. In this sample there was also a highly significant excess of heterozygous phenotypes. It would seem from these results that in Gir cattle natural selection favours the heterozygotes. Gir cattle are inhabiting the arid and semi-arid areas of India, and it is likely that other breeds of the arid tract may be having a similar structure of haemoglobin. It, therefore, appears that the genes for haemoglobin in cattle have adaptive significance.

Differences between breeds for serum proteins have also been reported by several workers. Evidence for the existence of a total of 5 alleles controlling bovine transferrins has been presented (Smithies and Hickman, 1958; Ashton, 1958a and 1959b); three alleles are confined to European breeds and two to Zebu breeds. There is a need to further investigate whether the Zebus of arid and semi-arid regions in India have distinctly different transferrins than Zebus inhabiting the humid and semi humid areas in India. The serum proteins of British breeds of sheep are reported to be controlled by different set of genes when compared with the Merinos of arid environment of Australia (Ashton, 1958b, c).

It is clear that there is gene controlled biochemical diversity in farm livestock and there is a localized environmental advantage on the individual possessing it.

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DISCUSSION

K. Goesswald: The investigations in applied zoology should be conducted to get the maximum possible harvest in arid zones by protecting the crop from damage by pests. The life history and the physiological behaviour of insects in the arid zone should be given attention for their control.

V. N. Kunin: In the U.S.S.R., the arid zones have been made to bloom wherever the irrigation has been provided.

D. K. Misra: The erratic nature of the rainfall is detrimental for the growth of the crops and vegetation in arid zone of W. Rajasthan. The high evapotranspiration rates reduce the plant production. As a consequence of high degree of aridity, the wind erosion menace is rampant. The transport of soil particle by saltation and surface creep is very large. These processes are largely responsible for the formation of sand dunes and hummocks. Poor soil fertility and limited uptake of nutrients are due to soil moisture stress and consequent reduction in plant production in this region. More detailed agronomic investigations are essential. Socio- economical problems as a result of poor crop production are illiteracy, ill health, poor housing and nomadism. There is a need to adopt conservation farming measures including stubble mulching and wind strip cropping to increase production in the region.

G. C. Taneja: The poor productivity of domestic animals in arid zone is reflected in low milk production and low meat production. Owing to the scarcity of food, water supplies, over grazing of the cattle the health and production of the rural population is low. The climatic stress is also reflected in the poor cattle health and production. More intensive investigations in animal production are stressed.

C. S. Christian: The emphasis should be placed on more efficient utilization of available water though very limited in the arid zone. Efficient use of the land to raise the productivity of crops and forages should be given priority. Investigations should be conducted to study the deficiency of cobalt and Mo in Western Rajasthan grasses. A survey of causes which are responsible for very low productivity in cattle and the proportion of cattle which have low or high productivity should be initiated in this region.

J. P. Hrabovszky: It is disappointing to note that in spite of a large number of sophisticated experiments the information which can help the farmers in increasing crop production is still lacking. A high rate of mortality in livestock is a serious set back to the economy of Western Rajasthan.

H. Waring: The study of nitrogen cycle in crops, grasses and livestock should be conducted. The status of trace elements should be thoroughly investigated.

W. V. B. Sundara Rao: A proper survey of micro-flora in arid zone should be taken in hand. It is essential to develop suitable strains of *Rhyzobia* which can resist aridity and salinity. Suitable manurial schedules for groundnut and castor should be worked out. The research on developing gas plant to work on forest waste products may be explored.

Ranbir Singh: The application of research results in the field of conservation farming are already being applied. Bunding alone increases crop production by 25 per cent. The stubble mulching and wind strip cropping are being recommended to the farmers.

P. G. Adyalkar: The possibilities of getting water from aquifers in the desert region are very limited. Drilling explorations have met with success at Chandan (Jaisalmer) in Lathi geological formation. Near Ladanu there may be some scope to locate water reserves.

ARIDITY — CAUSES, CRITERIA AND CONTROL[1]

by

A. KRISHNAN[2]

ARIDITY

Aridity is characterized by sparse and highly variable precipitation and evaporation. Drought due to lack of moisture is the characteristic of aridity. Arid zones are sharply delineated by the vegetation consisting of plants which are either xerophytes or short lived annuals. The weather over these areas is strongly seasonal with occurrence of high extremes of temperatures. In all these tracts, rainfall is by far the important factor in determining the crop production except in areas where there are sources of irrigation. The natural vegetation of trees and grass species is sparse since the water available is limited. Great adjustments are made by plants to enable them to grow in these lands. Drought escaping plants grow only where and when there is no drought. Drought evading plants are also present in this zone which are economical in use of limited soil moisture supply. High degree of drought resistance is noticed in some arid zone plants which are able to continue to grow even when soil moisture is unavilable. The crop production in the zone should therefore aim at the most efficient use of the available water and requires detailed study of plant-climate relationship so that the best suitable crop species may be grown in the available growing period. The potential of the land for the framing of land use other than the existing one can also be planned by such studies.

All these problems require the fundamental climatic element viz. evapotranspiration. Unfortunately the evapotranspiration has proved a difficult element either to observe or to predict. In fact there is no agreement between the workers on what to observe since this is a question full of difficulties. In principle, evapotranspiration is regarded as an atmospheric flux but in actual practice many complications arise on account of the complex nature of the surface from which it proceeds. Not only the movement of water for evaporation but also the vegetation cover add to the complexity of the problem. Thus the method of determination of evapotranspiration should take into account the physical properties of the soil and also the physiology of plants. A simplifying assumption is therefore made by the scientific workers in the field by defining potential evapotranspiration in which major soil and vegetation influences are removed by assuming an uninterrupted water supply. Thornthwaite (1948) made a really remarkable contribution in defining exactly what aridity means and evolving a quantitative measure for it. The potential evapotranspiration is defined by him as the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water at all times in the root zone for use of vegetation. Thus the computation of monthly potential evapotranspiration for various places in an area will give us their water requirements in different months. The water deficiency represents the amount by which the precipitation fails to meet the demands of potential evapotranspiration after all the soil moisture has been used up. In effect, it is a rough measure of supplementary irrigation required for efficient plant growth and development. The aridity index is defined as the ratio of the moisture deficiency to the annual water need expressed in percentage. This index delineates areas of different grades of aridity. As the actual aridity index of each locality signifies the magnitude of its aridity, a knowledge of the same is very useful in planning for development of the areas.

Thornthwaite has further defined moisture index by the formula $\frac{100S-60D}{N}$ where S is annual water surplus, D is the annual water deficiency and N is annual water need and systematically classified climate based on this index in the following manner:

Moisture index	*Climatic classification*
80-100	per humid
20-80	Humid
0-20	Moist sub humid
−20-0	Dry sub humid
−40 to −20	Semi-arid
−60 to −40	Arid

Based on this classification Meigs estimated areas of extremely arid, arid, and semi-arid zones in the world as follows:

Areas of arid lands based on climate

Semi-arid	8,202,000 sq. miles
Arid	8,418,000 sq. miles
Extremely arid	2,244,000 sq. miles
Total	18,864,000 sq. miles
Per cent 36 (Land area 51,970,000 sq. miles)	

1. Contribution from the Central Arid Zone Research Institute, Jodhpur.
2. The Climatologist of the Institute.

Thus nearly one-third of the globe comprises of these dry areas and the development of these lands is a paramount necessity. In India the principal arid zone lies in Western Rajasthan and adjoining areas of Punjab and Gujarat. There is also a small patch of arid zone in Bellary, Anantpur regions in Mysore and Andhra Pradesh states respectively and a small area around Sholapur in Maharashtra State. Ladakh in Jammu and Kashmir state constitutes the cold desert of India.

CAUSES OF ARIDITY

The map of the arid zones of the world clearly indicates that they are concentrated between 20 and 30° latitude which are the regions of sub tropical high during winter. While the deserts in Sahara and central Asia cover a wide continuous region the area occupied by it in Indian continent is comparatively less due to prevalence of monsoon circulation which is particularly effective in Indian longitudes. In arid zone of N-W India, however, the monsoon current is shallow with anticyclonic circulation and dry subsiding air above. Only during the passage of occasional monsoon depressions in West Madhya Pradesh, monsoon current penetrates over the arid region and gives wide spread rainfall. During the passing of the axis of monsoon trough across the area or recurving of depression in east Rajasthan also the area gets moderate rainfall.

The evaluation of Rajasthan desert was discussed thoroughly in 1952 symposium on Rajputana desert and much information on the subject had been given as deduced from geological history and archaeological evidences. According to Krishnan (1952) desert conditions must have gradually set in well after man appeared, possibly in geologically sub recent times while Deterra has expressed the opinion that Baluchistan was relatively well wooded around 4000-5000 B.C. According to Pandit Vats (1952) there is evidence that towards the end of the first millennium A.D. the population in the western part of the Sarasvati Valley became nomadic, probably as a result of the complete desiccation of land.

One thing that was pointedly brought out in that symposium was that Rajasthan desert is largely a man made desert. The desert conditions have been accentuated by the work of man in cutting down and burning forests for cultivating the area or for use as firewood. Bad agricultural practices and over grazing by cattle may have also been responsible for the deterioration of soils.

As regards increase of aridity in recent years Banerjee (1952) mentioned that the present trend is warmer and drier conditions and temperature is increasing at the rate of 1°C in a century. A statistical review of Blanford normal (1886) and I M.D. normal (1920, 1940) shows as a trend a general decrease of rainfall ($\frac{1}{2}''$ to $1''$ per annum) in the arid and semi-arid areas except on the Aravallis between Sirohi Jaipur and lower Sind. This view was, however, contradicted by Pramanik (1952) who concluded that no appreciable deterioration in meteorological conditions has occurred in Rajasthan and neighbourhood during last seventy or eighty years. Rao (1958) made a detailed study of rainfall of Rajasthan and concluded that the differences between 1920 and 1940 normals are mainly due to difference in the number of stations in each district taken into consideration in computation of these normals and not due to difference of rainfall incidence. By using the same stations, differences in normals become small and negligible. By employing various statistical analysis, he concludes that the rainfall of Rajasthan does not show any significant change up to 1954 in the history of rainfall of the area. Apart from the deficiency in annual rainfall, factors like late onset or early retreat of monsoon and occurrence of spells of rainy days interspersed with long spells of dry days or droughts during the seasons also cause famine conditions and pose difficult problem to agriculturists and hydrologists engaged in conservation of water.

CRITERIA FOR DELIMITATION OF ARID ZONES

The classification of climates will vary according to the purpose for which classification is made such as establishment of areas suitable for a crop or various comforts for human settlement. However, most widely known classifications are bioclimatological in nature and actually attempt to relate the extent and type of natural vegetation to climatic conditions.

An evaluation as to how far different standard climatic classification methods reflect the actual vegetation pattern of Rajasthan has been attempted, and the results are presented in a paper by Krishnan A. and Shankarnarayan, K. A. in this symposium volume.

CONTROL

It need not be emphasized that the final decision on the use of land in the arid and semi-arid areas for the production of food will depend on the availability of water, the first vital requirement in reclaiming the desert. Of all the factors affecting crop growth, the moisture needed by plants for the transpiration process and the associated transport of essential nutrients to various parts in the growing plants is very important. The vital importance of our conserving water resources for maximum use in food production and of augmenting the limited and unpredicted water resources by artificial rain making is therefore obvious.

EVAPORATION CONTROL

The control of evaporation may be achieved by the control of various natural factors affecting it in any one of the following manner.

(a) Control of wind factors and saturation deficit by well planned system of wind breaks consisting of rows of trees and hedges which not only help to decrease the velocity of the air but also to enrich it with more moisture which comes as water vapour transpired by the plant cover.

(b) Control of the timing of irrigation in case of irrigation agriculture.

(c) Sub soil irrigation.

(d) Covering the reservoir of water by spreading on it a thin layer of mono-molecular films.

During the UNESCO symposium on water evaporation control at Poona in December 1962, some aspects of this subject were discussed in detail by the scientists working on the problem on Laboratory scale as well as on field scale in lakes. Some of water retardants used in these experiments are as follows:

Cetyl alcohol $C_3(CH_2)_{14}CH_2PH$
Stearyl alcohol. $CH_3(CH_2)_{16}CH_2OH$
OED-70
OED (Suspension)
OED (Green) and
O.E.D.N.C.
} Used by Dr Mihara of National Institute of Agricultural Sciences, Tokyo, Japan.

When the mono-molecular film is spread over the surface of a natural lake or reservoir, it is subjected to additional disturbing factors like sun shine, wind and weather. In the arid and semi-arid zones of India, wind factor is likely to be predominant since wind velocity prevailing there during April to October is very high. Further the bacterial destruction will also play a more prominent part.

According to Ramdas (1962) out of the total land area in India of 12,69,640 square miles, the arid and semi-arid zones and areas which have long dry season will cover about 8,00,000 sq. miles. If 1 per cent of this area represents the area of the aggregate free water surface in the form of ponds, lakes, reservoirs, bunds etc., then an area of about 8000 sq. miles will need treatment with cetyl alcohol or other film forming material. This is equivalent to 8000×640 or $5{\cdot}12 \times 10^6$ acres.

Under still air conditions for 6 months of dry season with renewals every other day the amount of cetyl alcohol will be 1·65 lb./acre. Under average to strong wind conditions about 8 times this quantity will be required per acre viz. 13·20 lb. Hence total quantity needed will be $5{\cdot}12 \times 10^6 \times 13{\cdot}20 = 6{\cdot}7584 \times 10^7$ lb. This will be about 70 million lb per year. Thus he has recommended developing of process by N.C.L. for manufacturing of this chemical from the indigenous raw materials like cotton seed oil etc.

WATER BALANCE STUDIES

Apart from evaporation control studies mentioned above, water balance studies of the crops and plant communities in the arid and semi-arid areas and study of the dynamics of moisture movement would go a long way in the water conservation and better utilization of incident rainfall. These studies will help us in establishing relationships between the water loss from the soil and initial amount of water in soil, atmospheric condition and the characteristics of vegetation (Slatyer, 1961). A water balance experiment was started in the Central Arid Zone Research Institute for the native *Prosopis cineraria* community in 1963. The results obtained in this study during monsoon 1963 is presented below.

On the area of 1228 square metres of this experiment there are 6 *Prosopis cineraria* trees and seven dominant species of grasses including *Dactyloctenium sindicum*.

The total monsoon rainfall over Jodhpur for 1963 was only 157 mm as against a normal rainfall of 297 mm for the monsoon period of July to September. The change in moisture regime and the water balance of the experimental area for consecutive seven decades (ten day periods) covering the period 20th July to 27th September, 1963 are given in table below. This period obviously covers the monsoon period which lasted from 29th July to 13th September, 1963.

TABLE: showing moisture changes in soil, rainfall, run-off and evapotranspiration by vegetation.

Decad No.	*Mid date*	*Mean water content (mm)*					*Soil moisture change*	*Rain fall (mm)*	*Run-off (mm)*	*Evapotranspiration (mm)*
		0·50 *cm*	50-100 *cm*	100-150 *cm*	150-200 *cm*	0-200 *cm*				
21	25th July	5·9	11·4	17·8	20·5	55·6	—	nil	—	—
22	4th August	29·1	17·3	18·7	22·9	88·0	+32·4	52·4	0·2	19·8
23	14th August	41·4	19·2	18·0	21·7	100·3	+12·3	20·3	0·1	7·9
24	24th August	20·3	16·4	18·7	19·1	74·5	−25·8	nil	—	25·8
25	3rd September	23·5	11·3	17·0	18·7	70·5	−4·0	43·9	0·2	47·7
26	13th September	43·6	11·3	16·8	17·7	89·4	+18·9	40·3	0·2	21·2
27	23rd September	13·3	11·3	15·5	17·5	57·6	−31·8	nil	—	31·8

Monsoon rainfall affected the moisture regime only up to 100 cm. depth. Increase of moisture in the layer 50-100 cm. was noticed only for the initial rain spells occurring in the end of July and beginning of August. The run-off water which was measured in specially constructed runoff tank constituted only 0·4 per cent.

In the decad just before the onset of monsoon (20th July to 29th July 1963) the moisture content up to 200 cm depth was 56 mm while on the decad just after the withdrawal, the same was only 58 mm. Thus 157 mm of water was lost during the period as evapotranspiration of the vegetation. Since the moisture loss is due to transpiration by grasses, the peak values of evapotranspiration were reached in 5-6 weeks after the regeneration of grasses.

The water output of a *Prosopis cineraria* tree as estimated by torsion balance technique was 153·8 kg/day during winter; 112·3 kg/day during summer and 106·1 kg/day during monsoon. Assuming six trees in the site take moisture from the experimental area up to 200 cm depth, these losses would correspond to 0·75 mm/day, 0·55 mm/day and 0·52 mm/day respectively. Since so much moisture loss does not occur during a day in any of the season except monsoon it appears that *Prosopis cineraria* tree extracts moisture not only from wider areas but also take the same from the Kanker zone below 2 metre depth through which the roots of the trees penetrate. The grasses began to regenerate by 22nd decad and dry up by 29th decad. Thus these grasses required a minimum of 22 mm. water in 0-100 cm layer for their regeneration and growth. Similar studies for various crops would go a long way in increasing the efficiency of utilization of available rainfall.

ARTIFICIAL RAIN MAKING

As regards the augmentation of the limited rainfall by cloud seeding, it can be said that in arid and semi-arid region where rainfall is low and erratic, even a small increase in rainfall but strategically timed could bring about disproportionately great increases in agricultural production. The problems associated with weather modifications are not however simple and it would be too much to expect large scale control of weather could be effected by cloud seeding techniques. However, it has been established from the experimen's conducted in Australia and elsewhere that rain can be made to fall from both warm and super cooled clouds, provided they have already developed naturally to a suitable stage. Releasing of silver iodide from smoke generators located on the ground is rarely effective, since it fails to meet the height required and soon looses its value as an artificial freezing nucleus when exposed to sunlight. The standard method of artificial rain making developed in Australia and elsewhere is therefore based on seeding of clouds with silver iodide produced from a smoke generator located on the wings of air craft. Granulated dry ice was also dropped into layers of cumulus clouds sometimes for seeding clouds (Smith, 1949; Smith, Adderly and Walsh 1963, Smith Adderly and Benthwaite, 1965).

In the actual rain making experiments two nearly identical clouds in the same area can be selected one of which may be seeded but not the other. With the help of radar equipment, it can be verified whether clouds yield rain or not. Having established that rain can be produced by seeding of single clouds that are in suitable condition, the next step is to assess statistically whether or not increased rain fall could be produced over a wide area economically by cloud seeding experiments. For this experiments are to be conducted on a rigidly randomized basis in order to enable proper evaluations being made by separating out as far as possible the effects of variation in rainfall due to natural causes.

Another point in arid zones is that a small improvement in microclimatic conditions may be decisive as between a crop and no crop. For instance, underneath a tree cover, incoming and outgoing radiation, wind velocity and eddy diffusion are diminished. Humidity is increased and evaporation and daily range of temperature are reduced.

Modern research in physical climatology shows that climates owe their individual character to the nature of exchange of momentum, heat and moisture between earth surface and atmosphere. A knowledge of the same and the distribution of radiant energy which is a major controlling factor in important processes like photo synthesis and transpiration etc. is therefore very important. The following studies with reference to arid zones will also be very useful.

(1) Availability of soil water for plant growth and survival.
(2) The possible utility of atmospheric water by plants either as dew or water vapour which can serve as alternate source of water.
(3) Studies on measurement of evaporation and evapotranspiration of various plants and grasses.

Last but not the least is the study of wind erosion which results in formation of hummocks and sand dunes and removing of fertile soil from the crop fields. A strong wind belt is noticed in the middle of arid zone in Rajasthan covering Jaisalmer and Phalodi. On travelling from Nagaur and Bikaner, one comes across two distinct zones of sand dunes which probably correspond to the wind belts. A detailed study of the wind regime over these areas by establishing a number of anemographs for wind survey is not only necessary for tackling this problem but also for utilizing the wind power for lifting water for irrigation and for drinking purposes.

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DISCUSSION

E. Hovmoller: A brief review of the papers presented at the Symposium on the causes, Criteria and control of aridity, from a Climatological point of view was given. The India Meteorological Department and the World Meteorological organization should be consulted for pursuing work in this direction.

P. Jagannathan: There is need for caution as any hasty work on climate and aridity based on simple and single parameters may prove misleading. Quickly reviewing studies from small scale and short term aspects to global ones, demand more complex parameters involving all the meteorological factors, for obtaining climatic criteria for arid zone research.

H. Nath: The arid zone environment has a strong impact on man with special reference to food intake, nutritive requirements and adaptation.

V. P. Subrahmanyam: The water balance concept offers good scope for further work. A serious study of arid zone climatology in terms of aridity index should be conducted. Already work on this aspect is in progress at the Andhra University and the interesting conclusions have been arrived at on the nature of frequency of occurrence of droughts in the dry climatic zones of north and south India. Intense survey on arid zones of south India should be conducted from the aspect of agricultural and hydrological development.

A. R. Subrahmaniam: It is essential to work on droughts and aridity and take to water balance approach for arid zone reclamation and rehabilitation. The study of moisture adequacy (AE/PE) for agricultural studies in different zones is most essential.

C. S. Christian: There should be a quantitative approach to defining and delimiting arid zones for specific purposes like agriculture or human settlement.

J. Dresh: The application of the term "desert" to Indian arid zone which was more a semi-desert compared to the real vast expanses of the Sahara desert, appears to be anomalous. The humid climate of the Aravalli mountains, gradually degrade into a steppe land to the north and the west.

ARIDITY — CAUSES, CRITERIA AND CONTROL[1]

by

P. JAGANNATHAN

WHAT IS ARIDITY?

ARIDITY signifies deficiency of moisture to support vegetation. This is due to the fact that water available on the soil and in the soil is less than the evaporation potential. Dry climates are those in which water deficiencies exceed water needs, i.e. evaporation exceeds precipitation and no surplus water remains to maintain constant ground water level. It is essentially a climatic index relating to the ability of the region under consideration to support vegetation.

WHAT IS CLIMATE?

What exactly do we mean by climate? Before we proceed we should be clear about what is connoted by the term 'climate'. 'Climate' is a composite generalization of the variety of weather conditions experienced from moment to moment, day to day, month to month and from year to year. It is not just average weather alone, the variations from the average are equally important in its specifications. It should be painted in all its colours of the constant variations. It is the ensemblage of all significant weather elements such as temperature, humidity, rainfall, sunshine, etc. their frequency of variations and their inter-relationships which typify the climate. Further to distinguish clearly the climate of one place from that of another, it is necessary to refer to the daily, seasonal and annual variations of the weather elements, their extremes, etc. In the case of rainfall, in particular, besides the total amount one should know the frequencies of falls of specified duration and intensities. Thus when we talk of climate it is this composite picture that is sought.

CLASSIFICATION OF CLIMATE

No two localities have identical climates. The purpose of climatic classification is to identify those aspects which make a climatic region fairly homogeneous within itself and significantly different from the nearby region, which belongs to another climatic region. Scientists like biologists, geographers, agriculturists, weather forecasters, etc., whose spheres of activity are closely linked up with weather and climate have attempted to delineate the climatic zones according to their requirements. Primarily, temperature and precipitation, which are the most widely observed elements and which have an immediate bearing on the ordinary human activities have been considered in most of these classifications. Hoever, more advanced requirements of modern living require more complex combinations of the climatic elements, e.g. for classification of airfields and air-routes, we have to consider flying weather optimum the limiting conditions for different performance characteristics. Thus for every activity influenced by climate, we have a classification. Given the required data, we could determine the various climatic zones satisfying certain specified criteria.

Several schemes of climatic classifications have been proposed and most of them are purely empirical but none of them satisfies all requirements. The basic difficulty is inherent in the fact that there exists hardly any sharp boundaries between climatic zones except at the crest of mountains and at coast lines and the various climatic zones fade into each other. Further the shifts of general circulation from year to year bring fixed locations on the surface of the earth sometimes into one and sometimes in the other. Thus all dividing lines are essentially arbitrary.

CLIMATIC VARIATIONS

Well, is this climate completely steady? If this is so, we are completely justified in estimating the probability of future occurrences on the basis of past record. The risk for any climatic eventuality could be evaluated correctly and provided for.

There is evidence that climate is not steady as we would like. Geologists and palaeontologists have established that the earth had experienced several vicissitudes of climates. From mineral contents of rocks, from fossil remains of vegetable and animal life, it has been possible to establish that the earth enjoyed warm genial climate when even the poles were free from ice, practically about 9/10th of its life. These normal climates of the earth were interrupted during the remaining 1/10th by 'Ice Ages', when polar peak ice encroached into the lower latitudes and the mountain glaciers spread

1. Contribution from Instt. of Tropical Meteorology, Poona.

to lower elevations. We have several historic evidence when increasing droughty conditions have led to extensive migrations to wetter regions.

During the great Ice Ages and geologically subrecent times, the Northwestern parts of the Indian sub-continent was not arid. Archaeologists have evidence that Baluchistan was relatively well wooded and was occupied by extensive human settlements down to about 4000 B.C. Mohenjo Dharo excavations reveal the existence of culverts constructed about 2750 B.C. to carry away storm water and that these sites were partially abandoned because of serious flooding by Indus between 2750 and 2500 B.C. Now we have here the most infertile region.

Now it is well known that climate does change and that there are fluctuations varying from small scale involving a century or so to the large scale involving millions of years. Presently we are living in an era of retreat of glaciers, of decreasing ice cover.

Climatic variability evokes manifold influence on man's natural environment, his welfare and to some extent practically every aspect of his activity both voluntary as well as involuntary.

This relation that the earth as a whole is experiencing a minor climatic fluctuation has provided the necessary urge. The modern science of meteorology has provided the objective means of indicating the extent and intensity of such changes. Thus there is considerable impetus to the study of climatic fluctuations in recent years. The most striking feature revealed by the studies is the general warming up in many parts of the world, which was maintained until about 1940, when in some places there appears to have been a levelling off or a fall of temperature. The rainfall picture is much more complicated. However, evidence is conclusive that in the subtropical and tropical regions, there was a sharp decrease of rainfall from a peak at the end of the last century to a minimum around 1930-40 and thereafter an increase. The decrease of rainfall was accompanied by a contraction of the equatorial rainbelt and a shortening of the wet seasons. A feature of the recent return of wetter conditions has been an increase of *tropical cyclones*.

Like many other meteorological phenomena, climatic fluctuation is one of formidable complexity. On the basis of both theory and observations it has been well established that:

(i) Climatic changes, especially of the slower fluctuations that span several decades are world wide in extent.

(ii) Climatic changes arise primarily from changes in large scale components of general circulations, which in turn are dynamically interrelated over large continental distances.

(iii) Changes in circulation results in changes in local climates. However, all changes in local climates need not result from changes in circulation.

FACTORS CAUSING ARIDITY

World's extremely arid regions are situated under the influence of subtropical high pressure cells, where weak circulation and subsidence prevails. Semi-arid lands are marginal to pure deserts and are situated in regions dominated by varying circulation conditions. The sub-tropical jet stream is usually present at about 9 km over Sind and Baluchistan and this brings in moisture from the North Arbian Sea as a Southeasterly stream over south and east Rajasthan. This current is, however, very shallow as at levels above 2 km it is dominated by the anticyclonic circulation bringing hot dry northerly air over running the moist monsoon current. When the monsoon air penetrates into the desert region, even the few clouds that exist in the easterly or southerly air are dissipated by the dry northerly current and the atmosphere is being continuously dessicated. Thus during the monsoon season, when the rest of India experiences considerable rain, over Rajasthan the skies are clearer with very little rain leading to intenser insolation, higher temperature and consequently greater evaporating power of the atmosphere.

CONCLUSION

Attempts have been made by several authors to delimit the climatic zones of India using one or other of the criteria. It is very difficult to say as to how Rajasthan became infertile during the last few thousands of years. Whether the deterioration was due to climatic changes or due to human activities, which could have initiated unproductivity through soil exhaustion or soil erosion only a proper appraisal of the various environmental features can reveal. While we can do precious little to modify the macro-climate, we should be able to modify the micro-climate and this is particularly important for harnessing the resources of arid and semi-arid regions.

IMPACT OF MAN ON ARID LAND — RETROSPECT AND PROSPECT[1]

by

A. B. BOSE[2]

INTRODUCTION

THE problems of Indian Arid Zone should be viewed in the context of human ecology since arid lands in this country are not virgin but have fairly high densities of population ranging from 4 persons per sq. km in Jaisalmer district to 122 persons per sq. km in Jhunjhunu district. Over-exploitation by man of water, plant and land resources has disturbed the delicate ecological balance. Over-grazed lands, shrinking forests and eroded agricultural fields show the imprints of man's activities on his environment. Any programme of arid zone development must, therefore, take into account the human factor for diagnosing the processes by which resources are being depleted, for assessing the nature and extent of present ills and for indicating the remedies. In the past there has been an unfortunate neglect of the social dimensions of the problems and most scientists believed that the objectives were achieved if they were just able to acquire knowledge about the resources and their optimum use and development in an arid environment. The recent change in trend of thinking for including the study of the human factor in solving the problems of the arid zone is a step in the right direction. For, man holds the key to the future by setting limits to the use of resources as also the priorities.

Problems of Indian Arid Zone — Let us now see the chief problems in the arid zone from the human factor point of view. The first and foremost is that pertaining to the future of nomadism. In the past the nomads performed a useful complementary function for the sedentary population. But now this position of mutual dependence is breaking up on account of over-pressure on grazing and water resources, development of means of communication and technological, economic and political changes. In the present Indian socio-economic and political context sedentarization is perhaps inescapable. The nomads themselves, faced with the problem of a declining income, have desired sedentarization and many groups have, in the course of last few decades, been sedentarising fairly successfully usually on land and animal husbandary. It is essential, therefore, to work out bold and well-conceived measures for rehabilitation making the best use of the scarce resources of the region, the skills of the nomads, their needs and their aspirations.

Another problem pertains to the fast growth of population. During the period 1901-61, the percentage variation of population was as high as 102·8 per cent in the arid zone of Rajasthan. The present broad-based population pyramid, practice of early marriage, and the prevailing social values which favour the birth of children, indicate a rapid rate of population growth in the future as well. Since the resources in the arid zone are limited, even a small addition of numbers puts a severe strain on the economy of the region. It is, therefore, necessary to initiate measures of population control.

Over-dependence of the population on agriculture has created problems of exploitation of even the marginal lands. The preference of people for agriculture inspite of the low and erratic rainfall is understandable for, apart from the traditional social values and ties concerning land and cultivation, under existing conditions, cultivation is more secure and remunerative than animal husbandry or caste occupations and can also support a larger number of people per unit of area. It is, however, necessary in the interests of better cultivation and more rational use of land to develop alternative sources of livelihood to which the cultivators of marginal lands could be diverted.

Subsistence farming, which tends to make the farmers security oriented rather than risk oriented, is an important cause for low levels of income. The over-emphasis on food and fodder crops as determined primarily by the needs of the family and the limited number of his transactions in the monetized sector of the economy makes it difficult for the planner to influence the farmer with price and other economic incentives and controls. Low capital investment, labour intensive agricultural operations, poor communication and inadequate marketing facilities impose further checks on efficient agriculture.

Although livestock ranks only next to land as the most important asset of the farmer, its contribution to the earnings of most of them is meagre. This may be traced to the high percentage of draught cattle in the adult bovine population, the traditional herding, breeding and management practices followed and the shortage of feed and fodder for livestock. There is acute overcrowding of livestock on grazing land largely due to the high concentration of people in agriculture. Raising of large herds of sheep, goats

1. Contribution from Central Arid Zone Research Institute, Jodhpur.
2. Sociologist-cum-Economist.

or other livestock is traditionally confined to certain castes who usually live in scattered homesteads making them less approachable to innovations. To a large extent the present composition and size of flock is the product of the grazier's resources and experience. For instance, sheep raisers almost invariably keep a certain proportion of goats because of its useful complementary role although they realize that theoretically sheep would give greater returns than goats. It would, therefore, be inadvisable to recommend measures without an understanding of the present practices in which sphere, one must admit, scientific knowledge is woefully lacking.

The other sources of livelihood in the rural areas are usually the traditional caste occupations which in the past helped to maintain the self-sufficient character of the rural community. Most of these are now on the decline on account of the gradually changing rural framework resulting in loss of income and insecurity of employment. On account of the rather crude and purely functional character of the goods turned out by these occupational castes which cater usually to the needs of the village only, it seems difficult to be able to revitalize or reorganize all of these for providing higher earnings and competing successfully with more sophisticated factory made goods. Hence the search for alternative employment in industry must continue so that the saturated agricultural sector gets some relief and the rural economy acquires a more diversified base.

Widespread indebtedness, chiefly due to loans incurred for non-productive purposes acts as a drag on the efficient functioning of the cultivator. The cooperative movement has not been able to eliminate the exploitative money-lender because of the uncertainty regarding the availability of loans, the tying up of the loans advanced to assets, their short term nature, pre-occupation with procedural niceties and inability to match the shrewdness and flexibility of the money-lender. Since adoption of many of the innovations require capital investment it is high time the movement is energized to meet the credit needs of farmers.

The transition from the old feudal order to a democratic set-up has undoubtedly been a step in the right direction. But inability to anticipate the social components of such a move has created some unexpected problems. The older institutional arrangement for a more rational use of resources which were enforced by the authority of the Jagirdar sought to mitigate to some extent, at least, the evils of uncontrolled grazing or cutting of trees or use of water, to mention only a few. The transition has, unfortunately, led to a more rapid deterioration of these scarce resources as the democratization of leadership has not been able so far to check the tide of misuse.

The rural social structure has functioned to conserve the hold of tradition and to slow down the process of change. Caste, the pivotal social institution, has restricted social and occupational mobility and fostered values concerning cultivation and animal husbandry some of which are definitely economically untenable. The ties of family and kinship have also resisted change. The increasing disintegration of joint households is more a change of form than a transition from familism. This has, however, created some unexpected complications, as for instance, increasing fragmentation of land, uneconomic but unavoidable duplication of assets and further pressure of livestock on land. Caste factions and inter-caste dynamics have released forces the full socio-economic implications of which are not yet clear.

Planned social change has not made much headway. The acceptance of improved agricultural and animal husbandry practices has been successful in only isolated pockets. To some extent this is due to the lack of appreciation of the social framework in which change is sought to be introduced and the failure to demonstrate effectively the efficiency of the innovations and thus dispel age-old beliefs which strangle the inflow of ideas. It must be admitted, however, that so far as the arid regions are concerned, the effectiveness under field conditions of improved practices and the related social, economical and physical components have not been studied in an integrated manner.

Prospects — The problems are thus many; they are also complex and deep-rooted. The knowledge about these problems and the means to tackle them is inadequate because science has so far largely concentrated its efforts and resources in more favourable areas. It would be worthwhile indicating the research needs from the human factor point of view in the spheres of human ecology, rural sociology, economics and extension. These are intended to help fix priorities rather than to limit the scope of experimentation.

I. HUMAN ECOLOGY

(a) Nature of inter-action between man, land and environment
(b) Nature and extent of symbiotic relationship between groups
(c) Spatial aspects of rural living
(d) Settlement types and social structure
(e) Human ecology and demography
(f) Regionalism
(g) History of land use and resource allocation

II. RURAL SOCIOLOGY AND SOCIAL ANTHROPOLOGY

(a) Cultural factors impeding planned social and economic change
(b) Diffusion of innovations
(c) Leadership and group dynamics
(d) Social systems of farming
(e) Rural social institutions

(f) Traditional social processes of competition and cooperation
(g) Rural social organization
(h) Social change

III. ECONOMICS

(a) Intra-farm allocation of resources
(b) Relationship between resources and products, resources substitution and factor relationships
(c) Efficiency analysis
(d) Agricu'tural land — problems and policies
(e) Agricultural insecurity, income inelasticities and disparities
(f) Farm management

IV. EXTENSION

(a) Action research pertaining to acceptance of improved agricultural practices
(b) Group work
(c) Community organization
(d) Improved home management through family budgeting, economic utilization of leisure time, change of dietary, etc.

Integrated land and socio-economic surveys of regions followed by some problem oriented studies would permit a better understanding of the problems of Indian arid zone. The results so far have been encouraging and hold promise for more fruitful applications and research possibilities.

The ability of arid lands to raise productivity would depend upon the sincerity, determination and vision of scientists, administrators, extension agents and the farmers themselves. It is not just enough to lay the blame on man for misuse of scarce resources. Often he is aware of the disastrous consequences of his short sighted policy but the absence of alternatives leaves him with no choice. The task is neither easy nor are the goals within reach in the foreseeable future. The journey is likely to be long and fraught with difficulties but hopeful signs are already visible pointing to the possibility of more productive arid lands and a better deal for man.

DISCUSSION

P. K. Misra : Results of researches are often not applicable, or acceptable. Gadolya Lohars and Banjaras are poor and possess poor state of health. Everybody is willing to help. In Chittorgarh the State Government of Rajasthan set up a plan for rehabilitating Gadolya Lohars by providing houses schools, agricultural lands, etc. Yet scheme was not successful. Failures were due to the fact that Amravati nomads were called to settle at Chittorgarh. From Maharastra nomads were called when there were nomads available in Rajasthan. Money for rehabilitation was given in small amounts and at irregular intervals. The workshop goods manufactured by them could not be marketed. In Pushkar Gadolya Lohar colony exists which is fairly successful because of smaller number of families and their eagerness to settle. In Beawar also they have sedentarized successfully because their goods can be marketed successfully. For rehabilitating nomads sociological studies are necessary. The rehabilitation should be carried out by stages. Their confidence should be gained by team of dedicated workers.

J. P. Hrabovzsky : Planning for social and economic change is most essential. In the past excellent plans were made but the execution was not always satisfactory. The blame was usually put on people. A good plan must have possibility of carrying out administratively and by providing incentives to the people.

C. S. Christian : The basic function of the Human Factor Studies Division is to understand the community, their susceptibilities, their needs and willingness to change.

J. P. Hrabovzsky : Education of the community is most essential. Rajasthan is relatively backward. Education is necessary to bring the best of the human elements.

P. C. Raheja : In the Community Development Blocks steps are being taken to increase production. Prices of commodities which go to increase production have been fixed and steps taken to ensure fair return to the farmers. Innovations cost money. The credit required for this has been increased so that the farmer gets credit more easily. Long term credit is also being increasingly given. For boosting agricultural production, demonstrations have been intensified. The climate for agricultural development is improving.

E. W. Russell : It is necessary to work out a viable system of farming and animal husbandry which can withstand the periods of climatic stress.

A. B. Bose : Problem must be viewed in an integrated fashion and innovations to be introduced must be pre-tested.

Ranbir Singh : There is a strong case of adopting a programme of intensive demonstration rather than general extension.

J. P. Hrabovzsky : There is a large amount of risk and uncertainty involved in taking to new innovations. It is of paramount importance that such innovations must yield results.

P. G. Adyalkar : The innovations should be pre-tested at various places in different agro-climatic tracts in the arid zone.

P. C. Raheja : Varieties now being introduced have been tested against bad years and then only recommendations are made to the farming community.

N. S. Jodha : Price incentives are sometimes not workable here. Therefore, the agricultural produce does not come in the market. Credit has usually been cornered the larger farmers.

J. P. Hrabovzsky : On the credit side you must have a blue print for carrying out the objectives.

P. C. Raheja : In country more than 55 per cent of the households are members of Cooperatives. This shows success of Cooperatives and their increasing coverage. Educating farmers on use of credit is most essential. The incentive of greater production is being channelled by the Community Development Organization.

P. K. Misra : The membership of the Cooperatives should be viable which uses credit for productive purposes.