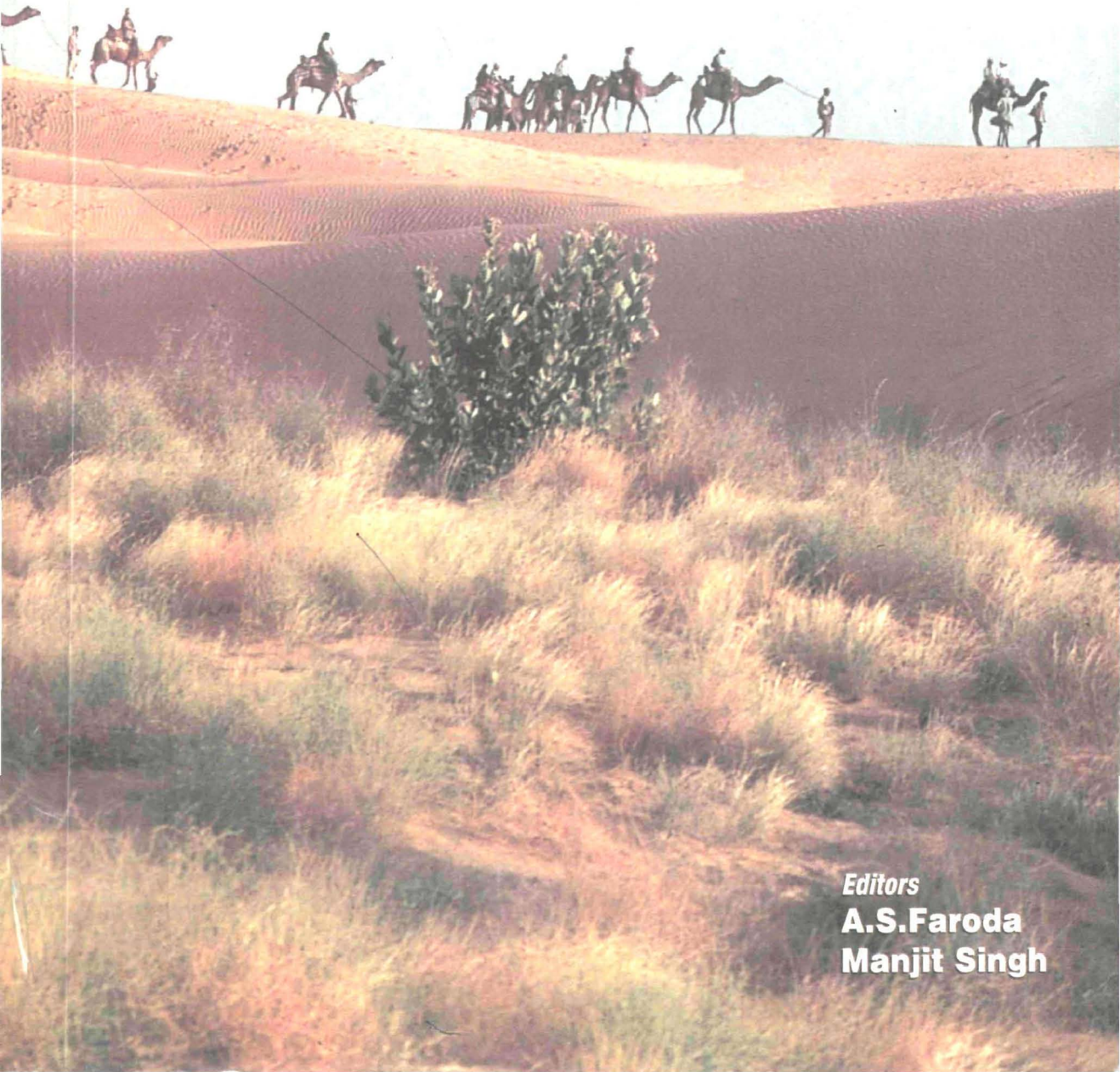


# **Fifty Years of Arid Zone Research in India**



*Editors*  
**A.S.Faroda**  
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# **Fifty Years of Arid Zone Research in India**

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# Preface

During the years of green revolution the emphasis on increasing food production had been on irrigated lands. Now the focus has shifted towards arid zones all over the world. Planners in our country, however, realised the importance of arid zone very early. Soon after independence, in 1952, a modest beginning was made by establishment of Desert Afforestation Research Station at Jodhpur that was upgraded to Central Arid Zone Research Institute in 1959. The importance given to these lands is evident from the number of institutions that have come up in this region. This book on Fifty Years of Arid Zone Research is part of Golden Jubilee Publications and is a tribute to the visionaries and number of scientists, technicians and other staff members who toiled in the barren lands with a zeal to understand every aspect of this area and came out with number of innovative technologies that have played an important role in development of the region.

Last five decades in arid region of India have witnessed unprecedented increase in human and livestock population, the consequence of which has been stress on the limited natural resources in this fragile ecosystem. The scientific approach towards understanding the problems of this unique region and development of various technologies have helped in the arrest of desertification and in achieving the goal of increasing productivity without adversely affecting the natural resources. One dimension of the approach towards understanding the arid zone had been integrated natural resource survey and monitoring. The soils, plants, natural vegetation, water, landforms, landuse, etc. were studied along with studies on socio-economic aspects. In the initial years techniques like sand dune stabilisation, shelterbelt plantations, increasing productivity of rangelands by improved management practices like fencing, contour bunding, reseeding, played important role in development of the region. Subsequently we have not only improved upon the technologies of fifties and indigenous knowledge, but also have come a long way by diversifying research and development activities covering solar and wind energy, animal management, dryland farming, watershed development, arid horticulture, improvement of crop varieties, integrated pest management strategies, post harvest technologies, etc. This book contains papers written by scientists of Central Arid Zone Research Institute, Jodhpur. As editors, we express our sincere thanks to the authors who submitted their manuscripts in time and helped in resolving any problems faced during editing. We also thank Mr. A. Angel for his secretarial assistance.

A. S. FARODA  
MANJIT SINGH

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# ARID ZONE RESEARCH - AN OVERVIEW

A.S. Faroda

The Planning Commission in its First Five Year Plan (July 1951, page 134) devoted a paragraph on "Extension of Deserts" mentioning that recent topographical surveys show that the great Indian desert of Rajasthan has been spreading outwards in a great convex arc .... In 1952, Dr. Sunder Lal Hora, President, National Institute of Sciences of India, New Delhi in his opening remarks in the Symposium on The Rajputana Desert stated

"...that the Rajputana Desert is an important national problem which requires not only a great deal of knowledge and thought but a careful planning and suitable action. Though Governments have started taking some action already, I wonder if any one knows precisely what Rajputana Desert is, how it came into existence, what is its present behaviour and why it is spreading, if it is spreading at all. I have failed to get a proper answer either from geographers or geologists or even from biologists and archaeologists. Every one has replied that very little is known about this desert and what little we know cannot form the basis for planning for the immobilization of this desert. A great deal of research and investigation is, therefore, needed before the problem can be satisfactorily tackled."

Shri M.D. Chaturvedi, Inspector-General of Forests pointed out in this Symposium that "the Ministry of Agriculture recently appointed an *ad hoc* committee to go into the question of the immobilization of the desert." The main recommendations of this committee was "a desert research station is proposed to be set up at Jodhpur to study among other things, silviculture of indigenous vegetation, its succession and propagation; suitability of exotics; study of soils, hydrographic conditions and wind velocities." Guided by the general policy of an accelerated socio-economic development of the country using modern science and technology and looking to the special nature of the problems of the desert, the Govt. of India established a Desert Afforestation Research Station, at Jodhpur in the year 1952, which on the recommendation of UNESCO Adviser C.S. Christian from Australia, was reorganised in the year 1959 into a comprehensive, multi-disciplinary set-up, the Central Arid Zone Research Institute. Since then several other specialised organisations and agencies have come into being both under the central and state administrations and a wealth of information and technologies have been generated in the Indian arid zone.

Regional Station of Botanical Survey of India, Jodhpur was established in 1960. In the year 1972 Desert Regional Station of Zoological Survey of India was established at Jodhpur. In the

same year a research Project on Dryland Agriculture (All India Coordinated Research Project, New Delhi) was also launched. All India Coordinated Project on Rodent Control was established in CAZRI, Jodhpur in 1977. National Research Centre on Camel, Bikaner was established in 1984. This institution carried out research in camel nutrition, physiology, breed improvement and veterinary aspects. National Research Centre on Arid Horticulture, NRC Equine (production unit) and CSWRI Arid Zone Centre have also been established at Bikaner. Other important institutions which came up include Defence Laboratories, Jodhpur, Desert Medicine Research Centre, Jodhpur, Central Groundwater Board, Jodhpur, Regional Remote Sensing Service Centre, Jodhpur (Estd. 1988) and Arid Zone Forestry Research Institute, Jodhpur (Estd. 1988). AFRI comprises of Divisions of Forest Ecology, Silviculture, Forest Resource Management, Social Forestry, Tree Genetics and Breeding, Forest Protection and Non-wood Forest Products.

The Rajasthan State Government institutions include Rajasthan Agricultural University with campuses at Bikaner, Udaipur and Jobner and Agricultural Research Stations at Bikaner, Mandore (Jodhpur), Fatehgarh, Keshwana, Sriganganagar, Hanumangarh, Nagaur and Sumerpur (Pali); J.N.V. University, Jodhpur; Rajasthan Groundwater Department, Jodhpur; Forestry Training Institute; and State Remote Sensing Centre, Jodhpur. Agricultural universities in Haryana, Punjab, Gujarat, Karnataka and Andhra Pradesh are also tackling the problems of arid zone of their region.

Water has always been a major issue in arid zones. Mr. A.N. Khosla, Chairman, Central Water and Power Commission, New Delhi, in his opening speech in the symposium on Rajputana desert held in 1952 by National Institute of Sciences of India said that,

“In the field of irrigation, the importance of exploring all possibilities for conservation and utilisation of surface and ground water has been receiving the attention of the Government from very early days. As early as 1903, the Indian Irrigation Commission underlined the importance of providing suitable water facilities for agricultural and domestic purposes. To recommend the best manner in which this could be done, a consulting engineer was appointed in 1905. He made a detailed examination of the water problem of Rajasthan and recommended a number of projects, most of which have been taken up and completed by now. A more recent instance of Governmental interest in the problem is afforded by the appointment of an Expert Committee headed by Sir William Stampe by the Government of Jodhpur in 1940. Examining the situation in the former Jodhpur State, the Committee discounted the possibility of large-scale irrigation by tubewells but recommended in a greater measure the utilisation of surface and ground water in areas where the rainfall is relatively greater. As recently as towards the end of 1949, the Government of India set up a Rajasthan Underground Water Board with the primary objective of promotion and conduct of operations for exploring the underground resources of Rajasthan.”

Rajasthan canal, now known as Indira Gandhi Nahar Pariyojana (IGNP), was inaugurated in 1958. Dr C.S. Christian in his report in 1959 stated "The Rajasthan Canal project will have considerable influence on a larger area of western Rajasthan. ... The project, itself, also is likely to present a number of problems which will require investigation. ... water table, is likely to vary from place to place and will require investigation and careful watching. Many of the soils of the area are saline and so investigations will be necessary to determine the most efficient use of water compatible with salinity conditions of the area. ... There will also be need for extensive investigations to determine the best forms of production according to land type and to achieve the most efficient use of water. This will pose the question of to what extent the use of irrigated land can be combined with the use of grazing country which cannot be commanded, in an integrated and complementary system of land use." Arid zones have harsh climates and the problems facing these are not simple. The words of wisdom of Dr Hora, guiding spirit of Dr Christian and untiring work done by number of veteran scientists and their staff has made Thar desert as one of the most well studied deserts of the world. An over view of salient research findings and technologies generated in last few decades with particular reference to Central Arid Zone Research Institute, Jodhpur is presented here.

### **Natural Resource Appraisal**

Krishnan (1968) made a delineation of arid and semi-arid zones of the country based on Thornthwaite moisture index. The area with moisture index value of less than 40 was considered arid zone. Efforts have been made to sub-divide arid region using various criteria and approaches. For example, National Commission on Agriculture (1974) made 15 subdivisions based on the quantum of rainfall received during the rainy season (June to September). ICAR in the year 1979 initiated agricultural research based on the agro-climatic zones under the auspices of NARP. Of the 126 zones, 10 agro-climatic zone fall in hot arid region. NBSS&LUP (1990) divided the whole country into 60 sub-regions; arid zone of Rajasthan has two zones (viz., M9E1 and M9E2). Planning Commission of Government of India in the year 1988 launched a project on agro-climatic regions and divided the country into 15 regions. The regions (6, 8 and 14) are partly or fully present in arid zone of Rajasthan. There is need for more detailed and objective based comprehensive sub-regionalisation using modern techniques.

CAZRI has been involved in holistic and integrated survey of natural resources since its establishment and has so far surveyed approximately 0.24 million km<sup>2</sup> (i.e. about 3/4th) of the hot arid zone of India. Data of survey of natural resources viz., landform, soil, vegetation, surface and ground water, present land use and land degradation status have been integrated into a conceptual framework of Major Land Resource Units (MLRUs) for devising sustainable developmental plans. Such an appraisal has been completed for 79287 km<sup>2</sup>. Survey has been completed in 43919 km<sup>2</sup> at reconnaissance level, 197047 km<sup>2</sup> at semi-detailed level and 827 km<sup>2</sup> at detailed level. Semi-detailed survey of 4699 km<sup>2</sup> is in progress. Wasteland mapping in five districts of Rajasthan

was undertaken using Landsat TM and IRS LISS-II FCC where as much as 37.4 per cent of the geographic area (75474 km<sup>2</sup>) was wasteland. Mapping using satellite imagery revealed that 68.4 per cent area of western Rajasthan is affected by wind erosion/deposition alone, followed by water erosion (11.0%), salinity/alkalinity (2.4%) and water-logging (0.7%). About 21 per cent area is affected by desertification of severe intensity, while 40 per cent area is under moderate intensity of desertification (Singh *et al.* 1992). In the last four decades this Institute has made valuable scientific contributions for the management and judicious utilisation of various natural resources like water, soil, flora and fauna, solar energy, etc.

## **Water Management**

### **Monitoring**

Buried former streams (i.e. the courses of a number of prior drainage systems like Saraswati river as those existed in this region prior to the onset of aridity, and their subsequent disorganisation) have been identified as potential and perennial sources of ground water. Buried courses of the Saraswati river in the Kishangarh-Tanot sector of west Jaisalmer were mapped in detail using satellite imagery, and geophysical depth soundings were carried out at some promising locations.

Assessment of potential of surface water on the basis of circulatory ratio and elongation ratio in the streams, and Index Catchment Technique to assess surface water from dune landscape has been standardised. The concept of *Index catchment* as a geohydrological unit has been developed for the areas lacking integrated drainage system (Vangani and Chatterji, 1990).

### **Harvesting**

Number of approaches have been tried for water harvesting to meet the water demand in less than 200 mm zone. Improved designs of *tanka* (cistern) for capacities ranging from 10 to 600 cum, improved *nadi* with LDPE lining, and *khadin* have been developed and standardised. About 11,469 different capacity improved *tankas* with total storage capacity of 4,75,200 m<sup>3</sup> were constructed in western Rajasthan to meet the drinking and cooking water requirements for a population of 1,32,000 throughout the year.

Use of *tanka* water for 2, 4 and 6 irrigation, increased average fruit yield of *ber* by 46.4, 80.3 and 124.0 per cent and of pomegranate by 69.8, 112.5 and 191.7 per cent, respectively. Circular catchments of 1-2 m diameter for rain water harvesting in a plain land proved effective in boosting the growth of various fruit and tree plants. On sloppy lands, half moon terraces were effective. In the cultivated fields catchments sealed with plastic effectively collected rain water.

### **Conservation and Utilisation**

For conservation of water field bunding, mulching and use of bentonite clay as subsurface barrier were found effective in crop lands. Use of fly ash (15%) in sandy soils increased water

retention by 46 per cent at 0.3 MPa. *Cymbopogon jwarancusa*, *Cenchrus ciliaris* and *C. setigerus* as vegetative barriers across the slope of cultivated fields proved effective materials in conserving moisture and increasing crop production. The runoff volume was reduced between 22 per cent and 71 per cent. The fields with such barriers stored 2-13 per cent more moisture and increased the yield of clusterbean by 37-51 per cent. These barriers are easy to raise, less expensive and provide fodder during the lean period and hence are becoming popular among the farmers.

In areas facing problems of over-exploitation of groundwater, the inducement of recharge by artificial methods is very dependable technique for rehabilitation of such depleted aquifers. If the source water for artificial recharge is easily available on long term basis, the unconsolidated alluvial deposits with higher storage and transmitting capacities can be selected for storing water by artificial means for the beneficial use of the society. Artificial recharge can be accomplished by spreading or induced recharge or by injection methods. Artificial recharge by spreading method comprises increase in the surface area of infiltration, thereby allowing more surface for infiltration water. Anicut, sub-surface barrier, percolation tank, water harvesting platform, etc. are used for this purpose. Induced recharge method involves changing of natural conditions like hydraulic gradient and vertical head to allow rapid movement of infiltration waters and to allow more space of storage. In injection method water is fed directly into the depleted aquifers by providing a conduit access, such as tubewells, shaft or connector wells. Recharge by injection is the only method for artificial recharge of confined aquifer or deep seated aquifers with poorly permeability. In the artificial recharge of groundwater using pondage method, very high rate of percolation ( $44 \text{ mm day}^{-1}$ ) was observed at static water head (SWH) 3.8 m in the month of July. Desilting of pond before the onset of monsoon accelerated the percolation. While pond remained full to its capacity (depth 4.2 m), the rate of percolation had declining trend during August and September. In the month of February, 1997 (SWH 0.8 m) the rate of percolation reduced to  $4.1 \text{ mm day}^{-1}$ . Out of the total water loss of 6.33 m, percolation accounted for 85.5 per cent.

For optimal use of limited water resources, techniques of drip and sprinkler systems of irrigation for different crops have been standardised. Due to increase in yield, the initial investment on drip installation is paid of in 2-3 years by growing high value crops. Yield of tomato increased from 23 to 100, watermelon from 28 to 128, maize from 4 to 12 and long gourd from 18 to 56  $\text{t ha}^{-1}$  (Singh *et al.*, 1989). Sprinkler irrigation has been found suitable for most field crops and grasses imparting saving of 20 per cent of irrigation water.

## **Soil and Plant Management**

### **Sand Dune Stabilisation and Shelterbelts**

Sand dunes are a dominant formation in 30.6 per cent and sub-dominant associate in 34 per cent areas of the desert region. Thus, 64.6 per cent area of western Rajasthan is under the dunal activity causing setbacks to agricultural lands, roads/rail tracks, buildings and settlements, etc. In

the Indira Gandhi Nahar Project, sand blowing has created enormous problems to canal construction and maintenance.

The technique of sand dune stabilisation developed at CAZRI consists of (a) fencing of the area, (b) establishment of micro wind breaks on the windward side of the dune in 5 m chess board pattern or in 5 m parallel strips, and (c) sowing of grasses and transplanting of trees and shrub species with the onset of monsoon.

For raising micro-wind breaks, locally available brushwood materials like *Leptadenia pyrotechnica* (Khimp), *Ziziphus nummularia* (Pala), *Crotalaria burhia* (Sania) and *Panicum turgidum* (Murath) can be used. Suitable tree species for sand dune stabilisation are: *Acacia tortilis*, *Prosopis juliflora*, *Prosopis cineraria*, *Acacia senegal*, *Parkinsonia articulata* and *Tamarix articulata*. Among grasses, *Lasiurus indicus* and *Cenchrus ciliaris* and among creepers *Citrullus colocynthis* are most suitable. Aerial seeding technique has also been employed for mass stabilisation of sand dunes (Kumar and Shankarnarayan, 1988).

Wind erosion is one of the foremost problems of the desert region. Both the areas from where the sand blows and where it is deposited, are turned into wastelands. Plantation of shelterbelts is basic to any management programme in the desert region. This is because wind action on the soil surface has to be controlled before stepping into other practices including those involving agricultural activity. Five row or three row shelterbelts, depending upon the magnitude of the problem, with staggered planting and in pyramidal shape have been recommended. Suitable shrub species for flank rows are *Acacia bivenosa*, *A. ampliceps*, *Ziziphus mauritiana* and *Calligonum polygonoides*. For central rows the suitable tree species include : *Acacia nilotica*, *A. tortilis*, *Cassia siamea*, *Albizia lebbek* and *Prosopis juliflora*.

### Afforestation of Rocky and Mined Areas

Nearly 8.8 per cent of the area surveyed in western Rajasthan is occupied by bare rocky/semi-rocky hill terrain and rocky out-crops known as *magras* in local parlance. The technique for plantation on such habitats to provide them with some vegetative cover is now available. *Acacia tortilis*, *Prosopis juliflora*, *Acacia senegal*, *Grewia tenax*, *Anogeisus rotundifolia* and *Euphorbia caducifolia* are some of the suitable tree species for such sites.

The rehabilitation technique standardised for gypsum and limestone mined areas involves determination of an optimum combination of water harvesting technique, soil profile modifications and plant species. *Acacia senegal*, *Prosopis juliflora*, *Tamarix aphylla* and *Cercidium floridum* grown in microcatchments and inward sloping bench terraces for water harvesting techniques proved promising.

Work on the rehabilitation, management and utilisation of rocky rangeland for sustainable production has been under taken at Range Management and Soil Conservation area Bhopalgarh. The reseedling of *Cymbopogon jwarancusa* and *Cenchrus setigerus* succeeded the best on the barren rocky surface (0-10 cm soil depth) and *Dichanthium annulatum* and *Cenchrus ciliaris*

established and produced higher forage on lands having soil depth 10-20 cm. The reseeded of these grasses increased herbage yield during last 8 years (1988-95) by 140 per cent over protected natural pasture.

Different tree species have been identified for rehabilitation of saline lands. These include: *Atriplex* sp., *Haloxylon* sp., *Tamarix articulata*, *Prosopis juliflora* and *Salvadora oleoides*.

## **Arid Horticulture**

### **Jujube (*Ziziphus mauritiana*)**

Improved varieties of *Ber* (Gola, Seb and Mundia) identified by CAZRI have made a big impact in semi-arid and arid regions. Depending upon rainfall, these varieties yield 320-400 q ha<sup>-1</sup>. These varieties of *ber* are, however, susceptible to fruitfly (*Carpomyia vesuviana*). Fruitfly resistance from *Tikadi* is being transferred to cv. *Seb*. Propagation technique of *Ber* through budding, control of *ber* fruit fly, water harvesting through microcatchments, optimum spacing, fertiliser requirement, post-harvest technology, etc. have been standardised.

### **Pomegranate (*Punica granatum*)**

Cultivar Jalore-seedless of pomegranate was identified, and recommended for commercial cultivation in arid and semi-arid regions. It has deep red aril colour, more juice content (50-54%), soft seeds and higher yields (25-30 kg plant<sup>-1</sup>) and is less prone to cracking. Agrotechnique for its cultivation has been standardised. Irrigation through drip system (8 lit per hour, 2 hours daily) during flowering and fruiting increased yield to the tune of 146 per cent over basin system with considerable reduction in fruit cracking. Propagation technique using semi-hard wood cuttings has been standardised.

### **Bael (*Aegle marmelos* L.)**

Evaluation of Bael cultivars revealed that cultivars Dhara Road and Faizabadi Local are performing better with higher yield (60-70 kg plant<sup>-1</sup>) and big size of fruits (2-2.5 kg). Propagation techniques of Bael by budding has been standardised.

### **Aonla (*Emblica officinalis*)**

Evaluation of Aonla cultivars revealed that cvs. Kanchan and Krishna are promising in terms of optimum growth and yield. The cultivar Kanchan is having medium size fruits with heavy bearing and producing on an average 155 to 175 kg fruits per plant under limited irrigation water in arid regions. Propagation techniques of Aonla by budding has been standardised

## **Post Harvest Technology**

Methods and recipes have been standardised for the preparation of squash, jam and preserve of *ber*; squash, jelly, and anardana of pomegranate; jam, preserve and shreds of aonla; and squash, preserve and jam of bael.

## Tree Introduction and Improvement

CAZRI has paid considerable attention to the introduction and selection of fast growing exotic tree and shrub species from various isoclimatic regions of the world. Among 112 *Eucalyptus* spp, 75 *Acacia* spp and 90 miscellaneous ones introduced and evaluated, *Eucalyptus camaldulensis*, *E. terminalis*, *Acacia albida*, *A. tortilis*, *A. bivenosa*, *A. ampliceps*, *A. eriopoda*, *Colophospermum mopane*, *Dichrostychnus nutans*, *Prosopis* sp. (Peruvian), *P. alba*, *P. chilensis*, *Hardwickia binata*, and *Pongamia pinnata* have shown promise in Indian arid zone.

Plus trees of *Prosopis cineraria*, *Tecomella undulata*, *Acacia albida*, *A. senegal*, *A. nilotica* subsp *cupressiformis* and *A. tortilis* subsp *raddiana* have been identified. Progeny trials and seed orchards of these species have been established. Genetic polymorphism in natural populations and mating systems have been investigated using isoenzyme markers.

Methods for macro-propagation of plus trees of *Prosopis cineraria* have been developed and utilised for establishment of clonal seed orchard. Exotic *Prosopis* species have been successfully propagated through vegetative means. Vegetative propagation techniques for multiplication of female plants of Jojoba in mist-chamber have also been standardised. Non-thorny clones from exotic collections of *Prosopis* species have been identified. Thorny stocks of *P. juliflora* have been transformed into non-thorny types by cleft grafting with non-thorny shoots.

## Micropropagation

Protocols for *in-vitro* micropropagation of date-palm using apical meristem from off shoot for production of callus, *P. cineraria* using shoot and root segments for production of primary/secondary shoots, and *Simmondsia chinensis* using coppice shoots as explant have been developed (Kackar *et al.*, 1992,1993). Hardened plantlets of *P. cineraria* have been successfully transferred to the field. A new technique for raising monoxenic culture of root knot nematode through tissue culture has also been standardised.

## Non-conventional Trees

Non-conventional trees and shrubs have been identified for their potential economic value. These include oil yielding plants like Jojoba (*Simmondsia chinensis*) and *Citrullus colocynthis* and plants of medicinal and industrial value like *Balanites aegyptica*, *Commiphora wightii*, *Euphorbia antisyphilitica*, *Haloxylon* *Cassia angustifolia*, etc. Number of compounds of industrial value have been isolated from under utilised and unexploited plants. These include:

- Diosgenin (0.8%) - an anti-fertility agent - from fruits and vegetable oil (43-45%) from seeds of *Balanites aegyptiaca*.
- Candelilla wax from *Euphorbia antisyphilitica*
- Rotenone from *Tephrosia villosa*
- Triaccontanol from *P. cineraria* and *P. juliflora*
- Scopolamine from *Datura innoxia*



- Cineole from *Eucalyptus viridis*
- Essential oils from leaves of *Cymbopogon martinii*
- Oleo-resins from *Commiphora wightii* and edible gum from *Acacia senegal*.

## Grassland Improvement and Management

Grasses are ideally suited for the desert ecosystem. CAZRI has screened a number of promising strains of desert grasses, viz., *Cenchrus ciliaris* (Anjan), *Lasiurus indicus* (Sewan), *Cenchrus setigerus* (Dhaman), *Dichanthium annulatum* and *Panicum antidotale*. Improved strains with respect to dry matter and seed yield of *Cenchrus ciliaris*, *Cenchrus setigerus* and *L. indicus* have been released for commercial cultivation in arid regions.

Technology for bulk grass seed production and its pelleting has also been developed. Pellets are prepared by pellet making machine having rotary tyre device. Pellets 0.5 cm in diameter containing 2-3 spikelets, are prepared by mixing seeds of grass, clay, FYM and sand in the ratio of 1:30:5:5.

The overall productivity of grasslands has been increased by using genetically improved strains, incorporating perennial legumes like *Lablab purpureum*, *Clitoria ternatea*, *Stylosynthes* spp. and by application of 20 kg ha<sup>-1</sup> each of N and superphosphate. Inclusion of top feeds like *Ziziphus nummularia*, *Dichrostychnus nutans*, *Colophospermum mopane*, *Prosopis cineraria*, etc. further add to the productivity and carrying capacity of the rangelands. Soil working by creating contours, furrows and bunds on sloppy lands encourage regeneration of grasses and increase the range productivity.

## Dryland Farming

Suitable dryland crops varieties matching with the rainfall pattern of the region and efficiently utilising rainfall and stored soil moisture have been developed at CAZRI. These include Maru guar, Maru moth, Maru Kulthi-1 and CZ-IC-923 variety of pearl millet. The agro-techniques of these varieties have been standardised. Number of promising varieties of various crops have also been developed by Universities of the region. Some of these are: pearl millet - MH 179, HHB 67, HHB 68, GHB 183, GHB 1399; moth bean - RMO 40, Jadia, Jwala, IPCMO 880, T 88; mung bean - Asha, S-8, K851, RMG 131; clusterbean - FS 277, HG 75, HG 182, RGC 936, HGS 365, PLG 119, PLG 85, Suvidha, Naveen; mustard - Pusa bold, T 59, Kranti, CR 15, etc.

For farmers having a choice of pearl millet alone, triplet planting or border cropping system proved better in production than sole cropping besides saving 1/4th fertiliser input. Inter-cropping of pearl millet with greengram/clusterbean reduced the risk of crop failures and was found remunerative over sole cropping. Technology involving use of FYM over seed furrows in crust prone light textured soils has been developed to mitigate the adverse effects of crust formation on germination of pearl millet. The Soil Plant Air Water (SPAW) model has been used for estimating soil moisture stress and grain yields of pearl millet.

Many of the water resources in this region are highly saline. In some cases salinity of ground water is low but these contain higher amount of residual sodium carbonate (RSC). Irrigation with such water results in the development of sodicity in the soil. Gypsum applications have been worked out for wheat, raya, *Cumin*, chillies and other cash crops. Studies on the farmers' fields revealed that the soils degraded due to irrigation with high RSC water in Buriwara, Janiana and Kuship villages could be restored to their normal productivity by application of gypsum @ 100 per cent of soil gypsum requirement ( $G_2$ ) + the quantity of gypsum needed to neutralise RSC in excess of  $5 \text{ me L}^{-1}$ .

Sulphur mixed urea, 1:8 (sulphur:urea) for pearl millet and 1:6 for oilseed crops is recommended for reducing volatilisation losses and increasing N-use efficiency. It is suggested that 50 per cent of the recommended dose of N to pearl millet is applied as FYM/compost (basal dressing) and remaining 50 per cent as urea (top dressing) depending upon the rainfall to reduce the risk involved in arid agriculture. Inclusion of grain legumes in crop rotation save 20 kg fertiliser  $\text{N ha}^{-1}$  to pearl millet.

Efficient nitrogen fixing bacteria i.e. *Rhizobium* for clusterbean and moth bean and *Azospirillum brasilense* for pearl millet and grasses have been identified for enhancing biomass production.

Both plants and soil micro-organisms contribute towards building up of phosphatases in arid soils. Soil organic phosphorus (about  $100 \text{ kg ha}^{-1}$ ) can be mobilised by employing Phosphate Producing Fungi (PPF) for higher plant production (Tarafdar *et al.*, 1995). *Aspergillus ferreus*, *A. mugulosus*, *A. fumigatus* and *A. niger* were identified as most efficient phosphatase producing fungi in arid soils. Inoculation of these fungi enhanced the uptake of P, N, K, Ca, Mg, Fe and Zn in plants.

VAM fungal infections of *Glomus* and *Gigaspora* were found on the roots of almost all arid plants with varying density varied from one species to the other. Performance of arid legumes including trees is better upon inoculation with VAM fungi. *Glomus mosseal* has been identified as most efficient VAM fungi for arid crops and *G. fassiculatum* for arid trees and horticultural plants.

## **Pest Management**

Pest flora damaging crops, grasses, tress and horticultural crops has been surveyed. Integrated disease and pest control measures for various crops have been developed. *Neem* and *Calotropis* extracts have also been effectively used for control of number of pests.

CAZRI's field-tested schedule for the control of the *ber* fruitfully comprises one spraying of 0.05 per cent endosulfan in mid-October followed by one of quinalphos (0.03%) three weeks later, and finally by a spray of carbaryl (0.1%) six weeks after the second spray. Soil treatment with 5 per cent aldrin dust and 2 per cent methyl parathion dust should be an added advantage.

Effective measures for the control of the major termite pests of forestry plantations (*Odontotermes brunnes*) and of wheat crop (*Microtermes tenuignathus*) have been devised.

The pearl millet crop is susceptible to downy mildew. The disease may be effectively controlled by adopting biological control agents like *Trichoderma harzianum* and *Aspergillus flavus*, and management conditions, like ES-NW row orientation or by taking it as an intercrop with clusterbean. Soil solarisation technique for the control of soil borne diseases was standardised (Lodha, 1995).

In clusterbean measures to control bacterial blight by treatment with streptocycline (seed treatment 0.025%; spray 0.01%) and dry root rot were evolved. Source of resistance (RBC 471 and Kutch 8) against dry root rot was identified and incorporated in the breeding program and agronomically superior resistant strains (CAZG 27-1 and CAZG 55-1) were developed. Integrated practices for management of dry root rot were developed by incorporating seed treatment with carbendazim, resistant strain, keeping low density of plants (1-4 lac ha<sup>-1</sup>) and through incorporating 10 t ha<sup>-1</sup> FYM in the soil.

Rodents cause serious damage to food grains, grasses/pastures, stored materials, orchards, natural vegetation and tree plantations. Studies on rodent ecology have generated valuable information with respect to optimum seasons for control operation, effective way of bait placement and required distance between bait stations. Pearl millet flour mixed with ground nut oil (3%) and zinc phosphide content of 2 per cent has been found to be the most effective poison bait for desert rodents.

## **Alternate Land Use Systems**

With the uncertain rainfall and frequent droughts that prevail in the desert region it is increasingly realised that tree and grass systems can provide the much desired production stability in this soil-climatic region. Silvi-pastoral and agri-pastoral system have been evolved for this purpose. *Prosopis cineraria*, *Hardwickia binata*, and *Tecomella undulata* have been found suitable for plantations in range/pasture lands. Strip cropping of grain legumes - mung bean, clusterbean, moth bean and desert grasses - *Cenchrus ciliaris* and *Lasiurus indicus* was found suitable.

Agroforestry and agri-horticulture systems involving *Z. rotundifolia* + mung bean/moth bean/clusterbean and *Z. mauritiana* + mung bean/clusterbean, respectively have been found environmentally protective and economically viable systems even during drought years and are recommended in rainfall zone above 300 mm. The yield of mung bean under *A. nilotica* and *A. albida* with 10 x 10 m<sup>2</sup> spacing were at par with the control. A silvipastoral system of *Z. rotundifolia* + *C. ciliaris*/*L. indicus* has better tree/grass compatibility and thus could be recommended for areas having less than 300 mm annual rainfall

Studies on integrated farming systems have shown that besides producing multifarious products (fruits, fuel, fodder and timber), could also result in improvement in resource base animal productivity and sustained economy. Agro-horticulture system besides producing normal yields of dryland crops clusterbean (400 to 600 kg ha<sup>-1</sup>) mung bean (400 to 800 kg ha<sup>-1</sup>) cowpea

(700 to 1000 kg ha<sup>-1</sup>) also gave fruit yield (2 to 4 t ha<sup>-1</sup>) and fuel (1.5 to 2.5 t ha<sup>-1</sup>) with a sustenance of 800 to 1000 goat/sheep days ha<sup>-1</sup> year<sup>-1</sup>. Similarly, crop production with *P. cineraria* enhanced productivity of dryland crops by 15 to 20 per cent. Horti-pastoral system involving *C. ciliaris* + Jujube cv Gola yielded 33 q of grass and 25 kg of grass seed per hectare in addition to 29 kg ber fruits per tree. This resulted in 15 per cent increase in income over pure orchards.

## **Watershed Management**

Watershed development and soil conservation has been an important arena for holistic development of arid zone agriculture. Besides DDP and DPAP, the special schemes in Rajasthan include employment assurance scheme and Jawahar Rozgar Yojna. It is estimated that about half of the total land of the country is suffering from the degradation. To tackle the problem of these wastelands, National Wasteland Development Board was set in the year 1985. In Rajasthan revised NWDPR (National Watershed Development programme for rainfed areas) was commenced as a centrally sponsored programme by GOI in 1990-91. At present scheme covers all blocks where less than 30 per cent of area is irrigated. 204 watersheds in 190 Panchayat Samitiés in the state have been covered under the scheme. The Integrated Watershed Development project was launched in four districts of Rajasthan viz., Ajmer, Bhilwara, Jodhpur and Udaipur with the world bank assistance w.e.f. November 1990. Livestock development programme has been an integral part of the NWDPR and IWDP.

CAZRI has been engaged in development of the Jhanwar watershed comprising of 1200 ha area as a model watershed for the arid areas. About 60 ha of community grazing land was developed as an ideal pasture for animal grazing. Besides 6 to 7 t of grass seed year<sup>-1</sup>, the land which was lying almost barren could yield a good quality dry forage of 2 to 3 t ha<sup>-1</sup>. Improved dry farming technology including the sustainable land use systems were widely adopted by the farmers.

The rocky and gullied catchment treated with various physical and biological land treatments resulted in increase in the biodiversity upto 813 per cent. The water conservation structures resulted in rise in ground water recharge at the rate of 0.75 m year<sup>-1</sup> in the watershed. An additional 3240 m<sup>3</sup> of surface water potential were generated in the watershed by farm ponds of 271 m<sup>3</sup> capacity and which was found to be economic (R/C = 1.66) in raising agro-horticulture system.

The programme has resulted in an overall resource conservation, and thereby increased crop productivity by 25-30 per cent with a sustained socio-economic development. This watershed was given the UNEP award (1996) "saving the drylands" for outstanding contribution in combating desertification and controlling land degradation in dryland environments.

## Livestock Management

### Non-conventional Silage

The shortage of fodder in arid regions and the resulting dependence of desert livestock on poor quality feeds and agricultural by-products of low crude protein affects survival, productivity and ultimately desert ecosystem. To manage the problem of availability of feed during lean periods and scarcities, a "Non-Conventional Silage" has been developed. Unlike traditional silage, non-conventional silage making does not require green fodder of high nutritive value, but can be made from crops and grasses harvested at maturity, poor quality agro-by-products like straw, stovers, etc. and even tree leaves with incriminating taste, texture, or organic wastes of domesticated animals.

Since the non-conventional ensiling harnesses microbial energy, it is simple with basic manual operations of fodder pre-treatment, filling and storage under anaerobic conditions in silos. Innovative use of cheap and easily available additives like molasses/animal grade jaggery, urea and butter-milk for carbohydrate, NDN and starter culture source, make the process economic with treatment cost of barely 7-10 paise, kg<sup>-1</sup>. The benefits are manifold including increase in crude protein content to 3.5-4.5 fold, 65 per cent replacement of concentrate feed thus reducing ration cost and 35 per cent increase in milk production with enhancement of milk fat by 40 per cent.

Tumba (*Citrullus colocynthis*) seed cake, a by product of oil industry containing 16 to 22 per cent protein, is another non-conventional feed successfully used for feeding heifer @ 250 g day<sup>-1</sup> (12.5 % of the concentrate ration). It results in net saving of 25-30 per cent feed cost of cattle.

High tannin content in many top feed is a limiting factor for its utilisation by domestic animals. Tannins from *P. cineraria* leaves could be removed by heating them with 0.5 N aqueous solution of sodium bicarbonate.

### LPM

Various ICAR institutes and veterinary colleges are involved in LPM. Promising technologies like improved management practices for improving production and reproduction of sheep and wool, improved breeds for wool and mutton like Avikalīn, lamb feeding system for economic mutton production, broiler rabbit rearing for meat production, artificial insemination and embryo transfer in sheep have been developed at CSWRI, Avikanagar. Similarly package of practices for improvement of reproductive efficiency in the field camels have been prepared by NRC on Camel.

At CAZRI, scientifically managed Tharparkar heifers calved at the age of 35 months under arid conditions. Milk production performance and quality of milk was found to be better.

Low blood potassium and low erythrocyte glutathione levels (LK-G-SH<sup>L</sup>) sheep and goats classified on the basis of blood polymorphic combination showed lower body water turnover rate indicating their more adaptivity than LK-G-SH<sup>L</sup> animals to desert environment.

A mineral mixture (IBOWMIX) developed to achieve faster body growth rates given daily to animals through drinking water has shown positive results as indicated by body weight gain, wool production and early maturity in sheep and goats.

The productivity and adaptability of various goat breeds like Marwari, Parbatsar, Shekhawati, Jakhrana, Kutchi, Barbari and Jamunapari were studied.

## **Energy Management**

The solar appliances developed by the Institute for adoption in the rural as well as urban areas include: (i) Collector-cum-storage type solar water heater, (ii) Solar water heater-cum-still, (iii) Solar water heater-cum-steam cooker, (iv) Solar cabinet dryer with auto regulation of temperature, and (v) Solar candle machine and poly-houses, etc. These have been widely used by small entrepreneurs, public sector undertakings, Govt. departments and individual farmers.

Different solar dryers of various capacities developed and tested for drying fruit and vegetables like spinach, coriander, tomato, okra, mint, onion, carrot, sweet potato and green chillies, industrial products like magnesium carbonate, sodium alginate, sugar coated aniseed and salt coated aonla. Based on this design, a solar dryer of 110 kg capacity has been installed by an entrepreneur.

Solar candle machines technology has already been transferred to NRDC, New Delhi for commercialisation. Solar cookers of different designs have been developed for domestic and community purposes. Use of transparent insulation material (TIM) in solar cooker was found preparing animal feed was also developed and tested. The community solar cooker based on energy technology has been adopted by "Air Force Women Welfare Association (AFWWA), Jodhpur.

Annual energy saving from 1 m base area of different type of solar dryers indicated that most of the dryers can save more than 200 kWh year<sup>-1</sup>, while, the inclined solar dryer can save 306 kWh year<sup>-1</sup>:

A solar cooker for animal feed has been designed, developed and field tested (Nahar *et al.*, 1994). The device can be used to boil 10 kg of animal feed per day, sufficient for about 5 cattle. The cooker is made up of locally available materials e.g. clay, pearl millet husk and horse excrete. It can be constructed even by an unskilled village lady except cover glazing and cooking utensils which are to be fabricated by a carpenter. The animal feed with the water is kept in the morning in the cooker and feed is ready by 3.00 PM. The cooker has been installed in a village Paladi Mangalia under Institute Village Linkage Programme of the ICAR. The farmers are benefited by the use of this cooker.

A light weight solar PV duster with storage facility was developed to dust insecticide powder on crop. In this unit, the PV panel provides shade to the worker and electricity to run the device. This system can also be used for lighting in addition to plant protection. A solar PV pump operated drip irrigation system has been installed to carryout simulated studies for growing

orchards in arid region. Suitable LPC drippers compatible to the variation of solar PV output were identified and used in the system for growing 100 pomegranate plants. The two row planter has been designed and developed to facilitate mechanisation in experimental sowing.

## ***Socio-economic Investigation and Evaluation***

To develop need based technology, it was realised, since very beginning, that social and economic aspects of the desert dwellers must be thoroughly investigated. Surveys on these aspects have been carried out in different regions of arid Rajasthan. Evaluations are also regularly made about the socio-economic acceptability and techno-economic feasibility of various recommendations given from time to time.

Cost benefit analysis shows that various techniques like, pasture based livestock management, afforestation using fuel/fodder tree species, agro-horticulture, agri-pasture, sand dune stabilisation etc. have positive net present value and annuity in a comparable system prevalent in arid and semi-arid areas. The internal rate of return on adopting these technologies are favourably comparable with the long term rates of return on borrowing from banks. The only constraint is the longer gestation period associated with these technologies.

Considerable development efforts have been made for rural development since independence. Number of technologies developed in the zone were transferred through developmental programmes like Drought Prone Area Programme (DPAP), and Desert Development Programme of Government of India initiated in 1972 and 1978, respectively. The main thrusts of these programmes has been integrated development of land, water and other natural resources.

Besides trainings by ICAR institutes, SAUs, and state departments through several programmes, KVKs have played important role in imparting trainings to the farmers, rural women, unemployed youth, etc. In arid Rajasthan first KVK was started in 1976 at Fatehpur. KVKs of Fatehpur, Jhunjhunu, Sikar, Bikaner, Jaisalmer, Jalore and Nagaur are supervised by RAU, Bikaner; KVKs at Jodhpur and Pali are supervised by CAZRI and those at Barmer, Churu, Sangaria and Sri Ganganagar are supervised by voluntary organisations.

The increase in human and livestock population in arid zone is much higher than the rest of the country. The very fact that desert has been able to sustain all these pressures and of late there is some increase in the vegetative cover, is a testimony to the contributions and impact of agricultural research and development in this region.

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# CLIMATIC FEATURES AND CROP PRODUCTION

A. S. Rao and R.S. Singh

The Indian hot arid zone extends in an area of 0.32 million km<sup>2</sup> in parts of western Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, Andhra Pradesh. These areas experience an annual rainfall between 100 and 500 mm with a coefficient of variation varying from 40 to 70 per cent. Low and erratic rainfall combined with extreme temperatures result in frequent crop failures and considerably affect the agricultural economy in the region. Occurrence of consecutive droughts leads to wind erosion and creeping of the sand dunes covering fertile agricultural lands and blocking of roads and rail tracks. In such harsh climates with limited resources, there is a need for suitable technologies to combat drought impacts and managing limited rain-water for increasing crop production.

The agrometeorological research in Indian arid zone was initiated at the Central Arid Zone Research Institute in 1962. Since then, considerable research in the fields of climatology, micro-meteorology, evapotranspiration, crop-weather modelling, incidence and spread of droughts and floods, sand dune dynamics, etc. during the past four decades was conducted. Six agrometeorological observatories in the arid Rajasthan are under operation and the weather data being documented and supplied to several researchers. Using an aridity index, the boundaries of the principal hot and cold arid zones of India (Krishnan, 1968a, b) have been delineated (Table 1). The study showed that 3,17,090 km<sup>2</sup> geographical area comes under hot arid, whereas 70,300 km<sup>2</sup> comes under cold arid conditions.

Table 1. Distribution of the arid areas in India

State	Area (km <sup>2</sup> )	Percentage to the total arid area
<b>Cold arid zone</b>		
Jammu & Kashmir	70,300	
<b>Hot arid zone</b>		
Rajasthan	1,96,150	61.8
Gujarat	62,180	19.6
Punjab	14,510	4.6
Haryana	12,840	4.0
Maharashtra	1,290	0.4
Karnataka	8,570	2.7
Andhra Pradesh	21,550	6.9
<b>Total</b>	<b>3,17,090</b>	

## ***Climatic Features of the Indian Arid Zone***

### **General Atmospheric Circulations**

The Indian arid zone comes under the influence of the sub-tropical high pressure belt extending from north-west Africa to Asia. The atmospheric temperatures begin to rise from mid-March onwards and they attain a peak during May when temperatures as high as 46°C are occasionally recorded. During this period, the high pressure system over the region is replaced by a heat low. The high atmospheric temperatures associated with the sparse vegetation over the whole of the area give rise to dust raising winds and dust storms which create considerable problem of wind erosion. The wind direction during this season remains predominantly south westerly and the wind speeds are also at their peak during this season.

The south-west monsoon sets in over the region during the fag end of June. However, the monsoon circulation is shallow, limited to about a kilometre or so and is over run by dry air from north circulating anti-cyclonically, inhibiting proper cloud development over the region. Due to this, the region receives low rainfall with a highly variable distribution in spite of the presence of high precipitable water content in the atmosphere comparable to those recorded at some of the high rainfall regions of the country. Rainfall over this region mostly occurs in spells associated with depressions across the country and recurring over the Rajasthan region.

The monsoon withdraws from the region by the second fortnight of September and clear skies prevail and secondary maxima in air temperature is observed during the post-monsoon season. The day-time temperatures, however, begin to decrease from mid-November onwards and winter sets in slowly over the region.

### **Rainfall Features**

The mean annual rainfall over the region varies from more than 600 mm in the south-eastern parts to less than 150 mm in the north-western and western parts of the arid region (Table 2). More than 85 per cent of the total annual rainfall is received during the south-west monsoon season (July to September), mainly under the influence of depressions passing across the Rajasthan. The eastern parts of the state get rains by the last week of June and gradually cover the entire arid region by middle of July. The withdrawal phase of monsoon again starts in the extreme western part by middle of September and retreats by the end of September. The rainfall received is at its peak during August and generally comes to an end by the second fortnight of September. Thus, the rainy season over the region varies from 50 days in the western part to 80 days in the eastern part thereby showing that more length of crop growing period due to favourable rainfall conditions prevail in the eastern as compared to the western Rajasthan. A small quantum of rainfall, constituting about 7 to 10 per cent of the annual, is received during the winter season under the influence of western disturbances. Small quantities of rainfall are received occasionally during the hot weather period also from circulation systems associated with dust/thunderstorm activity.

Rainfall is low and erratic and the coefficient of variation of annual rainfall varies from 37 per cent to more than 59 per cent (Table 2). The high inter-annual variability of rainfall is the major single factor influencing crop and pasture yields. The variability in annual rainfall at Jodhpur (Fig. 1) shows that the low rainfall was confined to certain periods like the one occurred in 1985 to 1989, but later the trends were reversed with better rainfall conditions during subsequent years.

Table 2. Normal annual rainfall and its coefficient of variation at some locations in the Indian arid region

Station	Rainfall (mm)	Coefficient of variation (%)
Barmer	267	63
Bikaner	287	47
Churu	360	37
Ganganagar	245	53
Jaisalmer	188	64
Jalor	382	52
Jodhpur	366	52
Jhunjhunu	403	36
Nagaur	340	53
Pali	421	49
Sikar	457	42
Hisar	446	45
Bhuj	342	65
Kandla	433	52
Nalia	452	81
Lakhpat	338	79
Jamnagar	490	50
Anantpur	562	50

The annual rainfall in arid Kachchh region (Gujarat) varies from 338 mm at Lakhpat to 452 mm at Nalia. The number of rainy days varies from 12 at Khavada the interior plain to 20 days at Kandla in coastal areas. The coefficient of variation of annual rainfall at Nalia is 81 per cent whereas at Bhuj it is 66 per cent. The growing season commences from by 25th June and continues upto 15th July (53% of occasions). Studies on the amount of assured rainfall at 33 per cent probability level indicated higher risk in crop production in this region (Singh *et al.*, 1991).

Rainfall distribution models of Jodhpur (Ramakrishna *et al.*, 1988) indicate that out of 97 years (1901-97), 52 years at Jodhpur recorded average to above average (350 to more than 400 mm) rainfall which indicates that one in two years receives substantial rainfall. About 19 years

recorded 250-350 mm rainfall. Appropriate crop production technology can stabilise yield levels in such years. The rest 26 years received less than 250 mm. In such years crop production is severely impaired. This indicates that with appropriate crop production and management practices satisfactory crop yields can be achieved from Jodhpur region in 2 out of every 3 years. This would mean developing a viable crop management technology to overcome the specific drought situations that occur on an average once in two years either during the seedling establishment stage (15% probability) and flowering and reproductive stage (32% probability) adversely affecting crop production. The crop growing period in the arid Rajasthan varies from 7 to 14 weeks depending upon the location and type of soil (Rao *et al.*, 1994).

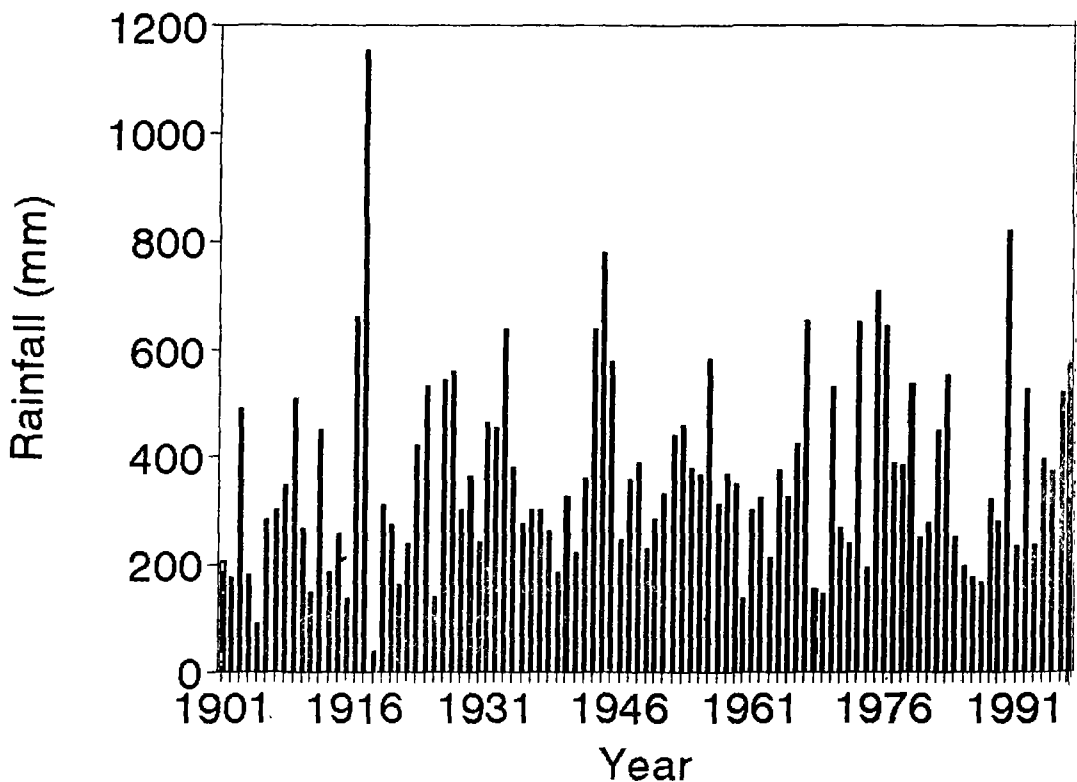


Fig 1. Annual rainfall variation at Jodhpur

Another important feature of the rainfall distribution with respect to crop production is the occurrence of sowing rains. Even though the normal period of occurrence of sowing rains (>25 mm per week) over the area is during 1st to 15th July, rainfall records of the Indian arid zone show that the sowing rains can be delayed as late as 1st week of August in the western parts and 3rd week of July in the eastern parts of the western Rajasthan. The sowing rains on the other hand

can also occur at times as early as 1st week of June in the eastern parts and 2nd week of June in the western parts. Such aberrant weather situations of early or late commencement of sowing rains lead to a larger variability in the year to year crop productivity.

### **Air Temperatures**

The Indian Thar desert is subjected to extreme temperatures between  $-5.7$  to  $50.0^{\circ}\text{C}$ , considerably influencing the vegetation demanding higher water requirements. The eastern region of the arid Rajasthan generally records slightly lower day and night temperature compared to the western part and a east-west gradient in temperature pattern exists over the area. The mean maximum temperature over the region during the winter varies from  $24.0^{\circ}\text{C}$  in the east to about  $26.5^{\circ}\text{C}$  in the west. The highest temperatures recorded during the winter months however, vary from  $26.5^{\circ}\text{C}$  in the eastern part to  $33.3^{\circ}\text{C}$  in the western part.

The temperatures increase sharply during the hot weather period. The mean maximum temperatures during this period vary from  $36.1^{\circ}\text{C}$  in the east to  $38.3^{\circ}\text{C}$  in the west while the mean highest day time temperatures vary between  $36.0^{\circ}\text{C}$  and  $42.9^{\circ}\text{C}$  in the east to  $38.8^{\circ}\text{C}$  and  $45.5^{\circ}\text{C}$  in the western most part of the arid region. Occasionally temperatures above  $46^{\circ}\text{C}$  are recorded when a heat wave passes across the region. The day time temperature decreases sharply with the onset of monsoon over the region. The mean maximum temperatures during this period vary from  $32.1^{\circ}\text{C}$  to  $34.5^{\circ}\text{C}$  across the area. Temperatures, however, increase intermittently when 'break monsoon' conditions prevail leading clear sky conditions.

The temperatures rise once again with the recession of monsoon from the region and often maximum temperatures varying between  $35^{\circ}\text{C}$  to  $38^{\circ}\text{C}$  are recorded over the region during October. The slope of the isotherms during the post monsoon season is from north-east to south-west. The mean maximum temperatures during this season vary from  $30.9^{\circ}\text{C}$  in the east to  $33.5^{\circ}\text{C}$  in the west.

The mean minimum temperatures over the area are the lowest during the winter season varying from  $9^{\circ}\text{C}$  in the east to about  $11^{\circ}\text{C}$  in the west. January is the coldest month with an average temperature of  $6.5^{\circ}\text{C}$  to  $9.5^{\circ}\text{C}$  while the lowest temperatures on individual days occasionally reach to less than  $3^{\circ}\text{C}$ . The minimum temperatures are comparatively higher in the western part compared to the central and eastern parts.

The minimum temperatures increase sharply to  $23^{\circ}\text{C}$  to  $24^{\circ}\text{C}$  during the hot weather period especially from April onwards and the temperatures are the highest ( $27^{\circ}\text{C}$  to  $28.5^{\circ}\text{C}$ ) in June. The minimum temperatures remain higher during the monsoon season also and due to the prevalence of lower day time temperatures during this period, the diurnal temperature range is the lowest in the monsoon period. The night time temperatures begin to decrease sharply from October onwards to less than  $20^{\circ}\text{C}$  and the decrease continues until they attain the lowest values in January. The extreme lowest temperatures recorded in western Rajasthan were  $-5.7^{\circ}\text{C}$  at Jaisalmer,  $-3.3^{\circ}\text{C}$  at Phalodi and about  $-2.0$  to  $-3.0^{\circ}\text{C}$  in the other regions.

## Soil Temperatures

The soil temperatures recorded on these sandy tracts show that the maximum surface soil temperatures reach beyond 62°C during May and June, The soil temperature, in general, remain higher than air temperature by 10°C. The diurnal range of surface soil temperatures in the dunny areas vary between 25 and 40°C during monsoon periods (Ramakrishna *et al.*, 1990b).

## Wind Regime

The wind direction over the Thar region remains predominantly south-west from April onwards upto October and generally from north-east during intermittent months. The wind speeds generally are lower over the area during the winter season. However, an east to west increasing trend in wind speed is observed across the area with the average wind speed varying from 3 kmph to 8 kmph. The wind regime starts building up along with the temperature regime from April onwards. However, peak wind speeds are recorded in June when the average wind speed across the area varies from 14.6 kmph to 18.5 kmph. The average wind speed during the hot weather season as well as the monsoon season vary from 9 kmph to 13 kmph. The wind speeds decrease sharply from October onwards and remain less than 7 kmph during the post monsoon season.

## Relative Humidity

Low relative humidity prevails during March and April months and was often less than 30 per cent. Humidity builds up sharply from May onwards and is highest during July and August when monsoon current brings in high amount of water vapours. The mean day time relative humidity during August varies from 60 to 80 per cent. The relative humidity drops sharply during October due to the withdrawal of the monsoon current from the region.

## Radiation and Duration of Sunshine

The solar radiation is generally high even in the coldest month of January with values ranging between 7.98 and 16.17 MJ m<sup>-2</sup> with a mean of 14.70 MJ m<sup>-2</sup>. During the summer months of April and May, the daily values of incoming solar radiation ranges from 8.40 to 27.30 MJ m<sup>-2</sup> with a mean of 22.05 MJ m<sup>-2</sup>. The daily duration of bright sunshine hours in the region remains above 10.0 in May and reduces to 6.6 in July and August and is above 8.8 hours in the winter season.

## Evaporation

Evaporation is low during winter months of December and January with an average rate of 5 mm per day. The evaporation rates increase sharply from middle of March onwards, along with the increase in day-time temperature and reach 15-16 mm per day by May. During the monsoon period, the evaporation is low (6 to 8 mm per day) but again increases in September onwards till December. The annual estimated potential evapotranspiration values ranges from 1600 mm in eastern parts to more than 1800 mm in the western arid Rajasthan.

## Dust Storms

The dust storm activity is another major weather hazard which not only disturbs the ecological balance of the arid region of north-west India but also creates weather changes in the arid environment. The region experience dust storms on an average 3 to 8 per year. In general, whenever the rainfall during the monsoon season was very low, there was a sharp increase in dust storm activity in the subsequent year and vice versa (Ramakrishna *et al.*, 1987). Dust particle size distribution recorded using a 100 feet micro-meteorological tower at Jodhpur showed a sharp increase in the concentration of smaller size particles in the winter period. Humidity profile during dust storm period revealed that it was lowest (39.9 to 47.4%) during the onset phase and later on it gradually increased to a maximum of 66.4 per cent at 4 m height during the withdrawal phase of the dust storm. Temperature decreased with the height during the period of dust storm prevalence. Temperature during the onset phase was highest and almost isothermal with a maximum value of 50°C at all levels in comparison to other phases of the storm (Singh *et al.*, 1992b, 1993a; Rao *et al.*, 1995a).

Dust concentration, sensible, latent heat and momentum fluxes at 1, 2, 4, 8, 15 and 30 m height were recorded using a 100 feet micro-meteorological tower installed at the Institute. A significant increase in heat-flux before the coldest day was observed one day before the coldest day between 1 m and 15 m heights and inversion conditions were experienced soon after the coldest day. The momentum flux has shown change in sign with change in the wind direction just before the occurrence of the hottest or coldest days. An increase in latent heat flux was seen on the days of rainfall followed with increase in relative humidity in the atmosphere. Mixing ratio remained higher during rainy season with peak value of  $13.15 \times 10^{-3}$  kg of water vapour per kg of air at 1 m height. It was lowest ( $4.73 \times 10^{-3}$  kg) during December. An inversion was always present during morning hours of winter months (October to March) continuously from surface to 30 m heights. But, this inversion layer breaks slowly and rises to 8 m height when ground heating starts after sunrise (Singh *et al.*, 1992c; 1993a).

## Micro-environment and Movement of Sand Dunes

A comparative study of the morphological, micro-climatic and soil moisture regimes over a stable and an unstable sand dune at Shergarh revealed that the stable parabolic dune is characterised by finer sand and the vegetation over the dune creates a buffering effect, reducing the maximum and minimum temperature difference by 1 to 3°C compared with the unstable barchan. The moisture content over the parabolic dune was comparatively less by 30 per cent as a result of moisture utilisation by vegetation. During periods of severe gusty winds, peak rates of erosion of grains upto 0.2 mm size were of the order of  $43.5 \text{ kg m}^{-2} \text{ h}^{-1}$ . The period of turbulence at the crest of the barchan was relatively higher by 23 per cent than that over the parabolic dune principally because of the barrenness of the barchan. This factor, along with the loose sand grains, led to a higher ratio of sand erosion (43%) from the barchanoid, causing increased forward

displacement of the barchan (by 7 m) than the parabolic dune (0.5 m) over a year (Ramakrishna *et al.*, 1990a). The thermal, soil moisture and wind regimes across a barchan in the western part of the Thar desert at Pokaran were studied for four years (1987-90) in relation to the geomorphological properties of the dune and its movement. The average rate of movement of the barchan during the recorded period was  $31.7 \text{ m year}^{-1}$ , but there was significant yearly variation, depending upon the rainfall condition in the previous monsoon season and the wind speed, during the current summer (Ramakrishna *et al.*, 1994).

### **Climatic Changes**

The arid region has a history of about 3000 years (Pant and Maliekal, 1987). Winstanley (1973a, b) analysed the rainfall of Bikaner and Jaisalmer of north-west India and reported that the monsoon in the arid region was favourable during 1900 to 1930 and has been unfavourable since 1970. Pant and Hingane (1988) studied the trends in rainfall and temperature during 1901-82 for the north-west India covering the regions of Punjab, Haryana, west Rajasthan and west Madhya Pradesh. Their studies showed an increasing trend in the mean annual rainfall (141.3 mm per 100 years) and a decreasing trend in air temperatures ( $-0.52^{\circ}\text{C}$  per 100 years) contradicting the earlier studies made by Winstanley (1973a, b).

The climatic changes at three selected locations along the Indira Gandhi canal region were studied (Rao, 1996) using the past records of annual rainfall (1926-93) and air temperature (1950-93). Though, Ganganagar region has been imposed with canal irrigation since the past six decades, the increase in annual rainfall was apparent only during the last three decades (1961-93). The long term rate of increase in the annual rainfall of Ganganagar was  $1.029 \text{ mm year}^{-1}$ . However, in the areas where irrigation has been imposed during the past two decades at Bikaner and most recently at Jaisalmer, the irrigation effect on rainfall was not observed. In general, decrease in the air temperatures were observed in the region at a rate of  $0.039^{\circ}\text{C year}^{-1}$  at Ganganagar,  $0.023^{\circ}\text{C year}^{-1}$  at Bikaner and  $0.009^{\circ}\text{C year}^{-1}$  at Jaisalmer (Rao, 1996). The studies on identification of causative factors of desertification in the Osian and Jodhpur region though showed a marginal increase in long term rainfall in the region, a phenomenal increase in human and livestock may be factor in desertification processes (Rao and Miyazaki, 1997).

### **Drought Climatology**

Drought is a natural hazard considerably influencing water resources, crop/fuel and fodder production. The frequency of occurrence of droughts in arid regions is much higher compared to in other climatic zones. Analysis of the incidence of droughts and their intensity in western Rajasthan during the current century indicated that 47 to 62 per cent of the years (41 to 50 out of 87 years) experienced drought of some intensity or other. The periods 1901-10, 1911-20, 1961-70 and 1981-90 recorded highest number of moderate to severe droughts (3.72 to 4.00 years per decade). Sometimes they occur in consecutive years like the one which occurred in 1984-87



having multiplier effect on human and livestock population. Priority areas of research taken up at the Institute contributing for evolving management strategies to mitigate drought (Rao *et al.*, 1997c) are : (a) drought prediction, (b) monitoring and early warning, (c) impact assessment, (d) adaptation and response.

Studies on the incidence and movement and cessation of drought over the western Rajasthan have revealed that generally droughts originate in the north-eastern parts of western Rajasthan around Churu, move in south westerly direction into the Barmer area and then dissipate with an easterly movement into the Pali region (Ramakrishna and Sastri, 1980; Sastri *et al.*, 1982). A study of the impact of drought on the productivity of pearl millet in Rajasthan (Ramakrishna *et al.*, 1981; Ramakrishna *et al.*, 1984) indicated that yield in 1984, 1985 and 1986 drought years decreased to 76, 31 and 39 per cent to that recorded in Rajasthan in 1983 (Table 3).

Table 3. Impact of drought on productivity of pearl millet

Station	Pearl millet yield in q/ha		
	Good monsoon year (1983)	Mean of three drought years (1984-85 to 1986-87)	Per cent decrease
Barmer	2.85	0.65	77
Bikaner	2.96	0.34	88
Churu	2.88	2.33	19
Ganganagar	4.71	3.68	22
Jaisalmer	4.05	0.31	92
Jalor	4.68	1.05	77
Jodhpur	3.37	0.79	77
Jhunjhunu	7.56	3.57	53
Nagaur	7.21	2.65	63
Pali	5.53	2.48	55
Sikar	5.23	3.93	25
Mean for 11 districts	4.31	1.63	62

The productivity of pearl millet in the arid districts of western Rajasthan during the drought years (1984-85, 1985-86 and 1986-87) showed that the mean productivity in 8 out of the 11 districts was less than 50 per cent, the most affected districts being Jaisalmer, Bikaner, Barmer, Jodhpur and Jalor. However, the impact of drought on pearl millet was considerably low in Churu, Jhunjhunu, Nagaur, Pali and Sikar districts due to favourable rainfall patterns even during the drought years.

In the arid Kachchh region, the net area sown decreased during drought years by 19 per cent under mild drought to 45 per cent under severe drought conditions. The productivity of pearl

millet decreased from that of normal years by 14, 61 and 74 per cent, respectively, under mild, moderate and severe drought conditions. The Kachchh region experienced droughts in 63 per cent of years with crop growing season less than 9 weeks. Hence, short duration (60 to 70 days) crops can be harvested successfully at least in 63 per cent of occasion in the Bhuj region (Singh *et al.*, 1993b, c).

The drought impacts on pearl millet was assessed in Jodhpur district by using a Soil-Plant-Air-Water (SPAW) model by simulating the profile soil moisture and stress in pearl millet (Rao and Saxton, 1995b). The simulated profile soil moisture content using the SPAW model was close to the observed data under rainfed crop. The Water Stress Index (WSI) calculated using the SPAW model had a linear but an inverse relationship with the productivity of pearl millet. The regression equation between them was  $Y = -258.9 \text{ WSI} + 3847.2$  ( $R^2=0.94$ ) showing the WSI of the SPAW model was useful for pearl millet yield estimation in the Indian arid region.

### Heavy Rain Showers and Floods

Cloud burst or heavy rainfall associated with monsoonal depression/low pressure systems over Indian arid zone are not unusual. During 1901-1997, there were 25 instances of heavy rainfall in the arid region (Table 4). Severe and widespread floods in the region occurred 7 times in a period of 97 years. However, localised severe floods appear to be much more common (Dhir *et al.*, 1982; Singh *et al.*, 1992a).

Table 4. Occurrence of likely floods in the Luni basin (1901-1997)

Extent	Magnitude	
	Moderate	Severe
Localised	1919, 1931, 1937, 1938, 1940 1947, 1956, 1958, 1961, 1962	1903, 1905, 1910, 1912, 1916, 1917, 1921, 1924, 1929, 1931, 1945, 1946, 1960, 1967
Fairly widespread	1926, 1927, 1972, 1977, 1983	1928, 1941, 1943, 1952, 1996
Widespread	1975, 1994	1907, 1908, 1944, 1973, 1979, 1990

The analyses on probability and return period of rainfall (Table 5) showed that 1-day to 2-day rainfall amount was highest at Sirohi followed by Jalor, Pali and Jodhpur, the lowest being at Barmer. However, in the case of 3-day to 5-day spells with more than 5 years return period was higher at Barmer than at Jodhpur thereby indicating that in the case of longer duration spells (>3 days) the probabilities of getting higher rainfall is more at Barmer than at Jodhpur. Rainfall with different return periods for 3-day to 4-day spells were also highest at Sirohi followed by Jalor and Pali, but 5-day spell was highest at Pali for return periods above 5 years (Singh *et al.*, 1992a).

Table 5. Rainfall (mm) of different return period (1961-90)

Station	Return Period (Years)								Highest rainfall (1961-90)
	1	2.5	5	10	25	50	100	200	
<b>1-day</b>									
Sirohi	37	161	225	288	372	440	520	600	272.0
Jalor	19	90	128	165	216	260	310	360	268.0
Pali	20	75	102	128	160	190	220	248	304.8
Jodhpur	20	70	93	117	145	170	195	220	157.0
Barmer	15	54	75	93	120	140	160	185	312.2
<b>2-day</b>									
Sirohi	43	205	290	380	500	605	720	840	531.0
Jalor	20	112	167	222	305	375	450	530	429.0
Pali	20	99	140	182	245	300	350	410	490.8
Jodhpur	19	90	128	168	225	270	318	370	253.0
Barmer	13	66	96	126	166	205	240	280	472.2
<b>3-day</b>									
Sirohi	28	200	320	445	630	820	1020	1000	582.0
Jalor	9	116	305	320	490	680	900	1000	499.4
Pali	21	120	178	240	325	400	480	570	590.8
Jodhpur	36	108	140	170	215	235	265	295	301.0
Barmer	13	90	140	195	275	350	430	520	479.2
<b>4-day</b>									
Sirohi	31	220	340	470	670	850	1000	1000	628.0
Jalor	15	137	230	340	530	700	900	1000	540.4
Pali	19	130	200	270	380	480	600	735	629.8
Jodhpur	17	115	175	240	345	430	530	640	424.0
Barmer	16	120	190	265	380	480	600	740	494.6
<b>5-day</b>									
Sirohi	26	217	345	480	720	940	1000	1000	674.0
Jalor	23	185	295	410	620	800	1000	1000	541.0
Pali	10	138	290	510	960	000	1000	1000	631.9
Jodhpur	18	148	228	320	470	610	760	940	495.5
Barmer	10	128	320	340	540	730	960	1000	497.6

The July 1990 storm, which precipitated 516 mm rainfall at Jodhpur, has a return period of more than 25 years. However, similar intensity of rainfall can occur in Sirohi, Jalor and Pali regions with return period of 10 years only. Barmer station recorded rainfall of 497 mm during August storm which has also a return period of less than 25 years.

In 1990, the two storms in July and August generated rainfall volume of about  $26 \times 10^9$  and  $18 \times 10^9$  cubic metre, respectively over the five districts of Sirohi, Jalor, Pali, Jodhpur and Barmer. Thus, there is a considerable scope to harvest the excess rain water in the Indian arid region (Singh *et al.*, 1992a).

A study on probable maximum precipitation revealed that 1-day first probable maximum value is minimum at Jodhpur (300 mm) and maximum at Sirohi (590 mm). In the case of 5-day, spell it is highest at Pali (1415 mm) and lowest at Jodhpur (977 mm) with intermediate values at Jalor (1044 mm), Barmer (1115 mm) and Sirohi (1364 mm). But second probable maxima is always found to be highest at Sirohi and lowest at Jodhpur with respect to all 1- to 5-day spells over the region (Table 6).

Table 6. Probable maximum precipitation (mm) over arid Rajasthan

Station	Probable Maxima	Duration (days)				
		1	2	3	4	5
Sirohi	First	590	980	1173	1241	1364
	Second	544	769	962	967	1017
Jalor	First	464	668	829	922	1044
	Second	381	480	598	654	759
Pali	First	511	799	971	1124	1415
	Second	394	580	666	782	953
Jodhpur	First	300	441	550	742	977
	Second	268	367	463	547	592
Barmer	First	504	727	836	1025	1115
	Second	363	474	556	654	745

## Evapotranspiration Requirements of Arid Zone Crops

For planning to optimise the water resources in the region, lysimetric studies on evapotranspiration requirement of pearl millet, moth bean, clusterbean and mustard crops (Ramakrishna *et al.*, 1990a, 1991; Singh *et al.*, 1997a; Rao *et al.*, 1997a, b) were conducted at Jodhpur during 1988 to 1995. The crops were maintained at irrigated at 50 per cent and 100 per cent potential evapotranspiration and rainfed condition. The seasonal evapotranspiration (ET) of unstressed pearl millet, clusterbean, moth bean and mustard were 618, 654, 295 and 550 mm (Table 7). The respective water use efficiencies of these crops were 8.1, 2.5, 2.8 and 4.9 kg ha<sup>-1</sup> mm<sup>-1</sup>. The crop coefficients (ratio of seasonal evapotranspiration to class A pan evaporation) for these crops were 0.18-0.30 at initial stage, 1.12-1.20 at peak vegetative stage and 0.40-0.58 at maturity. Most of these arid zone crops showed highest water use efficiency at 50 per cent

Table 7. Evapotranspiration-grain yield relationships of some arid zone crops at Jodhpur

Crop/variable	Rainfed	Irrigated	
		50% ET	100% ET
<b>Pearl millet</b>			
Evapotranspiration (mm)	209.0	348.0	618.0
Grain yield (kg ha <sup>-1</sup> )	558.0	3408.0	5012.0
Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	2.7	9.8	8.1
<b>Moth bean</b>			
Evapotranspiration (mm)	228.0	261.0	295.0
Grain yield (kg ha <sup>-1</sup> )	492.0	655.0	818.0
Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	2.1	2.5	2.8
<b>Clusterbean</b>			
Evapotranspiration (mm)	332.0	447.0	654.0
Grain yield (kg ha <sup>-1</sup> )	785.0	1179.0	1665.0
Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	2.4	2.6	2.5
<b>Mustard</b>			
Evapotranspiration (mm)	226.0	291.0	550.0
Grain yield (kg ha <sup>-1</sup> )	1120.0	1490.0	2690.0
Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	5.0	5.1	4.9

potential evapotranspiration (PET) condition showing considerable scope to optimise scarce water resources of rid region limiting irrigation at a reduced rate. The water use efficiency (WUE) at 50 per cent PET rate were 9.8 for pearl millet, 2.6 for clusterbean, 2.5 for moth bean and 5.1 for mustard.

## Thermal Time (°Cd) Requirements

### Pearl Millet

Pearl millet (cv. MH 179) grown under two moisture regimes viz., optimal moisture and rainfed conditions at Jodhpur required 1490 to 1794°C d thermal time to reach physiological maturity (Singh *et al.*, 1998). Sowing date had considerably influenced the thermal time requirement of the crop, as it modifies the photoperiod, temperature and radiation regimes besides phyto-climate of the crop. The crop was more affected by canopy temperature rather than ambient temperature. Cumulative values of stress degree days for the optimal crop was lower than that of the rainfed pearl millet.

The leaf-tip appearance on the main shoot of pearl millet in relation to thermal time was almost linear under both moisture conditions requiring about 44 to 50°Cd  $\pm$  2.6°Cd leaf<sup>-1</sup>, till the appearance of the flag (last) leaf. However, leaf tip appearance on primary tillers was slightly slower and required 53 to 58°Cd  $\pm$  4.7°Cd for each new leaf. Appearance of first primary tiller

was later (at 320°Cd after emergence) under the rainfed condition as compared to the crop under the optimal moisture (at 250°Cd). Thereafter, the tiller appearance under both moisture conditions was at a linear rate of 53 to 56°Cd  $\pm$  9.5°Cd tiller<sup>-1</sup> (Singh *et al.*, 1998).

### Clusterbean

The leaf appearance of clusterbean was found to correlate strongly with the accumulated thermal time. The relationship between leaf appearance (Y) and accumulated thermal time (X) for crop grown under optimal moisture condition was:

$$Y = 0.022754 X - 5.49788 \quad (R^2 = 0.98)$$

and for rainfed crop:

$$Y = 0.018005 X - 6.51466 \quad (R^2 = 0.97)$$

Branching in clusterbean has been strongly influenced by the moisture availability conditions while the crop grown under optimal moisture initiated branching quite early (at 315°Cd), whereas effective branching was seen to initiate late (at 700°Cd) under rainfed crop when favourable moisture conditions prevailed. The relationship between appearance of branches and thermal time for the crop under optimal moisture condition was

$$Y = 0.015455 X - 4.48936 \quad (R^2 = 0.95)$$

and under rainfed conditions was:

$$Y = 0.020132 X - 13.5707 \quad (R^2 = 0.95)$$

### Mustard

The relationships between leaf initiation on the main shoot after emergence with accumulated thermal regime in respect to mustard crop grown under three moisture availability conditions are as below :

(i) Control (three irrigations) crop

$$Y = 0.018 X - 0.615 \quad (R^2 = 0.98)$$

(ii) 50% PET crop

$$Y = 0.23 X - 1.361 \quad (R^2 = 0.98)$$

(iii) 100% PET crop

$$Y = 0.022 X - 0.861 \quad (R^2 = 0.98)$$

where Y = Leaf number and X = growing degree days from date after emergence.

The above relationships were found to hold good upto the initiation of the 12th leaf or elongation of the main shoot. Study revealed that the heat unit requirement for physiological maturity is highest (1714 to 1792 degree days) in case of crop grown under maximum soil moisture availability condition. Also the difference in accumulated degree days upto maturity stage suggest differential response to short period changes in soil moisture and ambient thermal environment (Singh *et al.*, 1996c).

## **Agrometeorological Approach for Optimising Crop Production**

For deciding the cropping pattern, the available growing season of different length and their corresponding probabilities of occurrence was considered. The crop growing period (CGP) in western Rajasthan varies from 3 to 13 weeks under shallow soils and from 5 to 15 weeks under deep soils (Rao *et al.*, 1994). The choice of crops should be based on CGP at the location. It is also found that less than 8 weeks crop growing duration occurs in 32 per cent of occasions in Bhuj (Kachchh) region which is not enough to support any rainfed crop in the region. Therefore, it is appropriate that 32 per cent of the agricultural land should be under pastures or silvi-pastoral system, in contrast to only 11 per cent of the area under grasses in the existing cropping pattern. Thus the risk involved in crop production can be compensated through animal husbandry. In the remaining 68 per cent of the occasions when a growing season of more than 8 weeks can be expected, the chances of a growing season exceeding 12 weeks is 45 per cent. Therefore the present land use can consider 32 per cent area under grasses 23 per cent under pulses and 45 per cent under longer duration crops like pearl millet and sorghum for obtaining stable productivity from the region (Singh *et al.*, 1993b, c).

For the Kachchh region, various types of crop weather relations were developed for the estimation of yields of pearl millet, groundnut, kharif pulses and sorghum. Water use by pearl millet during 7-11 weeks of crop growth indicated a higher relationship with yield compared to total water use. The regression curve found as best fit is of the reciprocal hyperbola type.

$$Y = X/(0.09825 X + 0.02661) \quad (R^2 = 0.80)$$

where Y is pearl millet yield (q/ha), and

X is mean AE/PE ratio during reproductive phase.

Hoerl function fitted to predict the groundnut yield is as follows :

$$Y = 1.37 * 10^{-5} * 0.99^x * X^{2.64} \quad (R^2 = 0.86)$$

The predictive equations of the best fit between yield and water use by kharif pulses are:

$$Y = X/(-0.19X + 101.20) \quad (R^2 = 0.76)$$

$$Y = 3.31 * 10^{-6} * 0.99^x * X^{2.94} \quad (R^2 = 0.75)$$

Hoerl function predicted optimum yield of sorghum 4.2 q ha<sup>-1</sup> at 327 mm of crop evapotranspiration (Singh and Ramakrishna, 1994).

## **Micro-climate on Horticulture/agri-horticultural Systems**

Arid climate very much favours certain fruit crops. Central Arid Zone Research Institute, Jodhpur has played a significant role in increasing the area under horticultural crop in western Rajasthan.

## **Micro-climatic Studies on Jujube**

The relative humidity inside jujube orchard was always higher by 6 to 40 per cent, whereas the wind speed was lower in comparison to outside field, the condition which is beneficial for fruit

development (Singh *et al.*, 1993d, 1997b). The leaf transpiration was low in Tikadi cultivar indicating its suitability and adaptability to this arid climate. Gola cultivar has got higher potential to yield (39.4 kg tree<sup>-1</sup>) during good monsoon year, but it has drawback of higher yield variability in comparison to other cultivars in the region. Fruit setting takes place almost at same time in all the jujube cultivars, but fruits of Gola cultivar mature earlier than all other cultivars in the region. This is because Gola fruits take less degree days (1718°Cd) for its maturity in comparison to all other cultivars. Gola canopy may also maintain better and favourable micro-environment through much transpiration from its leaves during the good rainfall season.

Light interception under Gola cultivar was maximum at maturity stage, only 68 watt m<sup>-2</sup> reached the ground out of 915 watt m<sup>-2</sup> at the top of the canopy. High light interception was due to the dense canopy at fruit maturity stage. The percentage interception of light was maximum by cultivar Tikadi (84-92) followed by Seb (75-89) and Gola (78-92). The interception was lowest from cultivar Umran (69-82). This lower interception of light by Umran cultivar was due to its more open and dwarf canopy structure.

The relative stress (indicated by the difference between canopy and air temperatures) had indicated that all cultivars were able to maintain canopy temperature lower at least by 4°C than surrounding ambient temperature indicating that no cultivar was under stress.

Leaf transpiration from September to February was highest during fruit setting stage (October) irrespective of cultivar. However, the average leaf transpiration rate ( $\mu\text{g cm}^{-2} \text{s}^{-1}$ ) was high (166.6) in high yielding Gola cultivar and low (153.4) from local cultivar Tikadi whereas the leaf diffusive resistance were 0.01 and 0.02 s cm<sup>-1</sup>, respectively. The Gola cultivar of jujube reduces its transpiration by 31 to 49 per cent whereas local Tikadi cultivars minimised its transpiration rates by 21 to 36 per cent during low moisture periods.

For the jujube crop, the requirement of heat units for maturity varied from 1718°C day in case of Gola fruits to 2231°C day for Seb cultivar (Table 8). This could be the reason that Gola fruits mature earlier than other cultivars (Singh *et al.*, 1997b).

Table 8. Heat summation unit (GDD) for the maturity of jujube fruits

Cultivar	Heat unit accumulation (°C day)			Mean
	1990-91	1991-92	1992-93	
Tikadi	1998	1885	1956	1946
Seb	2353	2151	2190	2231
Umran	2237	2189	2190	2205
Gola	1806	1673	1675	1718
Hybrid (Seb*Tikadi)	1922	1740	1803	1822
Rainfall mm (May-April)	809	247	425	493

Relationships between *ber* fruit size (Y, cm) and accumulated heat units (X) after fruit setting for two contrasting cultivars (Tikadi and Gola) are as follows :



$$Y = 1.11 + 0.0003 X \quad (R^2 = 0.81)$$

$$Y = 0.78 + 0.0011 X \quad (R^2 = 0.94)$$

These equations bring out similar time for fruit setting by both the cultivars, the fruits of local Tikadi cultivar thereafter grow slowly and need more heat units (around 335°Cd) per mm of increase in size in comparison to the fruits of Gola cultivar which grow rapidly and require less heat units (90°Cd) per mm increase in fruit size (CAZRI, 1993).

### Micro-climatic Studies on Pomegranate

Pomegranate under irrigated condition showed leaf transpiration rate between 122.0 to 156.2  $\mu\text{g cm}^{-2} \text{s}^{-1}$ , 117.0 to 155.7  $\mu\text{g cm}^{-2} \text{s}^{-1}$  and 84.3 to 90.7  $\mu\text{g cm}^{-2} \text{s}^{-1}$  during afternoon period of its fruit setting/development stages, respectively. The leaf diffusive resistance ranges between 0.18 to 0.36  $\text{s cm}^{-1}$ . Higher transpiration rates from pomegranate shows more water requirement in comparison to jujube orchard (CAZRI, 1991).

Productivity, water and heat use efficiency (HUE) was highest in Jalor seedless cultivar (3504  $\text{kg ha}^{-1}$ ) compared to other cultivars. WUE ranged from 2.29 (cv. Dholka) to 3.84 (cv. Jalor) during the year, whereas HUE was found to be varied from 0.645 (cv. Dholka) to 1.09  $\text{kg ha}^{-1} \text{°Cd}^{-1}$  (cv. Jalor seedless) during the year 1991-92.

Pomegranate fruit size, fruit weight and total soluble solid (TSS) were correlated with growing degree days at base temperature,  $T_b = 5^\circ\text{C}$ .

- (i) Accumulated growing degree days (X) and mean fruit size of Jalor seedless cultivar (Y) were related as

$$Y = 2.96 + 0.0015 X \quad (R^2 = 0.96)$$

- (ii) Accumulated growing degree days (X) and mean fruit size of Jodhpur red cultivar (Y) were related as

$$Y = 4.02 + 0.00135 X \quad (R^2 = 0.94)$$

The study revealed that Jalor seedless required accumulation of 41 degree days whereas, Jodhpur red required only 33 degree days for per mm increase in fruit size after fruit setting indicating that growth rate of fruit size is faster in case of Jodhpur red in comparison to Jalor seedless cultivar.

- (iii) Accumulated growing degree days (X) and fruit weight of Jalor seedless cultivar in gram (Y) were related as

$$Y = -56.99 + 0.095 X \quad (R^2 = 0.92)$$

- (iv) Accumulated growing degree days (X) and TSS (degree Brix) of Jalor seedless (Y) were related as

$$Y = 5.18 + 0.0045 X \quad (R^2 = 0.92)$$

It is found that accumulation of 13 degree days and 164 degree days are required to increase the fruit weight by 1 g and TSS by 1 degree Brix, respectively, after fruit setting in Jalor seedless cultivar of pomegranate (CAZRI, 1992).

### Micro-climatic Studies on Aonla (*Emblica officinalis*)

The relationships between the Aonla fruit growth and accumulated heat units, AHU ( $^{\circ}\text{Cd}$ ) from the date of fruit setting to the end of fruit growth with respect to its weight (g) as well as size (cm) are as follows:

$$\text{Krishna fruit weight (g)} = 9.21 + 0.017 \text{ AHU } (R^2 = 0.79)$$

$$\text{Kanchan fruit weight (g)} = -3.05 + 0.015 \text{ AHU } (R^2 = 0.85)$$

$$\text{Krishna fruit size (cm)} = 2.22 + 0.001 \text{ AHU } (R^2 = 0.90)$$

$$\text{Kanchan fruit size (cm)} = 1.26 + 0.001 \text{ AHU } (R^2 = 0.72)$$

The Aonla fruits of Krishna cultivar required  $49^{\circ}\text{Cd}$  per g and  $44^{\circ}\text{Cd}$  per mm of fruit growth, whereas the Kanchan cultivar required more heat units,  $80^{\circ}\text{Cd}$  per g and  $54^{\circ}\text{Cd}$  per mm of fruit growth. However, Aonla fruits of the both cultivars mature almost at same time and required about  $2435^{\circ}\text{Cd}$  thermal time for its maturity after fruit setting. The heat use efficiency (HUE) of Kanchan and Krishna cultivars were 37 and 25  $\text{g tree}^{-1} \text{ }^{\circ}\text{Cd}^{-1}$ , respectively (CAZRI, 1994).

### Micro-climatic Studies on Datepalm (*Phoenix dactylifera*)

Relationships between phenological growth stages of datepalm (cv. Halawy, Shamran and Zahidi) and ambient temperature showed that the datepalm fruit required 2304 to  $2601^{\circ}\text{Cd}$  heat unit to reach at doka maturity stage after spate emergence. However dang maturity stage required heat unit about 2769 to  $2879^{\circ}\text{Cd}$  which is normally not possible under Jodhpur condition before the start of rainy season (Singh *et al.*, 1997c).

Though total soluble solids (TSS) of Shamran fruit was reported slightly higher than the fruits of Zahidi cultivar, but variation in TSS with thermal time was better explained up to 95 per cent in Zahidi cultivar in comparison to the Shamran cultivar (83 per cent). In general,  $69.3$  to  $72.9^{\circ}\text{Cd}$  heat was required to increase TSS by 1 degree Brix after the fruit setting. TSS in datepalm fruits was found 8.0 to 8.6 degree Brix during the first fortnight of fruit setting irrespective of cultivar. However, at fruit maturity, the value of TSS was measured 33.6 degree Brix in Zahidi and 36.8 degree Brix in Shamran cultivar in the region.

Datepalm growth hot climate and its fruits required high temperatures during maturity. Study revealed that the datepalm fruit took 2304 to  $2601^{\circ}\text{Cd}$  to reach at doka maturity stage. However, the dang maturity stage required more thermal time (about 2769 to  $2879^{\circ}\text{Cd}$ ) than doka maturity stage. Therefore, datepalm fruits should be harvested at doka stage under Jodhpur conditions. Late harvest of fruits at the dang maturity stage causes damage due to rains in case of early and normal onset of monsoon before middle of July in the region (Singh *et al.*, 1997c).

### Micro-climatic Impacts on Agroforestry/silvopastoral Systems

In agroforestry/silvopastoral systems, trees and shrubs help in protection of the soil from the high winds and reduce the unwanted water losses. Studies on the role of shelterbelts in reduction of wind speed, evaporation rate, soil moisture and wind erosion showed that the tree system of

*Cassia siamea*-*Albizia lebbek* was more efficient in reduction of wind followed by *Acacia tortilis*-*A. lebbek* type of shelterbelt. There was also a decrease of 5-14 per cent in pan evaporation values in the leeward side. Soil moisture content was also higher in 0-30 cm depths in *C. siamea*-*A. lebbek* than other combination of trees (Gupta *et al.*, 1983; Rao *et al.*, 1983).

Studies on competitive/complimentary association between the natural stand of *P. cineraria* (100 plants ha<sup>-1</sup>) and two dryland crops viz., pearl millet (MH 179) and moth bean (Maru Moth) revealed that the competitive relationship existed between the components upto 2m radius from the tree base in both the crops (Rao *et al.*, 1993a; CAZRI, 1993). The relationship was additive between 2 to 3 m radius. At 5m and beyond this distance from the tree, the crop yields were relatively unaffected by the tree component. The consumptive use of pearl millet at 1, 3, 5 and 7 m distances from the tree was 188, 197, 206 and 192 mm, respectively, indicating less competition from the tree at 5m distance and beyond for moisture. The water use efficiency for dry matter production increased from 3.40 kg mm<sup>-1</sup> ha<sup>-1</sup> around 1m distance to 10.19 kg mm<sup>-1</sup> ha<sup>-1</sup> at 5m distance from the tree under pearl millet while it was 2.20 kg mm<sup>-1</sup> ha<sup>-1</sup> for moth bean at 5m distance. The micro-climatic variations under *P. cineraria* for inter crop planning were also recorded.

Studies on micro-climatic impact on *Cenchrus ciliaris* at Jodhpur showed that high air temperature and wind speeds prevailing in the arid region at Jodhpur had a negative correlation whereas, rainfall, humidity and rainy days had a positive correlation on forage and seed yield of *Cenchrus ciliaris*. Seed yield of *Cenchrus ciliaris* increased from 67 to 153 kg ha<sup>-1</sup> with a gradual increase in quantum of rainfall from 150 to 400 mm. Rainfall at flowering and seed setting stages reduced the seed yield (Rao and Singh, 1994).

Seed yield of *C. ciliaris* increased from 67 to 153 kg ha<sup>-1</sup> with a gradual increase in quantum of seasonal rainfall from 150 to 400 mm (Rao *et al.*, 1996). Rainfall at flowering/seed setting stages reduced the seed yield (Rao and Singh, 1994). Only in good rainfall years, application of N and P to the grass had a significant effect on forage but such a response was not observed on seed yield due to rain and high winds at seed setting/maturity stages. Accumulated stress degree days showed that *C. ciliaris* develops an early stress than *C. setigerus*. During low rainfall years, *C. ciliaris* produced higher dry matter yield, water and energy use efficiency than *C. setigerus* whereas under high rainfall conditions *C. setigerus* performed better than *C. ciliaris* (Rao *et al.*, 1993b; Singh *et al.*, 1996a). Rainfall explained one per cent seed and 36 per cent forage yield whereas the yield index was useful for prediction of variations upto 24 per cent seed and 76 per cent forage yield.

Unirrigated *L. indicus* at Jodhpur produced 2955 to 3587 kg DM ha<sup>-1</sup> of dry forage depending on the rainfall, varying from 182 to 775 mm, during 1990 to 1993. The water use values of the grass varied between 144 to 271 mm resulting in water use efficiency of 13.2 to 20.8 kg DM ha<sup>-1</sup> mm<sup>-1</sup>. The grass utilised the thermal energy efficiently under adequate moisture as indicated by the heat use efficiency values which varied from 0.60 to 0.77 kg DM ha<sup>-1</sup> °Cd<sup>-1</sup>. The soil water

balance and yield index values for the area during these years were calculated using RANGETEK model. The model predicted the dry forage yields of *L. indicus* Henr. within + 8 per cent to -12 per cent from the recorded yields (Singh and Rao, 1996; Singh *et al.*, 1996b).

Crop production from arid regions is very much influenced by low and erratic rainfall, high temperatures and high evapotranspiration requirements. Droughts are a recurring feature occurring once in every 2.5 years. Besides drought impacts on sole crops, in silvopastoral and agroforestry systems, climatic interactions with tree, crop and pasture grasses are very important.

Concerted efforts for weather adjustments, choice of alternate crops and varieties matching the rainfall patterns, rainwater harvesting and optimising the water resources for increased water and energy use efficiency, crop cultivation under controlled environments for commercial crops and floriculture etc. are some of the approaches identified for a sustainable crop production from the arid region. Also under the prevailing low and erratic nature of rainfall conditions in the Indian arid region, to manage these arid lands in a judicious way, a combination of arable crops, horticultural crops, silvicultural plantations and fodder crops is the need of the day. Weather information can be made use of for estimation and management of food grains as well as fodder resources for the large human and livestock population of the Indian arid region.

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# 3

## GEOMORPHOLOGY OF THE HOT ARID REGIONS IN INDIA

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The hot arid regions of India, constituting 0.32 million km<sup>2</sup> area, occur dominantly in the country's north-western part. About 90 per cent area of the arid lands in India is in this part. The state of Rajasthan accounts for the largest area (61%), followed by Gujarat (20%), Punjab (5%) and Haryana (4%). About 10 per cent area occurs in the southern part of the country, especially in Andhra Pradesh (7%) and Karnataka (3%). Geomorphologically, the north-western arid zone is better studied than the southern arid zone. Much of the research results were obtained in the post-independence era. Availability of new technologies, founding of new centres of research and better scopes for exchange of ideas, nationally and internationally, helped to provide new insights into the problems. Earlier reviews on the geomorphology of north-western arid zone are provided in Ghose *et al.* (1977a), Allchin *et al.* (1978), Singh (1977, 1994), Kar and Ghose (1983), Singh *et al.* (1992), Singhvi and Kar (1992) and Kar (1992a, 1995). Useful summaries on the southern arid zone are available in Vaidyanadhan (1964) and Singh *et al.* (1973). We provide here a brief account of the Quaternary evolution of the landforms and the present morphological features of both the north-western and southern arid zones.

### **Landform Evolution**

Studies so far in the Rajasthan part of north-western arid zone suggest that oscillations of climate between drier and wetter phases during the Quaternary period greatly influenced the dominance of land forming processes. While the aeolian processes were more prevalent during the drier and more arid phases, the fluvial processes were dominant in the wetter phases. Similar studies in other parts of the arid zone are few, but studies from the coastal tract of Gujarat and elsewhere confirm the secular nature and periodicity of the climatic variations. Evidences also exist in support of tectonic activities during the Quaternary period. The following is a brief account of the Quaternary landform history in the arid areas of Rajasthan and Gujarat, as deduced from multiple evidence of morphological characteristics, stratigraphy, pollen analysis and absolute dating through radiocarbon and luminescence methods (Goudie *et al.*, 1973; Singh *et al.*, 1974; Ghose *et al.*, 1977b; Allchin *et al.*, 1978; Wasson *et al.*, 1983; Merh and Vashi, 1985; Patel and Desai, 1988; Kar, 1989a, 1995; Chawla *et al.*, 1992; Singhvi and Kar, 1992; Merh, 1993; Wasson, 1995).

Roughly between 60 and 40 thousand years (kyr) before present, a wetter climate prevailed in the region, when better networks of streams from the Aravalli hill ranges used to drain a large part of the southern part of the desert. This was followed by somewhat shorter periods of good monsoon with intervening arid phases, till about 20 kyr when a major arid phase set in. Evidence of similar shifts of climate from wetter to drier before 60 kyr are also found in the stratigraphic records of the Quaternary period (Singhvi and Kar, 1992; Wasson, 1995). The Luni was a major stream, but there are remote sensing evidences of numerous shifts in its course in the past (Ghose, 1964, 1965; Ghose and Singh, 1968). There are also remote sensing evidences of several other former streams which used to flow through the desert at different times during the Early and the Middle Quaternary periods. Notable among these are the extinct Saraswati and Drishadvati rivers from the Himalayas (Ghose *et al.*, 1979; Kar and Ghose, 1984; Kar, 1993a). Vast alluvial plains were built by the Saraswati-Drishadvati river system and the Luni system in the Rajasthan part of the desert, while the Sutlej and its tributaries from the Himalayas, as well as the north-flowing streams from the Aravallis, built up the plains of the arid Punjab and Haryana. In the arid Gujarat a number of ephemeral streams contributed sediments in the plains.

The survival of the Saraswati-Drishadvati river system depended largely on the contribution of the Sutlej. Climatic changes and neotectonic activities also played their roles in the disappearance of these Himalayan streams, as well as in the obliteration of many palaeochannels in the Luni basin and arid Gujarat. In the Luni basin several anomalous drainage patterns and river terraces provide evidence of neotectonism, while in Kachchh and parts of Saurashtra upland the youthful nature of the terrain and drainage anomalies are the examples of such activities (Dassarma, 1986; Kar, 1984a, 1988, 1994, 1995; Wadhawan, 1988, 1992; Grover and Sarin, 1993; Sridhar *et al.*, 1994). The last major tectonic activity was in 1819 when a severe earthquake threw up a 2 to 6 m high earthen mound across the Great Rann of Kachchh, resulting in many drainage changes (Oldham, 1926; Biswas, 1971; Kar, 1993b).

The last major wet phase was approximately between 10 kyr and 4 kyr. The Pre-Harappan and Harappan settlements in the Saraswati-Drishadvati valleys flourished during this phase. It was followed by another dry phase. The arid phases were responsible for large-scale sand movement and formation of sand dunes. Most of the high sand dunes in arid Rajasthan were last formed during the arid phase which ended by 10 kyr (Ghose *et al.*, 1977b). During such periods fluvial activities were negligible and resulted in disorganisation or disappearance of many streams. Formation of dunes across the major stream valleys and wind erosion created several inland basins, some of which afterwards became the sites of periodic water and salt accumulation, leading to the formation of saline depressions (Ranns). A number of other factors, including tectonic disturbances were also responsible for the formation of many Ranns. Some of the major Ranns within the desert occur near Didwana, Chhapar, Pachpadra, Thob, Bap, Kanod and Lunkaṛansar. The Great Rann of Kachchh and the Little Rann were formed due to the recession of Arabian Sea. Presently, there are geomorphic evidence like stability of aeolian landforms, formation



of rills and gullies on the dune slopes and a higher drainage network to suggest a slight climatic amelioration, especially along the eastern part of the desert (Singh *et al.*, 1974; Ghose *et al.*, 1977b).

Evolution of landforms in the arid zone of southern India was mostly related to fluvial processes and suspected tectonic activities. Weathering and subaerial denudation of granite bosses resulted in the formation of numerous domes and inselbergs with associated piedmont plains. Streams like the Vedavati river and its tributaries formed a variable thickness of alluvium which are noticed in the older and younger alluvial plains downslope of uplands and piedmont plains.

### **Landform Characteristics in Northwest Arid Zone**

As a result of process changes over time and space a number of landforms have been sculpted to their present state. Although most landforms are polygenetic in nature, it is possible to classify them according to the processes which dominated for a fairly long period.

#### **Fluvial and Fluvio-marine Landforms**

The major fluvial landform sequence is hills and uplands-rocky/gravelly pediments (or pavements)-buried pediments (colluvial plains)-flat older alluvial plains-younger alluvial plains-river beds. The hill slopes in the arid areas have usually a general paucity of debris. Concave and straight segments dominate over the convex segment. Lithological and structural variations are faithfully replicated in the slope configurations, as noticed in the *cuestas* (e.g. Bhachau), *mesas* (e.g. Osian) and *hamadas* (e.g. Jaisalmer-Ramgarh), as well as in the shapes of the summits in hills formed of rhyolite, granite and other rocks (Kar, 1983, 1989b, 1995). The pediments at the base of hills usually have a slope of less than 4°, where the debris character is highly influenced by local lithology. The piedmont angle is more pronounced on sandstone and granite, but the least in rhyolite (Kar *et al.*, 1979, Kar, 1984b). The desert pavements occur in the very dry western part of the Thar, where the surface is characterised by closely packed gravels and pebbles. Down the slope from pediments and pavements, the buried pediments/ colluvial plains are composed of heterogeneous sediments. The thickness is more than a meter near the Aravallis, but decreases gradually westward where it varies from 30 to 60 cm. More than 50 per cent sediments are of 0.06 to 0.12 mm size. Similar depth and size characters exist over much of Kachchh and Saurashtra regions.

The flat older alluvial plains occur further downslope and are usually characterised by zones of illuviated soft nodular kankar, or gypsum at 20 to 150 cm depth within the alluvium. The dominant grain sizes are 0.06 to 0.18 mm (Singh, 1994). The younger alluvial plains occur downslope of the older alluvial plains, especially along the major ephemeral channels, including the Luni and its tributaries in the southern Thar, the Ghaggar in northern Thar, and similar major ephemeral streams of Saurashtra and Kachchh. The dominant grain sizes in the unit are 0.04 to 0.25 mm. The coastal alluvial plains occur in Kachchh and Saurashtra where the sediment depth is usually less than a meter. The unit was formed by fluvial and fluvio-marine processes. Repeated

Quaternary tectonic activities have also influenced these plains, and the configuration of other narrow coastal units, including the Banni (Kar, 1993b, 1995). The characteristics of the dominantly fluvial landforms and their vulnerability to natural hazards are summarised in Table 1.

### **Aeolian Landforms**

Wherever the activities of aeolian processes dominated, a set of new landforms was created over the existing fluvial landforms, especially as sand sheets, sandy hummocks and sand dunes. This happened mostly in the Thar and its northern fringe in Punjab and Haryana, as well as in the eastern fringe, especially during the dry periods. Parts of the flat buried pediments and older alluvial plains were transformed into sandy undulating buried pediments and sandy undulating older alluvial plains. Sand dunes and interdune plains are the other major aeolian landforms. The saline depressions are the results of a complex inter-play between the fluvial and aeolian processes.

Most high sand dunes in the Thar were last formed during the last Glacial period between 13 and 18 kyr. These include most of the presently stabilised and vegetated linear, parabolic, transverse and high obstacle dunes (Pandey *et al.*, 1964; Vats *et al.*, 1976; Singh, 1977, 1982; Singh and Shankarnarayan, 1986). Recent studies revealed that star and many different kinds of network dunes cover the northern and eastern parts of the Thar, and were formed during the earlier dry phases (Kar, 1993c). The average height of these old dunes varies between 15 and 30 metres.

The parabolic dunes cover the maximum area of the dune-covered landscape. The dunes occur in chains of 1 to 8 km length and have a three to four tier arrangement. The average width of the chains varies from 500 to 1500 m. The windward, flank and leeward slopes are 2° to 4°, 8° to 12° and 22° to 24°, respectively (Singh, 1982). The linear dunes occur mainly in the western part of the Thar, especially in Jaisalmer region, and are oriented in the direction of the wind. The dunes were earlier thought to have originated from parabolic dunes (Verstappen, 1968), but studies now suggest that the dunes develop from streams of barchans in the high wind energy zone to the west of 150 mm isohyet, and from lee vortices behind major obstructions, or along the major stream valleys through funnelling effect (Kar, 1987, 1990a). The dunes are characterised by a broad convex summit. The length varies from more than 10 km in the extreme west of the field to 1-2 km in the east. The high transverse dunes occur mainly to the west of Bikaner and were formed astride the path of sand-laden wind. The slopes of the leeward, flank and windward sides of the dunes are 22°, 10°-12° and 3°-4°, respectively. The average spacing between transverse dune chains is 300 to 800 m (Singh *et al.*, 1992).

Simple and compound obstacle dunes were formed on the windward and leeward sides of hills, creating in the process windward and leeward obstacle dunes (Singh, 1982; Singh and Shankarnarayan, 1986). The windward obstacle dunes show marked asymmetry. The steeper slope faces the hill. The slopes of the windward side and flanks of these dunes are 2° to 3° and 10°

Table 1. Dominant morphological characteristics of fluvial landforms

Landform unit	Slope (degree)	Nature of rock/ sediment	Average sediment depth	Drainage characteristics	Dominant hazards
Hills and rocky uplands	15-35 (1-5 in uplands)	Metamorphics along the Aravallis and its fringes; sedimentaries elsewhere. Granite and rhyolite in central Thar; basalt in Kachchh and Saurashtra; occasional duricrusts on uplands	More than 30 cm along the Aravallis and in Kachchh and Saurashtra; more rocky and barren in the Thar	Numerous ephemeral channels; dendritic and radial patterns	Rill and gully erosion. Aeolian deposition in foothills of western Thar
Rocky/ gravelly pediments and pavements	1-3	Boulders/ gravels and sheet rock exposure; frequent admixture of aeolian sand in the Thar	10-40 cm or rocky	Rills and occasional gullies; dendritic pattern	Sheet to rill erosion
Flat buried pediments and colluvial plains	0-1	In-situ weathered debris and short-distance transported colluvium, mixed with aeolian sand; calcretes present in depth	30-200 cm	Numerous channels, except in the western Thar	Rill to gully erosion; also aeolian deposition
Flat older alluvial plains and coastal plains	0-1	Sandy loam to clay loam, underlain by soft and hard calcretes (bed rock under coastal alluvium)	30-120 cm above lime concretionary horizon	Few channels; sheet flow dominant. Also palaeochannels	Slight sheet to rill erosion and salinity-alkalinity; also aeolian deposition in the Thar. Salinity hazard in parts
Younger alluvial plains	0-1	Sand, silt and gravel; mainly sandy loam; no lime concretionary horizon.	More than 1 m	Few short and parallel drainage lines along stream banks; also marks of palaeochannels	Slight rill to gully erosion on stream banks and slight aeolian deposition
River beds	0-1	Coarse sand and gravel	More than 1 m	Short banks and flat wide sandy beds; braided and meandering reaches	Bank erosion during high discharge

to 12°, respectively. The dunes are highly dissected by rills and gullies. A number of fossil dunes of indistinct shape occur along the wetter eastern margin of the Thar, especially between Delhi in the north and Palanpur in the south. These areas within the Aravallis now receive more than 500 mm annual rainfall, but were affected by aridity during the last Glacial period. The dunes define the limits of the past arid climate. Such dunes are also noticed near Patiala in Punjab, and near Tosham, Hisar and Gurgaon in Haryana (Allchin *et al.*, 1978). The dunes have higher silt and clay content.

In contrast to the above old dunes a number of new dunes are presently being formed in the desert. Under the natural set up the dunes are formed in high wind energy regime of the west, especially as 1 to 8 m high barchans and 20 to 40 m high megabarchanoids (Kar, 1990a, 1993c). These are crescentic in shape. Smaller barchans move fast. In the eastern part of the desert the wind strength is not sufficient to form these dunes under natural conditions. However, at places where the natural stability of the old aeolian landforms have been disturbed by human activities, especially around the settlements, localised fields of barchans can be noticed (Kar, 1993c).

Sandy undulating plains are characterised by sand sheets of 50 to 300 cm thickness, as well as low sand streaks and shrub coppice dunes. The height of such hummocks seldom exceeds 5 m. The average slope of the sandy undulating plains is between 1° and 3°. Like the crescentic dunes the low sandy undulations and loose sand sheets are of recent origin. In many cases these are associated with high human activities.

### **Saline Depressions**

As we have mentioned earlier, the saline depressions (Ranns) were formed due to a complex inter-play of fluvial and aeolian processes. Many of the Ranns and other such depressions in the Thar were formed due to strong wind erosion and deflation behind major hills and other obstructions (Kar, 1990b). Some of these (e.g. near Degana) have captured ephemeral channels which used to flow away from the depressions. Some others like the one at Pachpadra has developed at the confluence of streams (Ghose, 1964, Ghose and Singh, 1968). Tectonism played a significant role in the development of few others like the Sambhar Lake, while the Great Rann of Kachchh and the Little Rann are the remnants of the Arabian Sea. The Ranns are characterised by a flat surface which is hard when dry. Although the Ranns are dominated by fine sand and silt deposits in alternate layers, coarser particles are also numerous in them. The size of particles ranges from 0.04 to 2.00 mm.

Table 2 summarises the dominant morphological characteristics of the aeolian landforms and the saline depressions.

### **Landform Characteristics in Southern Arid Zone**

The physiography of Bellary district (Karnataka), which forms a major part of the southern arid zone, was described by Vaidyanadhan (1964). A number of granite hills dominate the

Table 2. Dominant morphological characteristics of aeolian landforms and saline depressions

Landform unit	Slope (degree)	Nature of rock/ sediment	Average sediment depth	Drainage characteristics	Dominant hazards
Sandy undulating buried pediments	1-3	Sandy hummocks and thick sand sheets dominate the topography; colluvium of variable thickness underneath	1-5 m high sandy hummocks and variable sand sheet thickness over the colluvium	Almost no drainage, except along the Aravallis	Aeolian deposition
Sandy undulating older alluvial plains	1-3	Sandy hummocks, fence line ridges and sand sheets dominate over the older alluvium	1-6 m high sandy hummocks and 1-2m thick sand sheet over the older alluvium	Almost no surface drainage	Aeolian deposition
Sand dunes	2-5 (windward) 18-32 (leeward)	Relatively stable and active dunes; semi-compact and calcareous sand within stable dunes; loose sand in active dunes	10-40 m for stable dunes; 1-6 m for most active dunes	No surface drainage, except a few rills in fringe areas	Moderate to severe aeolian deposition
Interdune plains	0-3	Mainly sand and sandy loam; flat, but some are sandy undulating; lime concretionary layers within profile	30-200 cm, except where rocky	Almost no surface drainage	Aeolian erosion/ deposition
Saline depressions	0-1	Silt and clay dominate; also aeolian sand; surface hard when dry; salt-encrustation with polygonal cracks; parts of Great Rann and Little Rann remain submerged throughout the year	More than 3 m; very deep in case of Sambhar Rann, Great Rann and Little Rann	Sheet flow and zone of accumulation	High salinity hazard

landscape and occur in the form of domes, whalebacks, inselbergs and koppies. Curvilinear joints are more common in whalebacks and flat domes. Hill slopes range from 34° to 38°. Pediments, pediment passes and pediplains are common downslope.

In Challakere taluka of Chitradurga district (Karnataka) the landform types have been classified as erosional, depositional, erosional-depositional and miscellaneous (Singh *et al.*, 1973). The erosional landforms include hills, rocky/gravelly pediments, gently to moderately sloping plains, very gently undulating plains and nearly level plains. The slope varies from 0°-1° to 3°-8°. Shallow to moderately deep and coarse to medium textured sediments (0.06-2.00 mm size) are the other characteristics. Saline and non-saline flood plains, and saline alluvial plains belong to depositional landforms. These have 0°-1° slope and are moderately deep to deep. Dominant grain sizes are 0.06 to 0.25 mm. The low lying alluvial plains and valleys, flat alluvial plains and piedmont plains belong to the erosional-depositional landforms. These are characterised by moderately deep, calcareous and non-calcareous sediments of medium texture (0.25-2.00 mm and 0.06-0.15 mm). Saline depressions and river beds have been categorised under miscellaneous type of landforms.

### **Human Influences**

The arid landscape is always in a very fragile state due to its climate and terrain characteristics. Studies with remote sensing, coupled with field information, suggest that human activities have now increased many fold in the arid areas, which have led to acceleration of the normal geomorphic processes. Consequently, there is now increased mobility of sediments from the fluvial and aeolian landforms, as well as more spread of salinity-alkalinity. Destruction of natural vegetation cover, increased mechanisation of ploughing and profuse irrigation without care for the land are some of the major causes identified within the north-western arid zone (Ghose *et al.*, 1977; Singh, 1987; Singh *et al.*, 1978, 1994; Kar, 1992b, 1996). For example, the erstwhile 'stabilised' old dunes have become reactivated and have a thick cover of recent sand which is advancing. New smaller dunes, especially barchans, are also forming in most parts of the sandy plains where none existed earlier. Gully erosion is increasing in the sandy plains of Sikar area, and waterlogging and salinity-alkalinity have engulfed large areas in Suratgarh-Rawatsar-Hanumangarh-Pilibangan tract where a number of canals are in operation. Some of these trends can be halted or reversed if the engineering structures and associated land use alternatives are suggested on the basis of a sound understanding of land-forming processes and vulnerability of the terrain to induced pressures.

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# 4

## GEOLOGY OF WESTERN RAJASTHAN

M.L. Sharma

The entire area stretching from the Sahara to the Thar appears to be a meteorological homogeneous one and the Thar desert is not an isolated desert (Raheja, 1964). The arid and semi-arid region of north-western India extends for 640 km from north-west to south-east with an average width of 300 km from west to east comprising vast areas of western Rajasthan, western Gujarat and south-western Punjab. It has well defined boundary in the east marked by the Aravalli Range which has been attributed to the geological processes in the form of the sheet movement leading to peneplanation, rapid changes in the drainage system and enormous accumulation of loose rocky materials. According to Heron (1936) the rocks of the Aravalli system of Late Precambrian period were deposited on the slightly uneven platform of the eroded basement complex of banded gneissic type and deposited by mature streams in a rather uniformly dry and arid climatic conditions. As such, a thick sedimentary sequence-ranging in age from early Palaeozoic to middle Eocene is exposed in the western Rajasthan region. However, the sedimentation with many intervening breaks, continued upto the late Palaeozoic times till the major uplift and erosion which preceded the next major marine transgression in the Jurassics.

Several pioneer workers laid the foundation of the geology of western Rajasthan. However, Dr. Impey (See Carter, 1861) was the first Geologist to undertake field work in 1826, who had observed the presence of sedimentary rocks with ammonites near Kuchchri 25 km south-east of Ramgarh followed by Blanford (1876) who attempted to delineate the stratigraphy assigning the name: Jodhpur sandstone as the oldest sedimentary formation in the region. There was a complete cessation of all geological works for a period of 25 years. Heron (1932) has recognised two varieties of granite, the pink and the grey one, with the difference in colour due to predominance of pink orthoclase felspar, less plagioclase and absence of ferromagnesian minerals other than biotite. While Pascoe (1950) inferred the Raialo basin of sedimentation forming a part of the geosyncline in which the rocks of Delhi system were deposited followed by the rocks of Vindhyan system belonging to the Great Eparchaeon interval of Indian Geology. However, Taylor *et al.* (1955) inferred that the Malani igneous rocks have invaded the Aravalli slates and the Delhis in a batholithic manner with volcanic activity following the plutonic emplacement. These studies were accepted by one and all giving the sequence of rock formations as the Delhi system, The Malani volcanics, Trans-aravalli Vindhyan, Pokran & Bap boulder beds, Mesozoics and the Tertiaries.

The ever first geological mapping was undertaken by Swaminath *et al.* (1959) of ONGC in Jaisalmer areas who presented the subdivision within the Mesozoics. However, systematic

geological mapping commenced in 1963 by Sogani and Khan (GSI) in reference to the topographical sheet No. 45F, indicating the sequence of sedimentary deposits forming the Vindhyan system of the Trans-Aravalli region.

Barooah (1950), Glaessner and Rao (1957) and Prasad (1961) have studied the fossil fish and crabs from the Fuller's Earth of the Kapurdi Mines. Jacob *et al.* (1957) have studied the microfossils from the gypsum deposits of Jamsar and Siassor. Singh (1951, 1952) made detailed study of foraminifera from Eocene beds of the Bikaner region and reported for the first time the presence of Kirthar beds in Western Rajasthan.

Narayanan (1964) of ONGC briefed the stratigraphy of Rajasthan shelf systematically with special reference to the Jaisalmer area through their deep drilling information. Chandrasekaran (1968, 1977) of GSI had studied the detailed Geology of the Malani Igneous province which cover about 51,000 km<sup>2</sup> area to the west of the Aravalli Range in the Thar desert of Western Rajasthan comprising multiple suites of intrusive and extrusive igneous rocks of diverse compositions. The basement rocks of the Malani rhyolites comprise the Delhi metasedimentaries and the Balewa-Harsani gneisses. The Malani volcanics are dominantly acidic flows with minor occurrences of basic volcanics. The acid volcanics of Jodhpur and Pali area are mostly welded tuff and ash whereas those of Barmer area are dominantly alkali rhyolites.

The volcanics as well as the plutonic suites of Siwana and Jalore granites are in turn intruded by acid and basic dykes.

The younger sedimentaries of the province include those of Marwar supergroup while the Barmer and Sanu sandstone of Cretaceous age followed by Mandai-Kapurdi formations of Tertiary age around Barmer.

Chatterji (1977) briefed the Geology of north-western arid zone correlating the rock formations from Late Precambrian to Quaternary period. Whereas, Pareek (1984) of GSI introduced the basin configuration for describing the geology of north-western Rajasthan. He attributed that the region west of the Aravalli range witnessed felsic volcanism during the Precambrian period which took place along deep-seated tectonic structures parallel to the Aravalli range followed by Palaeozoic, Mesozoic and Palaeogene sediments of north-western Rajasthan which were deposited in basins bounded by the Malani igneous suite on the south and on the east by the Aravalli range with the basement of Pre-Delhi and Delhi super group formations.

He recognised these basins as under :

- Nagaur (Cambrian) Basin
- Bap-Bhadura remnants basin (upper carboniferous-Permian)
- Lathi Basin (Liassic)
- Jaisalmer Basin (Jurassic-Middle Eocene)
- Barmer Basin (Cretaceous-Middle Eocene)
- The Palana-Ganganagar Shelf (Palaeogene)

The Marwar super group of rocks comprising the arenaceous Jodhpur group calcareous stromatolitic Bilara group and arenaceous Nagaur group with thick evaporite cycles present in the Nagaur Basin. The Birmania Basin, an isolated small Basin, exists south-west of the Nagaur Basin whereas the Randha sandstone and Birmania Dolomite are considered to be homotaxial to the Jodhpur and Bilara groups respectively.

The Cambrian sequence is overlain by the upper carboniferous glacial Bap Boulder Bed and the marine Bhadura sandstone increasing upto subsurface fresh water sediments. The Lathi sandstone of continental deposition overlies the Precambrian and Palaeozoic sequences and formed the largest basin spread over the entire north-western Rajasthan.

The marine Jaisalmer limestone, Baisakhi Shale, Bedasar sandstone, continental Parihar sandstone and marine Abur limestone form the Mesozoic sequence of Jaisalmer Basin. The Fatehgarh sandstone overlies the lathi sandstone in the Barmer Basin. The palaeogene succession presents Palaeocene and Eocene sequences which overlap the older rocks indicating erosional unconformity. In the Jaisalmer Basin the continental Sanu sandstone grades subsurface into marine and non-marine sequences, alternately and is correlatable to the Palana shale and Akli Bentonite of Palana area and the Barmer Basin respectively.

The Khuiala limestone and the Bandha limestone form the marine Eocene sequence of the Jaisalmer Basin; continental Marh sandstone and marine Jogira fuller's earth of the Palana area followed by continental Mandai sandstone and marine Kapurdi fuller's Earth of the Barmer Basin.

As such the north-western Rajasthan formed part of Indus Basin and extended southwards to Kutch with the upliftment of Rajasthan shelf finally in the upper Eocene and remained as land. However, the Kutch shelf and the lower Indus Basin preserve post Eocene succession.

Geochronological studies were attempted by Crawford (1969) determining the age of coarse Porphyritic nepheline syenite to be 1590 million years, medium to coarse grained nepheline syenite from Kishangarh to be 935 million years and sodalite to be 1290 million years. Compston (1970) who determined age of Malani rhyolite, felsite and tuff from Miniari, Barmer and Bissala to be  $745 \pm 10$  million years. While Sharma *et al.* (1975) have determined  $600 \pm 70$  million years as fission track age of Aplite from Pink granite of Jalore.

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# 5

## SOILS: DISTRIBUTION, CHARACTERISTICS AND NUTRIENT DYNAMICS

D.C. Joshi, Nepal Singh, B.K. Sharma and Pramila Raina

Arid region of north-western India has been endowed with a variety of soils. History of landscape evolution, present day climate and micro-topographic variations have contributed for the large variability in these soils. In arid region of Rajasthan, Haryana, Punjab and eastern part of arid Gujarat the soils have developed from the alluvial and aeolian parent materials where as in Saurashtra and Kachchh region basalt and coastal lime stone have been the parent material.

The alluvium and aeolian parent materials are the quaternary formations. During this period the region witnessed wide spread alluvial sedimentation but the overall environment was semi-arid (Dhir, 1989; Dhir *et al.*, 1994). This alluvium was reworked by the subsequent aeolian activities. Since the last glacial period the region has experienced two major periods of aridity separated by a long period of amelioration of climate during which natural vegetation reached its maximum extent (Singh, 1977). The dune building aeolian activity began at least 200 ka years ago and terminated around 13,000 years B.P. (Singhvi *et al.*, 1983). Vast alluvial plain of Haryana and Punjab was formed out of the sediments deposited by the rivers flowing from Shivaliks. During arid phase this alluvium was reworked by aeolian activity and resulted in the formation of sand dunes and sandy plain. Many stream courses were buried under the thick mantle of sand (Sidhu and Sehgal, 1978).

Physiography/micro-relief variations have also contributed to the pedogenic characteristics of soils (Pandey *et al.*, 1967; Khanna *et al.*, 1977; Lodha *et al.*, 1982; Ahuja *et al.*, 1978a). Because of aridic soil moisture and hyperthermic temperature regimes, the weathering and translocation of soil minerals and pedogenic manifestations within the profile have been weak. In aeolian plain, sandy soils are the major formation whereas in alluvial plain medium/fine textured soils are encountered. These soil groups within themselves have large variability in their colour, texture, calcareousness, salinity status and nature of the substrata. Extensive soil surveys in the region have brought out these differences and broad categories of soils occurring in the region have been recognised and their salient characteristics reviewed (Mathur *et al.*, 1972; Dhir, 1977a; Dhir and Jain, 1982; Dhir and Singh, 1985; Sehgal *et al.*, 1985; Kanzaria and Patel, 1985; Joshi, 1985, 1993a, b; Dhir *et al.*, 1992; Kolarkar *et al.*, 1997).

## **Soil Resources Appraisal**

### **Rajasthan**

In arid region soil survey started in early fifties both by central and state government agencies. These included: (a) pre-irrigation survey of IGNP command area, (b) soil survey as a part of integrated natural resources survey by the CAZRI, and (c) detailed survey for soil and moisture conservation including those on watershed basis. Dhir *et al.* (1980) have given an over view of the soil resources appraisal carried out by these agencies.

Aerial photographs are being used since beginning for recognition of soil features (Abichandani, 1965; Kolarkar and Abichandani, 1967; Dhir, 1974; Iyer, 1980; Dhir and Joshi 1980). Later on the satellite imageries became indispensable tool for soil mapping. Dhir *et al.* (1978) observed that with band 7 the dominant coarse loamy Typic Camborthids in association with dunes could be recognised. Hard pan soils were identifiable by the associated features whereas fine loamy Typic Camborthids could be identified with post-monsoon season imageries. Saline soils were largely inseparable from associated shallow soils. Joshi *et al.* (1997) found that the Landsat FCC LISS-2 November imagery was found better for mapping soil series in Jalor district. Different types of salt affected soils could be mapped by three season data (April, October, February). The Landsat/IRS FCC subscenes provided basis for mapping type and intensity of soil degradations.

In arid region of Rajasthan pre-irrigation survey of 16,080 km<sup>2</sup> of Indira Gandhi Nahar Pariyojana (IGNP) was carried out under assistance from FAO (1971-72) and area was classified according to land irrigability. The assessment showed that out of total area only 3.9 per cent area was good irrigable, 40.5 and 8.4 per cent area moderately good/good irrigable soils and remaining 47 per cent area comprised of high dunes which were non-irrigable. Iyer (1980) using aerial photograph carried out the irrigability survey of lift command area and reported that out of total 0.45 million ha, 0.38 million ha area was in class III and 0.07 million ha area associated with limitations like dune topography, coarse texture and shallow depth soils of class IV.

As a part of integrated natural resources programme CAZRI has been carrying out regular surveys since 1959. Initially surveys were done for Chohtan, Luni, Saila and Jalor development blocks and later on these were conducted on district basis. Soil series/phases were the mapping units. In arid region of Rajasthan soil survey has been completed in eight districts and total 85 soil series have been mapped, out of which 15 series have been recognised at national level (Sohan Lal *et al.*, 1994). Dhir (1977a) reported light brown sandy soil with dunes as dominant formation in 30.6 and as associated in another 34 per cent area, brown light loam in 1.7, grey brown in 13.6, hard pan in 5.9 and sierozem in 1.6 per cent area. While reviewing the distribution of sandy soils in Rajasthan, Kolarkar *et al.* (1989) reported that in 12 district of arid Rajasthan sandy soils occupied 14.3 million ha. The recognised soil data have been interpreted for their resource potential. Kolarkar and Dhir (1981) observed that on light textured soil series pearl millet was the



dominant crop but on dune soils it was mixed with moth bean and on medium textured soils besides pearl millet, mung bean, sesame and sorghum becomes increasingly prominent. The medium to fine textured soils are cropped with wheat under conserved moisture. Sharma *et al.* (1980) based on land capability and estimated surface runoff water in Rampura and Balarwa watersheds proposed respectively 65 and 40 per cent area for rainfed cropping with measures for conserving runoff generated from adjoining non-agricultural lands.

## Punjab

In Punjab, the south-west sector is occupied by arid soils. These are brown, yellowish brown to dark yellowish brown, loamy sand, sandy loam and loam, very deep having lime enriched horizon within 1 m, between 1 to 1.5 m and below 1.5 m. Sehgal *et al.* (1985) have classified these soils as Cambids, Calcids, Torripsamments and Torrifuvents. Associated with these sub-orders also occur Salic and Natric sub-groups as intergrade. The sandy soils which occur in plains and also as low sand dunes in districts of Ferozpur, Faridkot, Bhatinda and Sangrur and occupy 0.32 million ha (Sharma and Sidhu, 1989). Upadhyay *et al.* (1977) reported that the soils at the dune top are sandy in the control section and those on the dune sides and interdunes are sand/loamy sand in the upper 35-70 cm of profile and heavier below (sandy loam/loam). In Abohar tehsil 16, 49, 35 per cent area has been mapped under fine sandy, light textured and medium textured soils. The CaCO<sub>3</sub> is present in diffuse form (Anon., 1992a).

## Haryana

Singh *et al.* (1985a) have recognised desert, sierozem and arid brown soils in the arid region of Haryana. Karwasra *et al.* (1989) reported 0.94 million ha area of sandy soils in arid districts of Bhiwani, Hisar, Sirsa and Mahendragarh where sand activity was intense. Ahuja *et al.* (1978 b, 1980) based on the intensity and distribution of aeolian activity and cover, has classified the arid region in three zones viz. (1) west of 300 mm with high intensity of sand dunes, (2) between 300 to 400 mm with stabilised sand dunes/loamy sand to sandy loam/loamy sand to silt loam soils, and (3) between 400 to 500 mm with loamy sand/sandy loam/loam soils. Ahuja *et al.* (1978c) in the Jui canal command area of Bhiwani district observed that Torripsamments (dunes and plain) and Camborthids are deep, fine sandy/loamy sand and non-calcareous. These soils occupy respectively 80 and 9 per cent area. The Paleorthids are shallow and highly calcareous. In Mahendragarh district (Anon., 1981a) six groups of soils viz. desert, yellowish brown to brown, dune and interdune, riverine alluvial and regosols have been identified.

## Gujarat

Kanzariya and Patel (1985) have reported shallow black, medium black, residual and desert soils in the arid region of Gujarat. The Aridisols and Entisols cover respectively 10.6 and 13.8 per cent area of the state (Kaswala *et al.*, 1996). Sandy soils occupy 2.12 million ha area in Banaskantha, Mehsana and Kachchh districts (Patel *et al.*, 1989a). These are very deep soils

associated with sand dunes and sand hummocks, yellowish brown to pale brown, medium sand, slight to moderately calcareous with loose massive structure (Dhar *et al.*, 1982; Dhar and Lole, 1983). Soils of dune free sandy plain have weak pedogenic development in the form of granular structure and lime accumulation in subsoil/substrata.

In Kachchh district (Singh and Kolarkar 1996a; Anon., 1981b; Singh and Singh, 1996) reported that nearly 82 per cent area is occupied by saline and rocky/gravelly waste. These salt affected soils are associated with eroded land with salt crust, deltaic upland, flat older alluvial plain, coastal alluvium, mudflat of Banni, little/great rann, and mangrove. In main Kachchh land the soils have wide variability due to parent material and topography which has been recognised in 39 soil series and 55 mapping units. Most of these soils are clay loam/silty clay loam with 45-90 cm depth. Banni pasture lands are characterised by silty clay loam/silt loam deep soils classified as Aquic/Salids/ Haplosalids/Haplocambids.

In Jamnagar district, Joshi (1997a) has mapped seven soil series developed from basalt and one series from limestone. Gently undulating physiography associated with broad convex upland, integrated drainage system, inundation due to sea and aridic moisture regime have attributed to variations in morpho-genetic characteristics of these soils. These soils are generally clay loam to silt loam and 30 to 50 cm deep. For growing groundnut crop the Khambhaliya series has constraints due to soil aridity and adverse soil physical characteristics whereas Khambhaliya shallow phase and the Okha series normal/shallow phase have constraints due to shallow depth, low available water capacity and moderate/severe water erosion in addition to soil aridity and adverse physical characteristics. Thus only Khambhaliya soils were suitable for groundnut cultivation (Joshi, 1994).

## **Soil Degradation Studies**

Besides arid climate, the soils of arid region have a number of constraints for sustainable landuse (Joshi, 1996a) and upon irrational landuse (Dhir, 1977b) these are prone to degradation. Different soil degradation processes such as wind erosion/deposition, water erosion and salinisation due to brackish water irrigation and also due to water logging have been identified. Delineation of kind and intensity of soil degradation has been attempted by many workers (Kolarkar and Singh, 1988; Raina *et al.* 1991, 1993; Ramchandran *et al.*, 1992). With the help of Landsat Thematic Mapper subscenes types and degree of soil degradation has been mapped in the sandy plain. In an area of over 0.5 million ha 42 per cent was degraded by wind erosion and 50 per cent by accelerated water erosion. Nearly 70 per cent area was slightly affected followed by 17 per cent moderately and 6 per cent severely degraded (Raina *et al.*, 1991). In alluvial plain the Landsat TM FCC with ground verification revealed (Raina *et al.*, 1993) that out of 0.36 million ha, 52 per cent area was degraded due to soil stripping, sheet wash and gully erosion and 8 per cent due to salinity. Soil degradation due to combined effect of water erosion and salinisation covered 33 per cent area. Irrigation with high residual carbonate (RSC) water (15-20 meq/l RSC)

turned soils sodic, which acquired unusual hardness, reduced infiltration surface crusting and reduced availability of micro-nutrients (Joshi 1992a). Because of very low and un-economic yields the lands are abandoned for cultivation. Several thousands hectares of such lands have been desertified in this region. Technology involving gypsum treatment has been developed for management of high RSC waters for irrigation (Joshi and Dhir, 1991, 1994; Joshi, 1997c). Raina and Joshi (1994) have reported deterioration in physical, chemical and biological properties of soils which have been adversely affected nutrient availability, compaction of soil, surface crusting and loose sand deposition resulting in non-congenial soil environment for plant growth, micro-organism and nutrient availability.

### **Morphogenetic Characteristics**

In aeolian plain, soils associated with sand dunes are uniformly fine sandy in different horizons, single grain and pale brown (10 YR 6/3) to light yellowish brown (10 YR 6/4), having  $\text{CaCO}_3$  in diffuse form/lime segregation. The soil profile is devoid of any pedogenic manifestation. The associated interdunal soils have slightly more of silt and clay. Illuviation of  $\text{CaCO}_3$  is also pronounced in these soils. In sandy plains with scattered dune, the light brown sandy soils are brown (10 YR 5/3) weakly calcareous, loamy sand having lime concretionary horizon at 60 cm depth. Soils developed from proluvium are dark reddish brown (7.5 YR 3/4), sandy loam, weakly blocky and non-calcareous. The soils of alluvial plain are dark brown (10 YR 5/3), dark greyish brown (10 YR 3/2), loam, clay loam, silty clay loam and calcareous underlain by lime concretionary horizon.

### **Genesis of Cambic Horizon**

In soil profiles of aeolian and alluvial plains, there is slight illuviation of finer fractions of earth materials (Dhir, 1977c) which qualify for cambic horizon. Micromorphological studies revealed that though dune soils were without any specific microfabric features but the sandy plain soils were characterised by thicker bridge and bridge cutans (Choudhari, 1989a). Micromorphological investigations of alluvial soil profiles confirmed mineral alteration, and illuviation of clay by the presence of distinct micro-structure, ground mass and pedofeatures. Pedogenic calcite in Pipar series was pure but in Gajsinghpura it was impregnative. Joshi (1997b) based on fine clay/coarse clay, HA-carbon/FA-carbon, free iron, free manganese and distribution of  $\text{CaCO}_3$  in the profile observed illuviation between 40-110 cm in coarse and 40-60 cm in fine textured soils. Manchanda *et al.* (1983) in the Aridisols of Haryana observed shining faces and increase in clay content but patchy cutans were insufficient to qualify the argillic horizon. Sidhu *et al.* (1976) while studying the influence of dust fall on surface properties of Punjab soils suggested that for consideration of lithological discontinuity the sand/silt value of 0.2 and above should be taken.

Several workers (Sharma *et al.*, 1994; Kaswala *et al.*, 1996) have reported toposequence for the soils of Gujarat and inferred that the shallow black soils of Saurashtra region followed close physiography-soil relationship. Joshi and Raina (1996) have reported morpho-genetic characteristics of soils occurring at crest, mid slope and valley fill in the gently undulating basaltic terrain in Jamnagar district.

### Genesis of Calcic Horizon

Occurrence of calcic horizon at variable depths is typical formation of this region. The sandy plain soils have well developed horizon of  $\text{CaCO}_3$  at 60-120 cm depth (5-45 %  $\text{CaCO}_3$ ) in the form of concretions 5-35 per cent by volume. Abichandani (1964) reported calcareous nests and crust in the dune soil profile. Roy *et al.* (1969) concluded that the carbonate pan has developed due to katamorphic processes in the weathered zone of regional formations i.e. granite and volcanic. Dhir and Kolarkar (1977) suggested formation of calcic horizon during the late pleistocene. Dhir *et al.* (1982) revealed that strongly cemented and plugged concretionary formations and the lithic calcrete were associated with Plio-pleistocene and still older surfaces. The calcic layer in the late Pleistocene alluvial plain was a mixture of finely dispersed and hard macro-crystalline concretionary forms. Courty *et al.* (1987) after detailed field investigations and micromorphological studies suggested two mechanisms of secondary carbonate accumulations viz. (i) related with presence of ground water table enriched in dissolved calcium carbonate, and (ii) downward movement of  $\text{CaCO}_3$  and its gradual accumulation.

Characterisation of three lime segregation viz. calcified lense, concretions and lithic calcrete in Jaisalmer district (Joshi and Dhir, 1995) revealed that in the calcified lenses the dominant fraction was very fine sand, in concretions it was coarse sand and in lithic calcretes both, the coarse and fine sand were present in variable proportion. Calcareous material present in parent material has been redistributed by pedogenic processes and massive accumulation in localised depressions could be attributed to overland and subsurface runoff (Choudhari, 1994).

In arid and semi-arid region of Punjab and Haryana, Sehgal and Stoops (1972) recognised as many as nine forms of lime in calcic layer, amongst which compact calcite nodules with globular hollow and spongy calcite were extensive. Sehgal *et al.* (1985) also reported that soil profile below 250 mm rainfall was calcareous through out. With increase in rainfall the calcareousness in soils decreased and  $\text{CaCO}_3$  occur below 60 cm in semiarid zone. Manchanda *et al.* (1984) reported that the lime nodules in the soils of Haryana were not of secondary origin but were brought down by the rivers along with the alluvium and deposited during aggradational process.

### Genesis of Gypsic Horizon

Various views have been expressed regarding origin of gypsum in the arid region of India. Jacob *et al.* (1952) studied the micro-fossils from the Jamsar gypsum quarries and inferred that Rajasthan gypsum was deposited away from sea in inland basins or depressions in the late quaternary or sub recent times. Ghosh (1952) after comparing various hypothesis concluded that

as the result of percolation of the solution charged with suitable salts the gypsiferous soils have been formed. Deb (1952) after a detailed survey of the depressions around Lunkaransar (district Bikaner) reported that soils at the depth of about four feet contain 8 to 10 per cent gypsum. The gypsum bearing formation is invariably a dark grey coloured clayey material with an average depth of 2.5 feet. Top of this argillaceous bed usually contains small crystals while the bottom contains big crystals. Gypsiferous soils occupy 845 km<sup>2</sup> in arid region of Rajasthan (Dhir *et al.*, 1997). Two great groups of gypsiferous soils (sub-order Gypsid) viz. Petrogypsid and Haplogypsid have been recognised (Joshi, 1997 d). The Petrogypsid has petrogypsic horizon at 30-50 cm depth formed of gypsum crystals, CaCO<sub>3</sub> and sand cemented together which is indurated and impervious to water and roots. In Haplogypsid, the gypsic horizon is at 50-70 cm depth consisting of amorphous gypsum which is pervious to plant roots and water. The gypsiferous interdunes have high proportion of silt, CaCO<sub>3</sub> and salinity.

### Genesis of Salt Affected Soils

Problem of salinity, in arid region, has drawn attention of scientists since beginning. Auden (1952) while accepting the theory of wind blown origin of salts from rann of Kutch propounded by Holland and Christie suggested that presence of an arid region with low rainfall, high evaporation and sluggish drainage interrupted by accumulation of wind blown sand also provide an environment favouring accumulation of salt. Sarin (1952) attempted to draw attention to some of the problems that affect preservation and proper utilisation of salinity to national advantage.

Mehta *et al.* (1969) after an exploratory survey gave a broad distribution of these soils. Later on with the development of more sophisticated technique of survey like aerial photograph and satellite imageries, mapping of salt affected soils was taken up. Raychaudhuri (1980) reported that hot dry climate was essential condition for the formation of salt affected soils in the existence of vast depressional area having some kind of water course. Dhir *et al.* (1979) and Kolarkar *et al.* (1980a) with the help of aerial photograph reported that salt affected soils in the Luni basin generally occur along the stream courses and in localised micro-depressions. They could map five categories of salt affected soils viz. naturally saline, saline depressions, relict saline, secondary saline due to high water table and secondary saline due to saline water irrigation. Kolarkar *et al.* (1980 b) observed that mapping of salt affected soils was possible with the imageries of band 5 and band 7 together. Singh and Kolarkar (1996) with the help of satellite imageries identified 5807 km<sup>2</sup> salt affected area in Luni basin. Kalra and Joshi (1994) with the help of ground radiometer observed highest reflectance of salt encrusted naturally saline soils followed by sodic soils due to high RSC water irrigation, natural saline soils and saline water irrigated soils. Moderate and severe natural salt affected soils could be separately mapped by using Landsat MSS, Landsat TM, IRS LISS-I, IRS LISS-II and SPOT data of April and January (Kalra and Joshi, 1996). But for the differentiation between the saline and sodic soils due to irrigation waters both the October and the January imageries were required.

## Mineralogy

Comprehensive review on mineralogy of sandy soils has been published earlier (Choudhari *et al.*, 1989). Many research workers have made efforts for characterisation of mineralogy of fine sand and clay fraction and resume of the work is given below.

### Fine Sand Mineralogy

Nearly ninety seven to ninety nine per cent of fine sand fraction of sandy soils occurring at different geomorphic locations is made up of light mineral suite. Gupta (1958) reported varying amounts of easily weatherable minerals such as hornblende, feldspar, kynite and mica in desert soils of western Rajasthan and attributed to their aeolian origin. Choudhari (1988) observed orthoclase as the dominant feldspar mineral and heavy mineral constitute only 1.8 to 7 per cent. Choudhari (1989b) in the fine sand fraction of sand dune, interdunal plain, alluvial plains and pene-plain of arid region of Rajasthan observed that quartz was the dominant mineral followed by orthoclase plagioclase and microcline in light mineral fraction. The heavy mineral fraction comprised of chlorite, monazite, zircon, garnet, tourmaline, mica, kyanite and iron ore minerals. Choudhari *et al.* (1985) also reported mica, chlorite, mixed layer minerals, quartz and feldspar in reddish brown sandy soils. Fine silt fraction contains higher proportion of mica, chlorite and mixed layer minerals where as coarse silt is high in quartz and feldspar. Silt fraction of coarse loamy Cambids showed presence of quartz, feldspar, mica chlorite and calcite (Choudhari *et al.*, 1988).

Singh *et al.* (1974) and Upadhyay *et al.* (1977) found higher amount of weatherable minerals in dunes of Haryana and attributed their origin to the weathering products of gneiss and schists of Himalaya. There was no relationship between the mineralogy of sand fraction of dunes of Punjab and Haryana to that of Thar desert (Roonwal *et al.*, 1967; Upadhyay *et al.*, 1977).

### Clay Mineralogy

After study of soil profiles from different locations in 170-450 mm rainfall zone, Krishnamurti and Narayana (1968) showed that illite is the dominant mineral in all soils except the grey brown soils where montmorillonite dominated. Kaolinite and attapulgite were present in much lower proportion.

In dune and sandy plain soils clay fractions is dominated by illite/mica followed by smectite (Choudhari and Dhir, 1982a; Choudhari *et al.*, 1985). Much broadening of 10 Å spacing was attributed to interstratification of expansible layer (Choudhari and Dhir, 1982a). Smectite presence in sandy soils was assumed to be mainly of detrital origin and only a part of it was pedogenic due to transformation of mica. In reddish brown soils fine clays though dominated by mica also contained high proportion of smectite and/or vermiculite. Coarse clays were chiefly composed of mica, chlorite, smectite and mixed layer minerals (Choudhari *et al.*, 1985). In the medium/fine textured alluvial soils of arid region Choudhari and Dhir (1981) reported that clay fraction chiefly

consists of mica (illite), smectite, vermiculite and kaolinite. Fine clays of Gajsinghpura and Pipar soils are dominated by smectite whereas Palaripichkia by mica. A comparison of the clay minerals in soils developed from quaternary deposits of western Rajasthan revealed that mica, smectite and kaolinite are the inherited clay minerals (Choudhari and Dhir, 1982b). Accumulative and evaporative environment on mid-pleistocene surface favoured formation of smectite.

### **Amorphous Alumino-silicate**

Amorphous allumino-silicate are 3 to 15 per cent in different arid soils. The content was higher in dune soils followed by sandy alluvial and those developed on sand stone (Choudhari and Dhir, 1983; Choudhari *et al.*, 1985). The material in the fine clay fraction is twice more siliceous than in coarse fraction. The  $\text{SiO}_2/\text{Al}_2\text{O}_3$  ratio in amorphous alumino-silicates associated with the clay fraction of medium/fine textured soils was 2.43-4.56 in fine clay and 1.46-2.67 in coarse clay indicating siliceous nature of the clay mineral (Choudhari and Dhir, 1981).

### **Classification**

The soils of arid Rajasthan in 300-500 mm rainfall zone have been classified as grey brown desert and in the less than 300 mm rainfall zone as the desert soils (Raychaudhuri, 1964; Mathur *et al.*, 1972). The classification was too broad and included morphologically different soils. Roy and Sen (1968) improved the classification by separating out a group of dark coloured light to medium textured soil as red desertic soils. They also classified soils with deep seated lime accumulative zone as sierozems. Dhir and Mann (1978) recognised eight soil groups in arid region of Rajasthan. Raychaudhuri *et al.* (1963) considered the calcareous soils of Punjab and Haryana to be pedocal sierozem. Raychaudhuri and Govindarajan (1972), and Sidhu *et al.* (1972) later renamed them as calcareous sierozem.

The US comprehensive system of classification since its introduction in mid-sixties, has been attempted by various workers for classification of arid zone soils (Mathur *et al.*, 1972; Dhir, 1977a). Sehgal *et al.* (1986) observed that the light textured soils of sandy plains which have distinct distribution of alkaline earth carbonate and development of soil structure are characterised by loamy sand texture and thus coarser than loamy fine sand and accordingly get classified as Torripsamments with the sand dunes. They suggested a new sub group like Torripsammentic Camborthids to accommodate these soils. Dhir and Jain (1982) observed that soil with cambic horizon are calcareous in many situations and there is a need of modification to accommodate the calcareous soils having cambic horizon as cambids. These soils have been classified according to Key to Soil Taxonomy (Anon., 1992b) in two orders viz. Aridisols and Entisols (Dhir *et al.*, 1997). The Aridisols have been further classified in the sub-orders Cambids, Calcids, Gypsids and Salids and the Entisols in the sub-orders Psamments and Fluvents. The Aridisols occupy 41 and the Entisols 52 per cent area. The calcic, petro-calcic, cambic, gypsic, petro-gypsic and salic horizons

have been identified which are peculiar to the soils of this region and distinguish them from other soil orders.

### **Dynamics and Availability of Nutrients**

The arid soils because of their low productivity did not receive much attention for fertility investigations during sixties. For quite some time these soils were considered low in available nutrients. Most of the early work was related with the organic carbon, available phosphorus and potassium of soil samples collected during surveys. With the availability of Atomic Absorption Spectrophotometer (AAS) in early seventies research work on micro-nutrients got momentum. Since then research on adsorption, fixation and release of nutrient elements has been taken up. The work on forms and contents of both major and micro-nutrients in sandy soils has been reviewed by Joshi *et al.* (1989). The north-western hot arid zone present a variety of soils and efforts have been made to present the review of research on dynamics and availability of nutrients in these soils.

### **Organic Matter and Nitrogen**

Arid zone soils have low organic matter and are deficient in nitrogen. Low amount of organic matter in these soils has been attributed to high temperature, low rainfall, scanty and scrub vegetation cover and sandy texture of the soils (Jenny and Raychaudhuri, 1960). With increase in clay content there was increase in organic carbon content (Dhir, 1977). Mean organic carbon content of soils below 300 mm rainfall zone ranged between 0.05 to 0.2 per cent in coarse textured soils, 0.2 to 0.3 per cent in medium textured and 0.3 to 0.4 per cent in fine textured soils. Joshi (1990b) reported that bulk of organic carbon was present in non-humic form followed by fulvic and humic form. With increase in silt+clay mean value of HA-carbon/FA-carbon decreased.

Build up of organic carbon, nitrogen and C/N ratio (10:1) under vegetation cover has been reported by many workers. The soils of dunes stabilised with different vegetation as compared to unstabilised dunes (Aggarwal and Lahiri, 1981) and soils near grass clumps (Dhir and Gajbhiye, 1973) contained higher amount of organic matter. However Kolarkar *et al.* (1974) found very little difference between the organic carbon content of soils under rangelands and adjoining arable lands. Singh and Lal (1969) and Aggarwal *et al.* (1993) observed higher available nitrogen (250 kg/ha) content in soils underneath *Prosopis cineraria* than in the adjacent open soils.

Aggarwal *et al.* (1975) reported C/N ratio between 5.1 to 6.9 and 3.9 to 10.1 respectively in surface and sub surface soil. The non-hydrolysable and hydrolysable N ranged between 8.8-78.7 and 201.3-341.3 ppm, respectively. Amongst the different fractions the order of distribution was amino acid > unidentified N > ammonical N > hexose amine N (Aggarwal and Lahiri, 1977; Aggarwal *et al.*, 1990). The concentration of nitrate-N in the surface soils increases from 3 ppm in winter to more than 5 ppm in summer.



## Phosphorus

The available phosphorus content vary widely in different soils and mean content in different soil series is less than 20 kg/ha. Total P content was less than the adjoining soils. Indus and Gaggar alluvial soils contain slightly higher values (408-716 ppm; Ram Deo and Ruhai, 1972). Inorganic P constitute 80-85 per cent of total P, major part of which constitute Calcium bound P (Mehta *et al.*, 1971; Joshi *et al.*, 1973; Choudhari *et al.*, 1979; Choudhari and Jain, 1972; Talati *et al.*, 1975).

Total and inorganic phosphorus were irregularly distributed in the soil profiles of arid soils but organic P decreased (Pareek and Mathur, 1969; Talati *et al.*, 1975). In the arid soils of Haryana and Punjab, Ca-P was 80 per cent of the inorganic P. In these soils Al-P was higher than Fe-P. The amount of added P that becomes available to plants depends on P fixation capacity of soils, which was less for arid soils (0.87-1.35 g/100 g) than the semi-arid soils (Dhawan *et al.*, 1969).

## Potassium

Soils of arid region are generally well supplied with potassium. Total K content varied from 0.54 to 1.57 per cent and slightly higher values were observed for dune and interdune than the sandy plain soils (Joshi *et al.*, 1982). Total K was significantly related with clay and silt and inversely with sand in Haryana soils (Singh *et al.*, 1985) but such relationship was not observed for arid soils of Rajasthan. Coarse fraction (Lodha and Seth, 1970) and silt (Joshi *et al.*, 1978) were significant contributors of total K in arid soils of Rajasthan.

The amount of HCl-K was comparable in arid soils of Haryana and Punjab (Khanna and Prakash, 1970) but the contents in similar soils in Rajasthan were low (Dhawan *et al.*, 1968). Chahal *et al.* (1976) reported low content of fixed K (16-385 mg kg<sup>-1</sup>) in soils of Ambala and Gurgaon. In arid soils of Rajasthan wide ranges in HNO<sub>3</sub> soluble (30-1270 mg kg<sup>-1</sup>) and fixed K (20-1120 mg kg<sup>-1</sup>) have been reported. The contents of these fractions decreased in the order salt affected (Joshi, 1993c) > alluvial soils (Dutta and Joshi, 1983, 1989a) > interdunes > dune soils (Dutta and Joshi, 1989b).

In different soils the HCl and HNO<sub>3</sub> soluble and fixed K were positively related with CEC and the available K with CaCO<sub>3</sub> (Joshi, 1996b). The dune and interdune soils showed negative K fixation (Aggarwal *et al.*, 1979; Joshi *et al.*, 1982a). Increase in K fixation was observed soils in sandy plain (40-220 mg kg<sup>-1</sup>) and alluvial plain (30-370 mg kg<sup>-1</sup>) soil. The K fixation capacity was related with clay content, K-saturation per cent and weathered K bearing minerals (Dutta and Joshi, 1993; Mathur *et al.*, 1981). Studies have revealed release of K for replenishment of depleted K (Talati *et al.*, 1974; Joshi, 1986a).

The activity ratio for different arid soils were in the range of 3-21 x 10<sup>-3</sup> mol L<sup>-1</sup>. Labile K (K<sub>L</sub>), potassium adsorbed on specific (K<sub>s</sub>), non-specific (K<sub>o</sub>) sites, potassium buffering capacities (PBC<sub>K</sub>) and K-potential were generally low in dune, interdune and sandy plain soils than the medium/fine textured alluvial soils. (Dutta and Joshi, 1990, 1992; Joshi, 1992b, 1993c).

In soils of Saurashtra region wide ranges in potassium contents (me/100 g) in water soluble (0.003-0.21), exchangeable (0.03-2.0), non-exchangeable (0.32-21.7) and total forms (1.1-20.3) have been reported (Patel *et al.*, 1986, 1989b, 1993). Increase in CaCO<sub>3</sub> beyond 30 per cent enhanced the K fixation. Different K parameters viz. PBC<sub>k</sub>, AR<sub>k</sub>, -ΔG decreased with increase in clay content and the values were on lower side (Patel *et al.*, 1993). In soils of north Gujarat available K was low in 5.4, medium in 55.2 and high in 38.5 per cent soils (Kalyansundaram *et al.*, 1993).

## Iron

In the arid soils of Rajasthan forms of iron viz. total, HCl-soluble and free ranged from 1.2-3.4, 0.59-2.08 and 0.27-0.34 per cent respectively (Lal and Biswas, 1973; Joshi *et al.*, 1981; Sharma *et al.*, 1984). Slightly lower values for these forms have been observed for arid brown soils of Punjab and Haryana (Takkar and Bhumbla, 1968; Takkar, 1978). Soils rich in ferro-magnesian minerals contained higher amount of total iron (Joshi and Dhir, 1982). Dune soils occurring in better rainfall zone (400-450 mm) contained higher amount of HCl soluble and free iron (Joshi and Dhir, 1983a). Free iron and exchangeable Fe content were higher in interdune soils. The exchangeable Fe was in the range of 2.2 to 5.6 ppm in different arid soils. There was little difference in the HCl-Fe and free iron content of the salt affected and associated non-saline soils. Due to the effect of different soil parameters in salt affected soils the HCl-Fe was better predicted but free Fe had low predictability (Joshi *et al.*, 1988a). Exchangeable Fe content in the salt affected and associated non-saline soils was comparable. In the arid soils of Punjab reducible and exchangeable Fe were in ferrous forms while in Rajasthan and Haryana soils these were in ferric form (Shukla and Singh, 1973; Shukla *et al.*, 1975; Choudhari *et al.*, 1979).

Exchangeable and DTPA soluble iron in different arid soils of Rajasthan varied from 0.8-6.3 and 2.2-16.7 ppm, respectively (Dhir *et al.*, 1983; Sharma *et al.*, 1985). These forms of iron were not related with any of the soil parameters and showed irregular pattern of distribution with depth. In arid brown soils of Punjab slightly higher values of exchangeable (0.1-11.7 ppm, Takkar and Bhumbla, 1968) and DTPA (4.8-24.0 ppm, Arora and Sekhon, 1981) have been reported. Wide variations (0.2-54.7 ppm) in the DTPA-Fe in the arid soils of Gujarat have been observed by Dangarwala *et al.* (1983).

In the arid soils of Rajasthan none of the samples tested <2 ppm DTPA-Fe. About 40 per cent soil samples contained 2 to 5 ppm and 54 per cent 5 to 10 ppm DTPA-Fe (Joshi and Dhir, 1983b). In Haryana soils of Mahendragarh district were well provided while 25 per cent soils in Sirsa and 51.6 per cent in Hisar district were deficient in iron (Anon., 1976-77; Shukla *et al.*, 1975). Iron deficiency has also been reported in Bhatinda (38%), Faridkot (40%) and Sangrur (11%) districts. In Jamnagar, Kachchh, Banaskantha and Mehsana districts 8 to 23 per cent soils were deficient and 45 to 65 per cent samples marginal in available iron (Dangarwala *et al.*, 1983).

## Manganese

There were wide variation in different forms of Mn, viz. total (250-875 ppm), HCl soluble (142.8-405.6 ppm), free (15-225 ppm) and reducible (3.2-123.4 ppm) in the arid soils of Rajasthan (Joshi *et al.*, 1981; Lal and Biswas, 1973), Punjab and Haryana (Takkar and Bhumbla, 1968) and Gujarat (Dangarwala *et al.*, 1983). Total Mn content was higher in medium and fine textured alluvial and Gaggar plain soils than in the sandy soils. Total Mn was not related with any of the studied soil parameters. The HCl soluble Mn was significantly related with clay, silt and organic carbon. The reducible Mn was not so much governed by the pH and CaCO<sub>3</sub> effects as by the clay and organic carbon effects (Joshi *et al.*, 1981). Dynamic equilibrium between different forms of Mn has been reported by Johari *et al.* (1978) and Sharma *et al.* (1984). In the soils of extremely arid part total and HCl soluble Mn were comparable with the similar soils in arid part but the reducible Mn was in low concentration (8.9-45.1 ppm; Joshi and Dhir, 1982). Free and reducible forms of Mn were in lower ranges in dune soils located in low rainfall zone (Joshi and Dhir, 1983a). Contents of HCl soluble, free and reducible forms of Mn in salt affected soils were comparable with the associated non-saline soils but their predictability was much reduced (Joshi *et al.*, 1988a). Free Mn was negatively related with pH and CaCO<sub>3</sub> and positively with organic carbon. Biswas (1953) found increase in the exchangeable Mn with increase in clay content. However Lal and Biswas (1973) reported slightly higher exchangeable Mn in desert soils than the fine textured soils. The mean content slightly increased in sandy loam and then decreased in loam and clay loam soils. The mean values of reducible, exchangeable and DTPA soluble Mn decreased with increase in pH, CaCO<sub>3</sub>, finer fraction and organic matter but exchangeable form did not follow the steady trend (Joshi and Dhir, 1983a).

The DTPA soluble Mn in arid soils of Rajasthan varied from 1.1 to 25 ppm (Dhir *et al.*, 1983; Sharma *et al.*, 1985). The content was comparable with similar soils of Punjab (Arora and Sekhon, 1981) but the Haryana soils have been reported to contain higher amount (6.4-73.8 ppm, Shukla *et al.*, 1975). The DTPA soluble Mn in the arid soils of Gujarat showed wide range (0.8-104.4 ppm) and only <5 per cent samples were deficient (Dangarwala *et al.*, 1983; Dangarwala and Patel, 1996). In arid Rajasthan 23 per cent samples were below the critical limit, most of which were from the dune and interdune soils (Joshi and Dhir, 1983b). In Haryana 29 per cent samples were deficient in Hisar and 40 per cent marginal in Sirsa district but soils of Mahendragarh district were adequate in available manganese (Anon., 1982-83).

## Zinc

Wide variation in the contents of different forms of zinc viz. total (22.5-81.3 ppm), HCl soluble (9.8-48.4 ppm), exchangeable (0.24-1.28 ppm) and DTPA soluble (0.27-2.36 ppm) have been reported by Joshi *et al.* (1982b) and Sharma *et al.* (1983). HCl soluble Zn was associated with clay, silt and organic carbon but exchangeable and DTPA soluble forms were not related with any of the soil parameters. Lal and Biswas (1973) and Singh and Singh (1981) attributed

higher values of total zinc in arid soils to the presence of augite and hornblende. Medium and fine textured soils contained higher values of HCl soluble Zn. Total and HCl soluble forms were uniformly distributed but exchangeable and DTPA soluble forms showed irregular distribution with depth (Joshi and Dhir, 1981). In Haryana Singh *et al.* (1987) observed low exchangeable Zn in soils containing more of clay. In Guhiya catchment the salt affected and associated soils were not much different in the contents of different forms of Zn. But high salinity appeared to vitiate their predictability (Joshi *et al.*, 1988b). Sharma and Kolarkar (1983) observed slightly higher values of DTPA-Zn (0.87-1.97 ppm). Dangarwala *et al.* (1983) have reported zinc deficiency respectively in 44, 39 and 13 per cent samples in Banaskantha, Jamnagar and Kachchh districts. Studies revealed that about 80 per cent sample of Hisar, Mahendragarh and Bhiwani districts of Haryana and 25 per cent samples of similar soils in Punjab are deficient in zinc (Anon., 1982-83; Arora and Sekhon, 1981). But in arid Rajasthan Zn deficiency had been encountered only in 13.5 and 9.6 per cent samples respectively in Barmer and Jaisalmer districts.

### Copper

Wide variations in the forms of copper viz. total (11.9-48.6 ppm), HCl soluble (6.3-24.2 ppm), exchangeable (0.23-1.56 ppm) and DTPA soluble (0.28-1.25 ppm) have been reported in different arid soils (Joshi *et al.*, 1982b; Sharma *et al.*, 1985; Dangarwala *et al.*, 1983). Shukla and Anand (1969) reported higher range of total copper (10-246 ppm) in the sierozem soils of Haryana. HCl soluble Cu was significantly related with clay, silt, organic carbon and CaCO<sub>3</sub> contents of soils. The ammonium acetate soluble Cu was negatively related with pH and positively with clay. Exchangeable Cu was critical in arid brown and marginal in sierozem soils of Punjab and Haryana (Grewal *et al.*, 1969; Singh and Shukla, 1984; Singh *et al.*, 1988). Medium to fine textured soils contained slightly higher amounts of DTPA soluble Cu than the dune, interdune and sandy plain soils. Available Cu was significantly related positively with clay, silt, organic carbon and negatively with pH. Though there was no difference in the contents of these forms of Cu in salt affected and associated non-salt affected soils their predictability was considerably low (Joshi *et al.*, 1988b). Total and available pool of Cu were not in equilibrium. Most of the arid soils of Rajasthan (Dhir *et al.*, 1983), Punjab (Nayyar *et al.*, 1982) and Haryana (Singh, 1983) appeared sufficient in this nutrient. However, Takkar *et al.* (1976) reported respectively 22 and 25 per cent samples deficient in Cu in Sangrur and Gurudasapur districts. In the Banaskantha district of Gujarat 22 per cent deficient samples have been reported by Dangarwala *et al.* (1983).

### Adsorption of Zinc and Copper by Arid Soils

Arid soils because of their low clay/organic matter content, illitic nature of clay minerals, low cation exchange capacity, high base saturation and calcareous nature have characteristic adsorption and release behaviour for nutrients. The Zn adsorption by sandy soils followed the Langmuir adsorption equation. The quantity of Zn adsorbed by sandy soils was much less than the medium/fine textured soils (Joshi *et al.*, 1983b; Joshi and Sharma, 1986). Significant relationships

between the quantity, intensity and supply parameters indicated that sandy soils could maintain higher level of available Zn. The calcareous soils had low adsorption maxima and high bonding energy constants than the non-calcareous soils. Strong affinity of Zn with  $\text{CaCO}_3$  indicated low availability of Zn in these soils (Joshi, 1996c).

Copper adsorption by different arid soils followed Langmuir adsorption equation. Fine sandy/loamy sand soils adsorbed less Cu ( $1.7\text{-}3.1 \text{ mg g}^{-1}$ ) than the loam soils ( $3.3\text{-}5.4 \text{ mg g}^{-1}$ ). Soils having higher differential buffering capacity adsorbed less Cu. Fine textured soils having comparatively higher quantity, intensity and buffering capacity required greater dose of Cu for any change in the supply parameter (Joshi, 1986b). Studies on the influence of free oxides on copper sorption revealed that removal of free oxides decreased the sorption maxima but the effect on bonding energy were not consistent (Joshi, 1996d). Adsorption of copper by calcareous could be explained by Freundlich equation. In calcareous soils Cu could be adsorbed at low concentration but with increasing addition there was precipitation of Cu rather than multilayer adsorption (Joshi, 1995).

## Boron

High boron content in salt affected soil of arid and semi-arid regions of world have been reported. In the arid soils of western Rajasthan Satyanarayan (1958) reported 2.6-12.2 ppm water soluble boron while Moghe and Mathur (1966), Nathani *et al.* (1970) and Talati and Aggrawal (1974) observed higher ranges (0.89-10.24 ppm). Total and available boron ranges from 20.4-40.1 ppm and 1.6-8.3 ppm respectively (Mathur *et al.*, 1964). Gajbhiye and Kolarkar (1979) reported 0.43-2.58 ppm water soluble boron in rainfed soils of arid Rajasthan and it was significantly related with silt+clay and organic carbon. Mehta *et al.* (1964) in arid soils of Banaskantha and Mehsana districts observed available B in low ranges (0.3-1.1 ppm) whereas in Saurashtra region it was in higher range (0.2-1.5 ppm). In Haryana, Singh (1970) observed low content of various forms of B in coarse than in fine textured soils. Immediately available and absolutely available B content ranged from 0.13-1.56 and 0.75-5.75 ppm respectively. In Punjab soils, Singh and Randhawa (1977) did not observe relationship between available B and soil characteristics.

## Factors Affecting Dynamics of Micronutrients

While studying influence of soil parameters on DTPA extractable micronutrient Joshi *et al.* (1983a) observed in coarse, medium and fine textured soils, negative influence of  $\text{CaCO}_3$  on the DTPA-Fe and of soil pH on DTPA-Mn. The DTPA-Mn was influenced positively in coarse textured soils by organic carbon and free-Mn and in fine textured soils by free-Fe. The DTPA-Zn in coarse and medium textured soils was negatively influenced respectively by free-Fe and pH. In coarse and medium textured soils DTPA-Cu was related with organic carbon. Contribution of forms of micronutrients on their available pool was variable in the coarse, medium and fine textured soils (Joshi and Dhir, 1988). Various soil degradations processes viz. aeolian hazards, water erosion including floods have detrimental effects on micronutrient availability (Raina and

Joshi, 1994). The soils under natural pastures were low in available micronutrients than the soils under sown ungrazed pastures (Raina and Joshi, 1991). Soils irrigated with saline and high RSC waters were low to marginal in available micro nutrients (Joshi, 1988, 1990a).

## **Epilogue**

The soils of north-west arid zone of India during last five decades have been mapped and investigated for their resource potentials with the help of latest technologies including aerial photographs and satellite imageries. Major soils of this region have been studied for their morpho-genetic and fertility characteristics. These soils are fairly well provided to meet the requirement of natural vegetation and present level of cropping but have inherent soil constraints. Because of these soil and associated climatic constraints, intensification of agricultural activities during last three decades have resulted in soil degradation. Therefore future research efforts should concentrate on developing models for rational utilisation of soil resources and monitoring of soil degradation processes by using satellite data. Monitoring of soil resources particularly in vulnerable areas for nutrient depletion, salinisation/sodification, waterlogging and wind erosion/deposition should form an integral part of the future research thrust. Strengthening of knowledge on micro-pedological aspects will be an essential ingredient for sustainable use of soil resources.

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# 6

## RESOURCE APPRAISAL - SURFACE WATER

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The arid ecosystems cover about one-eighth of the world's land surface. Majority of these are hot arid ecosystems while the rest are under the cold arid ecosystems, located in the sub-tropical and extra-tropical regions. Indian arid ecosystem occupies 12 per cent of the country's geographical area and characterised by limited seasonal precipitation with an erratic distribution, high atmospheric temperatures with large diurnal and seasonal variations, strong wind regime and high evaporative demand. The surface water is too meagre to sustain suitable crop production systems or any other water related activities.

Despite climatic austerity, Indian arid zone remains one of the most densely populated yet traditionally exploited region of the world. This density of human population is dependent upon the development of water as resource. The surface collection and temporary storage of rain runoff permit seasonal settlement and of livestock herding. Permanent settlement are mainly in areas where facilities for year round water storage exists (Khan *et al.*, 1990).

### **Hydrological Features**

Hydrologically the Indian arid zone has wide variation in different tracts (Fig. 1). The Luni is the only organised drainage system in western Rajasthan. It rises in the Aravalli hills near Ajmer and is lost in the Rann of Kachchh. The main tributaries of the Luni river are the Lilri, Mithri, Sukri, Guhiya, Bandi, Jojri, Jawai, Rediya and Sagi. These are ephemeral streams and remain dry in non-monsoonal period. Even during monsoon period stream flow is of very short duration. Occasional flashy flow changes the stream course section radically. In the central and western regions, there is no defined drainage system. Catchments with sandy soil and sand dunes, because of very high infiltration rate, do not produce any runoff. Runoff occurs only in localised areas from catchments with isolated hills or shallow soils with impervious basement. The runoff caused in response to some high magnitude rain storms gets collected in short channel length and lost in transmission or disappear in sand. The water courses are frequently choked in deep alluvium or blown sand. In fact runoff from such area is collected in stock water tanks for human and livestock consumption. The flow is generally of short duration and flashy (Khan *et al.*, 1990). In arid part of Gujarat there is no major river but numerous ephemeral streams flow in direct response to the high magnitude rainfall.

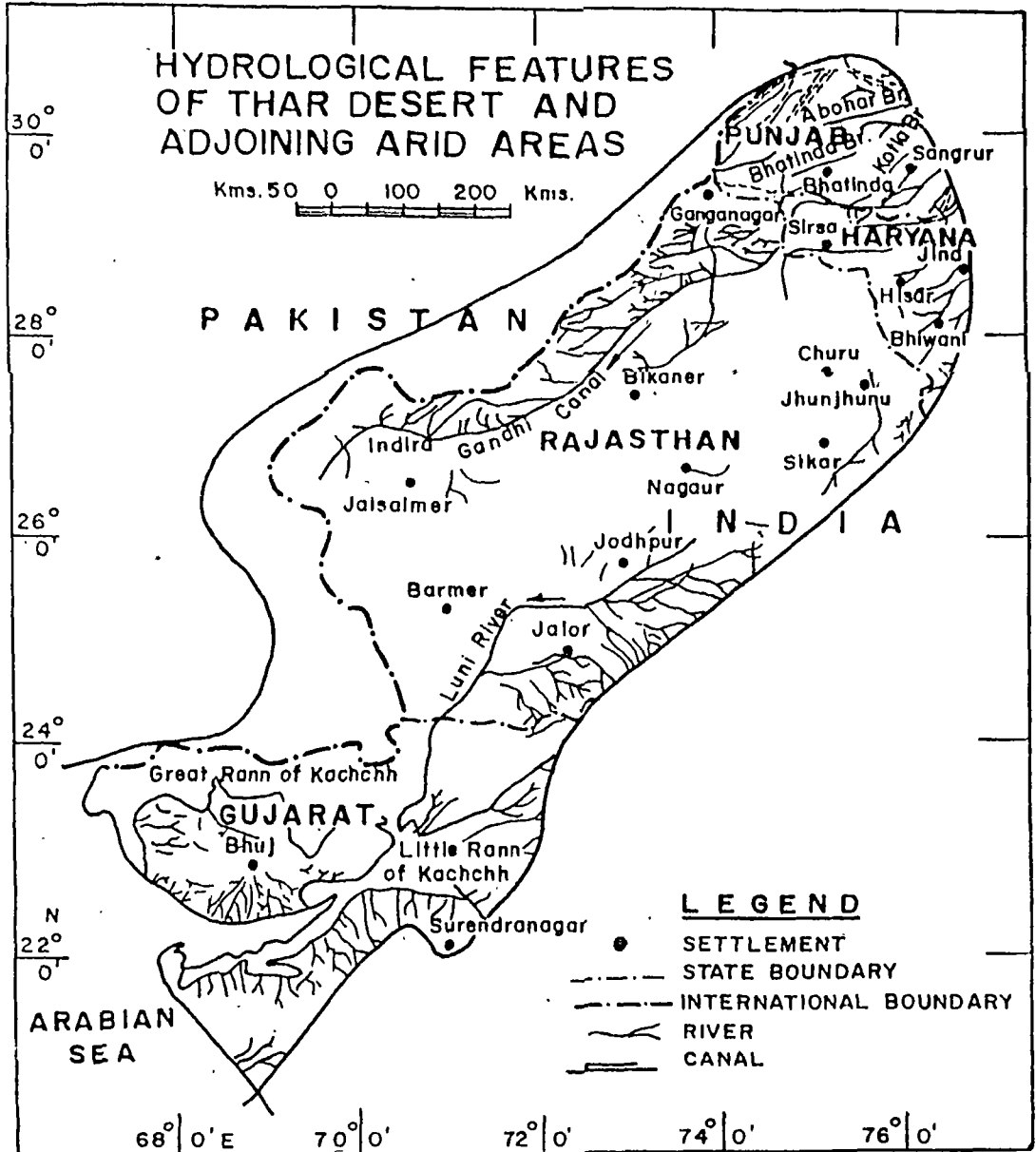


Fig. 1. Hydrological features of Thar desert and adjoining arid areas

The eastern part of arid region of Rajasthan and part of Gujarat have generally sloping topography with high relief in Aravalli hill ranges. The hill slopes because of excessive erosion in most of the places have very shallow soil. The central and western part of arid Rajasthan and a part of Gujarat, covering an area of 1,48,600 km<sup>2</sup>, have generally undulating to flat topography. The area is covered with sand interspersed by sand dunes, plateau and bosses of granite and rhyolite. The soil in general is light textured with high rate of infiltration and permeability and poor water storage capacity.

About one per cent area in north-west arid zone of Rajasthan is occupied by the canal network. The terrain of this zone is of sandy nature and, therefore, seepage losses are very high. At many places blown sand cover, subsurface barriers of clay and gypsum at varying depth are found which restrict vertical movement of water through them. In the state of Punjab, three arid districts of Ferozpur, Bhatinda and Sangrur and arid districts of Haryana, namely, Hisar, Bhiwani, Sirsa and Mahendragarh have very good canal networks to permit large scale irrigated farming.

### **Status of Surface Water Resources**

Surface water resources in the Indian arid zone are limited due to low and scanty rainfall and poor water yielding efficiency of sandy terrain. Major source of surface water in arid zone of Rajasthan is the Luni and its tributaries. In western Rajasthan, 550 storage tanks in the capacity ranging from less than 1.5 10<sup>6</sup>m<sup>3</sup> to 208x10<sup>6</sup>m<sup>3</sup> are functional (Khan, 1997).

The total utilisable capacity of these tanks is nearly 1169.28x10<sup>6</sup>m<sup>3</sup> for providing irrigation in 0.102x10<sup>6</sup> ha land. Out of these, six reservoirs viz., Jaswantsagar, Sardar Samand, Jawai, Hemawas, Ora and Bankali, are the major ones irrigating more than 4000 ha each. Jawai is the main source of drinking water supply to Jodhpur city.

Table 1. Districtwise number and storage capacity (10<sup>6</sup>m<sup>3</sup>) of reservoir/tanks in western

Rajasthan		
District	No.	Total storage capacity
Pali	91	608.35
Sirohi	42	156.20
Jalor	95	187.05
Barmer	62	42.77
Nagaur	59	44.07
Jodhpur	56	107.26
Jaisalmer	139	17.93
Bikaner	6	5.65
<b>Total</b>	<b>550</b>	<b>1169.28</b>

Source : Irrigation Department, Govt. of Rajasthan

The maximum surface water potential in the arid zone of Rajasthan is in the eastern part which runs parallel to Aravalli mountains comprising the drainage basin of the Luni river. Dhir and Krishnamurthy (1952) computed the surface water potential of the Luni basin using empirical formulae. They reported that there is nearly  $518 \times 10^6 \text{ m}^3$  of available surface water potential in the Luni basin. Dhruvanarayana *et al.* (1964) computed surface water potential of Luni basin as  $517.4 \times 10^6 \text{ m}^3$  using monsoon rainfall of the region and Strange's constants. According to Mehta and Kashyap (1970) surface water potential of western Rajasthan is  $1132 \times 10^6 \text{ m}^3$ , out of which  $939 \times 10^6 \text{ m}^3$  is in Luni basin. Rao (1975) computed the annual runoff from desert rivers of India as  $9943.2 \times 10^6 \text{ m}^3$ , out of it  $8000 \times 10^6 \text{ m}^3$  was from the Luni and its tributaries. According to another estimate the surface water potential of the Luni basin is  $858 \times 10^6 \text{ m}^3$ , out of which  $700 \times 10^6 \text{ m}^3$  is utilisable potential (Anon., 1980).

The mean annual basin outflow in the Luni and its tributaries was recorded as  $836.8 \times 10^6 \text{ m}^3$  and could be taken as surplus water potential during 1979-87 (Sharma and Vangani, 1992). Basin outflow in the Sukri and the Guhiya rivers between 1988 and 1992 were highly variable (Khan, 1993). The mean flow in these rivers were  $14.690 \times 10^6$  and  $20.313 \times 10^6 \text{ m}^3$ , respectively. In the upper Luni basin 1184 *nadis* (village ponds) in different size group are functional with utilisable capacity of  $69.666 \times 10^6 \text{ m}^3$  (Shankarnarayan and Kar, 1982). Sizewise distribution of *nadis* reveals that 41.81 per cent *nadis* are in the small group, 22.21 per cent in the medium size group and 35.98 per cent are in big size group. The stored *nadi* water is generally used for human and livestock consumption.

The central and western parts within the arid region of Rajasthan are comprised of sandy plains and have very low surface water potential. The flow from the hilly catchments occur in response to torrential rains. The inhabitants in the region rich in experience have evolved their own systems for harnessing meagre precipitation for human and livestock consumption and for biomass production in small patches (Khan, 1989). The systems include *nadis*, *tankas* (underground cistern) and *khadins*.

The total estimated water yield of Nagaur district is about  $449 \times 10^6 \text{ m}^3$  out of which only  $88.65 \times 10^6 \text{ m}^3$  is being stored in *nadis* and reservoirs. Nearly  $77.7 \times 10^6 \text{ m}^3$  of water drains to Sambhar and Didwana lakes (Chatterji and Kar, 1989). In the district 1194 *nadis* are functional with utilisable capacity of  $53.2 \times 10^6 \text{ m}^3$  and serve as source of domestic water supplies. However, the actual available water in *nadis* are much less due to high evaporative and seepage demand from the structures. The density of *nadis* in different landforms ranges from 3.6 (*nadis*/100  $\text{km}^2$ ) in sandy undulating buried pediments to 8.2 (*nadis*/100  $\text{km}^2$ ) in older alluvial plains. There are 37 irrigation reservoirs in Nagaur district. The capacity of these reservoirs ranges from  $0.035 \times 10^6 \text{ m}^3$  to  $88.520 \times 10^6 \text{ m}^3$ .

In Jodhpur district much of the runoff is utilised by way of 10 reservoirs with storage capacity of  $121.91 \times 10^6 \text{ m}^3$  and 292 medium and large *nadis* with total capacity of  $20.66 \times 10^6 \text{ m}^3$  (Anon., 1982).

The district Jālor is well drained area, where major ephemeral rivers system are the Jawai, the Bandi, and the Sagi. There are 1631 *nadis*, small (205), medium (413) and large (1013) groups having total storage capacity of  $39.752 \times 10^6 \text{ m}^3$ . Besides, there are 100 minor to medium irrigation tanks storing  $186.62 \times 10^6 \text{ m}^3$  of water. All the rivers are flashy, rises and recedes quickly unless long duration heavy intensity rain occurs. The peak discharge in the river section is highly variable. Between 1979 to 1987 in Jawai river it varied from 10.9 to 14.80 cumec, whereas, in the Bandi, the Sagi, the Mithri and the Khari it was 11.7 to 603, 2.5 to 400, 9.9 to 1380 and 2.8 to 518 cumec, respectively (Singh *et al.*, 1995).

The arid region of Gujarat which occupy 19 per cent area of Indian arid zone has two main streams namely the Shetrunji and the Bhadra on the south west coast. The rest of the area has disorganised ephemeral streams. According to Rao (1975) the annual average discharge of these rivers is  $1160 \times 10^6 \text{ m}^3$ . According to another estimate (Anon., 1989) surface water potential of the arid part of Gujarat state ranged between  $567.98 \times 10^6 \text{ m}^3$  during 1981-87 (Table 2).

Table 2. Surface water potential in the arid part of Gujarat

District	Annual discharge					
	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87
Banaskantha	99.83	141.28	147.39	161.26	53.99	35.64
Mehsana	70.59	47.76	868.57	253.31	440.79	2.01
Jamnagar	1518.69	164.09	897.92	174.27	22.07	197.05
Rajkot	106.75	45.53	342.41	134.22	55.13	299.27
Surendranagar	-	-	-	-	15.60	-
Junagarh	933.20	1382.21	697.72	55.74	159.13	33.96
Kachchh	4.08	1.01		2.68	12.96	0.05
<b>Total</b>	<b>25533.48</b>	<b>1781.88</b>	<b>2954.01</b>	<b>813.48</b>	<b>759.67</b>	<b>567.98</b>

The canal network extending from Punjab, Haryana and Rajasthan passes through different ecosystems and having varied length of irrigation regions. In the state of Punjab, the arid districts of Ferozpur, Bhatinda and Sangrur receive water from Bhakra canal network. With the introduction of canal irrigation intensive agriculture is being practised in this region. Uppal (1978) reported that the designed capacity of Ferozpur feeder and Bhakra canal is 314 and 510 cumec, respectively.

The western Yamuna and Bhakra canals are the main source of irrigation in the arid districts of Sirsa, Hisar, Bhiwani and Mahendragarh districts within the state of Haryana. The canal water potential in this region is  $6219.11 \times 10^6 \text{ m}^3$  and water allowance for 100 ha varies between 0.157 and 0.192 cumec (Gupta, 1987).

The surface water potential of Kachchh district is estimated as  $1049.21 \times 10^6 \text{ m}^3$ , out of which  $826.21 \times 10^6 \text{ m}^3$  flow to the sea or saline Rann (Patil, 1988). In an other study average annual runoff in the district is estimated as  $1482.71 \times 10^6 \text{ m}^3$  of which  $847.36 \times 10^6 \text{ m}^3$  is being stored in different irrigation storage reservoir and village tanks. Thus, nearly 57.15 per cent of runoff is surplus in the district and goes as waste into the sea and the Ranns (Vangani, 1996).

In Jamnagar district 36,820 to 1,52,540  $\text{m}^3$  of runoff per  $\text{km}^2$  area is estimated during average rainfall years. There are 16 medium and 30 minor irrigation reservoirs to store annually  $500 \times 10^6$  and  $77.66 \times 10^6 \text{ m}^3$  water, respectively. The check dams and percolation tanks are also able to store about  $11 \times 10^6 \text{ m}^3$  of water annually (Anon., 1997).

The Indira Gandhi Canal Project (IGNP) in north-west region of the state, envisages to use 9.3 billion cubic metre of Beas and Ravi rivers water in 1.8 million ha of desert land for agriculture, providing drinking water and afforestation etc. (Kapoor, 1997). So far, the quantity of available water in the canal system is quite liberal. During the period 1988 to 1995, the average rate of water use, measure in terms of water use at the head of feeder canal was 1260 mm against the designed value of 560 mm. These values for Gang and Bhakra project command areas, during the same period were 575 and 515 mm, respectively.

In distributory, the water supply for irrigation is 12.60 cumec, whereas in the minors the mean daily flow (1985-86) in kharif and rabi seasons it varies from 0.67 to 1.25 and 0.72 to 1.24 cumec, respectively. The Anupgarh branch system has fourteen distributaries and number of direct outlets from branch canals with a design capacity of 0.071 to 0.099 cumec. The mean daily flow (1985-1986) in Sangeeta, Ghasana and Khogewali distributaries varies from 17.92-20.48, 15.36-24.26 and 46.57-73.75 ha m, respectively (Anon., 1988).

With the introduction of Indira Gandhi canal network the desert ecosystem has transformed in complete production system. However, due to intensive canal irrigation, poor maintenance of canal network and mismanagement of water, waterlogging and soil salinisation problem has developed in  $111.9 \text{ km}^2$  and  $2401.1 \text{ km}^2$  area is under threat due to gradual rise in water table @ 0.8 to 1.0 m every year (Kapoor, 1997). Most of the waterlogged area is either along the canal or in depressions. The problem of waterlogging and soil salinisation can be minimised by adopting suitable water management technique such as reduction in water allowance, adoption of drip and sprinkler irrigation systems, reverse pumping of stagnated water in canal and diverting it in rainfed areas for irrigation. Due to high rate of water use in irrigation, the area under waterlogging is increasing year by year.

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# 7

## VEGETATION RESOURCES IN THE INDIAN ARID ZONE

Suresh Kumar

Vegetation constitutes primary source of life-support especially in arid zone where animal husbandry being major vocation of people, depends entirely on natural vegetation. Besides being of direct economic relevance, natural vegetation provides stability to wind prone sandy friable surface covering nearly two - third of Indian arid zone. Further, inhospitable climate, too deep or too shallow soils with less moisture and poor fertility, deep underground water which is often brackish or saline, coupled with intense biotic pressure permit specialised plants which are well adapted to these climatic, edaphic and biotic adversities and fluctuations. And hence, these features of vegetation have attracted botanists, range managers and foresters alike to solve not only academic enigmas but also use these plants for better management of deserts. The earliest botanical expeditions to the Indian desert were nearly 100 years ago. Since then, a large number of workers have contributed significantly to the body of knowledge on vegetation resources of Indian arid zone. An attempt is made here to trace these developments in both state-of-the-art and state-of-the-knowledge pertaining to vegetation resources along five major themes: Studies on understanding structure-composition, vegetation succession, vegetation mapping, vegetation biomass and vegetation use. In each theme, future line of work has also been indicated.

### ***Structure and Composition of Vegetation***

#### **Centres of Vegetation Research and Their Approaches in the Indian Arid Zone**

Following pioneering work of Blatter and Hallberg (1918-21), several workers belonging to eight distinct centres have described and discussed vegetation of the Indian arid zone. These are:

1. Forest Research Institute, Dehradun
2. Rajasthan State Forest Department
3. School of Botany, Bombay
4. French Institute, Pondicherry
5. School of Botany, Birla Institute of Science and Technology, Pilani
6. Botany Department, University of Jodhpur
7. Plant Ecology Unit of the Central Arid Zone Research Institute, Jodhpur, and
8. Department of Biosciences of Saurashtra University, Rajkot, Gujarat.

The approaches followed by these centres are broadly on the following five lines:

1. Studies based on Clement's climax concept
2. Studies following Braun-Blanquet's methods
3. Floristic, physiognomic and lifeform studies
4. Vegetation classification based on dominance indices, and
5. Multivariate approaches

### Vegetation Studies Based on Clement's Climax Concept

Champion (1936) recognised following types of forests in Indian arid zone:

Type name	Type code
Northern desert thorn forest	5BC1
Northern <i>Acacia</i> scrub forest	5BC2
Northern <i>Euphorbia</i> scrub	5BC3
Inland dune scrub	D Tr E 10

Vegetational element of top, middle and ground storey were also described. These types were assigned "formation" status.

Puri (1952) recognised five formations: aquatic, sand, gravel, rock and ruderal. Dominants of each formation and their associates were described. The aquatic and ruderals were mentioned only but their composition was not detailed. The remaining three, sand, gravel and rock correspond to Inland dune scrub, Northern *Acacia* scrub forest and Northern *Euphorbia* scrub of Champion (1936).

Enlarging upon Champion's classification Mathur (1960) reclassified vegetation of entire Rajasthan into seven types of which Tropical Thorn Forest and Subtropical Thorn Forest were shown in the extreme arid region.

Champion and Seth (1968) revised their earlier classification and recognised six types wherein Desert Thorn Forest 6B/C1 and Desert Dune Scrub (6/IS1) are the two major types. *Salvadora scrub* (6/E4) and *Acacia senegal* (6E2) are the edaphic types and *Ziziphus scrub* (6B/DS1) and *Euphorbia scrub* (6B/DS2) are degradational types. The Desert Thorn Forest is constituted by *Prosopis cineraria*, *Salvadora oleoides*, *Calotropis procera*, *Ziziphus nummularia*, *Tephrosia purpurea*, *Calligonum polygonoides*, *Crotalaria burhia*, *Aerva pseudotomentosa* and *Leptadenia pyrotechnica*. Among grasses, *Cenchrus ciliaris*, *Lasiurus indicus*, *Cymbopogon jwarancusa*, *Eleusine compressa*, *Aristida* spp., *Dactyloctenium indicum* are dominant.

The Desert Dune Scrub has *Prosopis spicigera* (now *P. cineraria*), *Acacia arabica*, *Ziziphus nummularia*, *Capparis decidua*, *Leptadenia pyrotechnica*, *Crotalaria burhia*, *Calotropis procera*, *Sida cordifolia*, *Aerva pseudotomentosa*, *Desmostachya bipinnata*, *Saccharum munja*, *Aristida* and *Cynodon dactylon*.

In the degradational stages of the Desert Thorn Forest *Ziziphus nummularia* and/or *Capparis decidua* predominate with poor representation of trees and grasses; whereas on rocky areas, *Euphorbia caducifolia* forms the pure colony upon degradation of *Acacia senegal* cover which has been given the status of edaphic climax on such sites. Likewise, *Salvadora oleoides* is edaphic climax on heavier saline soils.

### Studies Following Braun-Blanquet's Approach

Braun-Blanquet's (1932) system identifies associations of plants and group them into higher status of alliances, orders and classes. Association is defined as being an assemblage of plants of certain floristic composition, uniform physiognomy and structure. It takes into account all the floristic elements to define an association. Sen (1966) described 44 associations in 15 alliances and 8 orders for the vegetation in and around Jodhpur (Table 1). He correlated the orders with their specific edaphic conditions and also gave an idea of ecological amplitudes of species in adapting conditions of sand, gravel, sloppy, hill crevices and rocks. Bharucha (1975) recognised 13 associations in western Rajasthan and each association was given (1) the characteristic species, (2) facies species of hygrophilous, sandy, gravelly or rocky and ruderal associations (3) species of alliances, (4) species of order and (5) companion species and (6) escapes. As regards habitat affiliations, three associations namely *Pluchea lanceolata*, *Desmostachya bipinnata*, and *Eleusine compressa* were considered hygrophillous; *Panicum turgidum*, *Lasiurus hirsutus* and *Crotalaria burhia* on sandy soils; *Aristida adscensionis* and *Indigofera cordifolia* associations on sand dunes; *Aristida hirtigluma* and *Pennisetum cenchroides* var. *echinodes* on hard gravelly soils; and finally, associations of *Cenchrus biflorus*, *Cleome brachycarpa* and *Trianthema pentandra* as ruderal.

Table 1. A summary of associations, alliances and order based on the analytic characters

Association	Alliances	Orders	Classes
1. <i>Heliotropio-Tephrosetum purpurae</i>			
2. <i>Leptadenio-Tephrosetum purpurae</i>			
3. <i>Zizypho-Tephrosetum purpurae</i>	Tephrosion purpurae		
4. <i>Indigofero-Tephrosetum purpurae</i>			
5. <i>Grewio-Tephrosetum purpurae</i>			Arid plant communities on sand and gravel
6. <i>Aervo-Tephrosetum purpurae</i>		Tephrosetali	
7. <i>Tephrosio-Dactyloctenium aegyptium</i>	Tephrosion aervae		
8. <i>Sericostomo-Aervetum persicae</i>			

Association	Alliances	Orders	Classes
9. <i>Leptadenio-Acacietaum</i>			
10. <i>Pedalia-Acacietaum</i>	Acacion		
11. <i>Pedalia-Tephrosetum purpurae</i>			
12. <i>Acacio-Tephrosetum purpurae</i>		Prosopetalia Acaciae	Plant communities on sand dunes, gravel and fields
13. <i>Calotropo-Acacietaum</i>			
14. <i>Calotropo-Prosopetum</i>	Calotropion		
15. <i>Calotropo-Tephrosetum purpurae</i>			
16. <i>Salvadora-Barleretum</i>	Presopion		
17. <i>Leptadenio-Tephrosetum</i>		Farsetalia	Plant communities on exposed sands
18. <i>Sericostomo-Farsetum</i>	Farsetion		
19. <i>Farsetio-Sericostometum</i>			
20. <i>Phyllantho-Farsetum</i>			
21. <i>Cenchretum-pennisetiformo-biflorae</i>	Cenchrion		
22. <i>Cenchretum-setigero-biflorae</i>			
23. <i>Trago-Melanocenchretum</i>	Tragion	Cenchretalia Traga	Plant communities both on shaded to exposed habitats
24. <i>Aristido-Tragetum</i>			
25. <i>Barleretum-Hibisco-micranthae</i>	Barlerion acanthoideae		
26. <i>Barleretum-Cyperae</i>			
27. <i>Barleretum-Elusino-compreseae</i>		Barleretalia	Plant communities on slopy rocks with crevices and in gravel
28. <i>Euphorbia-Lepidagathetum</i>	Lepidogathion Tephrosae		
29. <i>Tephrosio-Lepidagathetum</i>			
30. <i>Indigofera-Tephrosetum</i>			
31. <i>Acacio-Euphorbetum caducifoliae</i>			
32. <i>Grewio-Euphorbetum caducifoliae</i>	Euphrobion		
33. <i>Sarcostemmo-Euphorbetum</i>		Euphorbetalia	Plant communities mostly on rocks

Assocation	Alliances	Orders	Classes
34. <i>Barlerio-Euphorbetum caducifoliae</i>	Euphrobion		
35. <i>Orygio-Euphorbetum caducifoliae</i>			
36. <i>Indigofertum-Cassio-pumilae</i>			
37. <i>Indigoferetum-Cleomo-papillosae</i>	Indigoferion		
38. <i>Boerhavetum-verticillato-Euphorbiae</i>		Solanetalia Indigofera	Ruderal plant communities on gravel, sand and moist places
39. <i>Solano-echinopetum</i>			
40. <i>Argemmono-Solanetum</i>	Solanion Argemonae		
41. <i>Argemmono-Heliotropetum</i>			
42. <i>Trigonello-Polygonetum</i>			
43. <i>Trigonello-Glinetum</i>	Trigonellion	Trigonelletalia	Plant communities on moist places
44. <i>Eclipto-Euphorbetum</i>	Ecliptae		

### Floristic, Physiognomic and Lifeform Studies

Floristic elements of different habitats in Jodhpur, north-west Rajasthan and Bikaner were described by Sarup in a series of papers (Sarup, 1952, 1953, 1957, 1958a, b) Agharkar (1952) mentioned plant species occurring on sand, gravel, rock, ruderal and in water. All these studies alongwith many others on floristics (Rao and Kanodia, 1962, 1963; Rao, 1970) have been reviewed and upgraded in the form of a book, the "Flora of the Indian Desert" (Bhandari, 1978, 1990) and included in the enlarged Flora of Rajasthan (Shetty and Singh, 1987-93). It emerged from this study that the Indian desert has 682 species belonging to 352 genera and 87 families of flowering plants. Of these 9 families, 37 genera and 63 species are introduced. Poaceae and Leguminosae are the largest families amongst monocotyledons and dicotyledons, respectively. Incidentally, Poaceae is the largest family of 57 genera and 111 species. Phytogeographically, 37% of the botanical species represent African elements, 20.6 % Oriental elements, 14% species being tropical and 10.3% cosmopolitan and 9.7% Australarian. Nearly 9.4% species are endemic to this region (Bhandari, 1990). Besides, a large number of species show polymorphism, which is more pronounced in herbaceous and graminaceous plants.

From the Pilani school have emerged work on plant ecology of Bikaner (Joshi, 1956), sand dune vegetation of Pilani (Joshi, 1958; Nair and Joshi, 1956; 1957), vegetation of Aravalli (Nair and Nathawat, 1957), vegetation of Jhunjhunu (Nair, 1961) scrub communities of Churu (Sharma, 1961), structure and composition of plant communities at Churu (Sharma, 1965), and phytosociology of sand dunes of Sikar (Sharma, 1972). Almost all of this work has been

concentrated in the easternmost boundary of the Indian desert. Raheja (1965) described present vegetation and floristics of arid zone of India in relation to microclimate. Gaussen *et al.* (1971) classified and mapped vegetation of Rajasthan into 12 types representing formations - halophytic, humid and dry conditions. In the arid zone, halophytes and dry types are predominant. Salt marshes, saline bogs and halophytic pseudosteppe constituted halophytic vegetation. The dry type is constituted by thorny and deciduous types. The thorny type is composed of three series viz., *Calligonum polygonoides* series, *Prosopis-Capparis-Ziziphus* series, and *Acacia-Capparis* series. These series have been subdivided on the basis of physiognomy of vegetation into spiny thicket, discontinuous thicket, bushy savanna, scattered undershrubs, scattered shrubs and trees in cultivated areas. Gupta (1975) distinguishes these types on specific landform types:

1. Spinous formations of thorn forest on medium and low altitude,
2. Mixed Xeromorphic thorn forests on graded alluvial plains or desert plains,
3. Mixed Xeromorphic thorn forests and riverain forest on flood plains
4. Riverain thorn forest on graded flood plains
5. Psammophytic desert scrub on sand dunes, and
6. Halophytic/scrub desert on shallow saline depressions

Gupta (1975) also tried to establish vegetation types on the basis of its physiognomy following Kassas (1966). The four types are (i) Accidental vegetation form, (ii) Ephemeral vegetation, (iii) Suffrutescent perennial and (iv) Frutescent perennial vegetation. Accidental vegetation appears only during high rainfall, say once in ten years, when rainwater collects in depressions where these species come up. They are mainly ephemerals with long dormancy. Ephemeral vegetation is constituted by herbaceous ephemeral, succulent ephemeral and ephemeral grasslands types. Herbaceous ephemeral for example, *Mollugo cerviana*, *Gisekia pharnaceoides*, *Indigofera cordifolia* come up only during rainy season and after completing their lifecycle marked by seed setting, they disappear. Succulent ephemerals survive for longer duration but within the growing season. Ephemeral grasslands consist of range grasses like *Eragrostis*, *Tragus*, *Cenchrus* which also are annual graminaceous plants completing their lifecycle within one monsoon season.

Suffrutescent perennial vegetation consists of three types: (i) succulent half shrub form, (ii) perennial grassland form, (iii) woody perennial form. Succulent half shrub communities like *Suaeda*, *Salsola* come up in extremely arid and saline conditions. *Haloxylon* and *Calligonum* communities belong to this category and survive by virtue of self stored water. The perennial grassland forms are represented by *Panicum turgidum* on sand dunes, *Lasiurus indicus* on sandy plains, *Cenchrus ciliaris* and *C. setigerus* on older alluvium. Woody perennial forms are dominated by communities of *Prosopis cineraria-Capparis decidua* on interdune plains, *Prosopis cineraria-Salvadora oleoides* on older alluvium; *Acacia senegal-A. arabica*, *A. leucophloea* and *Anogeissus pendula* on piedmonts and hills. Frutescent perennial vegetation has 2 types: succulent shrub forms and scrubland forms. *Euphorbia* community on hills and *Haloxylon* community on

old flood plains constitute the succulent shrub form, while scrubland form is constituted by *Ziziphus-Capparis* scrubs. <sup>1</sup>

Mertia and Bhandari (1980) are of the opinion that Raunkiaer (1934) terminology is inadequate for classification of plant forms of desertic regions and instead prefer Du Rietz classification as modified by Cabrera (1952). Following this they identified, Haloxiles (22%), Hemxiles (5%) and herbs (24%) and therophytes (45%) as four major forms in Jaisalmer.

### Vegetation Classification Based on Dominance Indices

By and large, two indices i.e., cover and Importance Value Index (IVI) (Curtis and McIntosh, 1950) have been used to identify dominant and codominant species in the vegetation of the arid region. Satyanarayan (1963) used cover as a measure of dominance for typification of vegetation in the Central Luni Basin and recognised five formations viz., 1. Mixed Xeromorphic thorn forest, 2. Mixed Xeromorphic woodland, 3. Dwarf semi-shrub desert, 4. Psammophytic scrub desert and 5. Succulent halophytic desert. In another study of desert vegetation, Satyanarayan (1964) correlated the recognised communities with different habitats and established their successional trends. Subsequently, dune vegetation was also typified on the basis of cover dominance (Shankarnarayan *et al.*, 1965; and Satyanarayan *et al.*, 1966). Temporal phyto-sociological changes during monsoon were studied using this index on rocky habitat (Gaur and Satyanarayan, 1967); alluvial plains (Satyanarayan and Gaur, 1967); semi-rocky habitats (Satyanarayan and Gaur, 1968); and vegetation surveys of different areas viz. Chohatan (Gupta and Saxena, 1971 a), Bikaner (Abichandani *et al.*, 1975, Saxena and Singh, 1976), central Luni Basin (Anonymous, 1963), Saila block (Anonymous, 1965), Ahor block (Anonymous, 1966), Jalore block (Anonymous, 1967), Luni block (Anonymous, 1969) and Chohatan block (Anonymous, 1970).

During this period (1960-1975), grassland types were named after dominants and codominants based on cover from line intercept data (Shankarnarayan and Satyanarayan, 1964; Nanda and Gupta, 1968; Gupta and Saxena, 1966; Gupta, 1971; Gupta and Saxena, 1971b, 1972; and Gupta, 1975). A comprehensive summary of these studies has been provided by Pandeya (1968) in his paper on the range resources of Rajasthan.

The year 1975 witnessed a major shift in approach: the dominance index based on Importance Value Index was used for the first time by Shankar and Saxena (1975 a, b) in studying ground vegetation under different tree canopies and in comparing 'vegetational changes on rocky habitats under protection. The IVI has been extensively used since then by Shankar and his associates in a large number of studies on desert vegetation and its phytosociology. Notable among these are phytosociology studies pertaining to the UNESCO's MAB project on Productivity of Arid Grazingland Ecosystem (Anonymous, 1976, 1977, 1978), ecological studies on arid shrublands of western Rajasthan (Shankar and Bhati, 1977), study on changes in dune vegetation due to protection (Shankar and Dadhich, 1977) and in ecological survey of vegetation in the Guhiya and the Bandi catchments (Shankar and Kumar, 1980, 1981a, 1982), Jaisalmer, Jalor, Barmer, Kutch,

Sikar and Jamnagar district (Shankar and Kumar, 1987; Kumar and Shankar, 1987b; Saxena, 1989; Saxena, 1996a, 1996b; and Kumar, 1997). In classifying the vegetation of the Guhiya and the Bandi catchments, the dominants and codominants in grasslands were determined on the basis of RIV (Relative Importance Value = IVI divided by 3) and a total of seven grassland types were established. Within each grassland type, tree-shrub dominants and codominants were listed according to landform, soil texture and soil depth (Kumar and Shankar, 1985). Efficacy of this system of classification and mapping vegetation was corroborated by diversity-dominance relations of perennials in different types of grasslands (Kumar and Shankar, 1986b, 1987a). However, some studies based on transects continued, such as the one by Rajpurohit *et al.* (1979) wherein vegetation communities were delineated along decreasing salinity at the margin of an abandoned salt pit at Pachpadra salt basin. Pandeya *et al.* (1967) devised a method of classification of Narmada forest which has been suitably modified by workers at Rajkot to describe coastal desertic vegetation of Kutch (Pandya and Sidha, 1985). This method combines density, cover and height alongwith the coefficient of variation to arrive at Relative Growth Value Index (RGVI). Jain (1968) described the vegetation and its succession in Kutch area while grasses and grasslands of Kutch were detailed by Kanodia and Nanda (1966).

Looking back, majority of work has been qualitative or semi-quantitative. The community characterisation even after using quantitative dominance index has been on the basis of landforms (Saxena, 1977a, b; Shankar, 1978), landform and precipitation (Gupta and Sharma, 1971), climate and landform (Nanda and Gupta, 1968) besides the purely qualitative and subjective characterisation combined with landform types (Sarup and Puri, 1960; Prakash and Nanda, 1961; Joshi, 1956, 1958; Nair and Joshi, 1956, 1957; Nair and Nathawat, 1957; Nair, 1961; Sharma, 1965). Because of this reason alone, the number of plant communities recognised by different workers in the Indian desert has varied. Even the same group of workers

classified grasslands into nine (Gupta, 1971), seven (Gupta and Saxena, 1972), four (Gupta and Sharma, 1971) and again seven types (Gupta, 1975). In fact, in their book on "Environmental analysis of Thar Desert", Gupta and Prakash (1975) described five types of vegetation classification wherein 7 to 12 plant communities have been recognised. In two publications appearing in the same year, the same author has recognised in western Rajasthan, six vegetation types in one paper (Saxena, 1977a) and nine in another paper (Saxena, 1977b). The six major formations recognised by Satyanarayan (1964) still continue to be most widely accepted. Most work of Plant Ecology Unit can be summarised into these six formations (Shankar and Kumar 1988) as follows. Besides basic composition in different rainfall zones, variations in these formations are also given.

### **Mixed xeromorphic thorn forest**

Besides the Aravallis as the boundary line, there are several rugged scattered hills which are mostly made up of sandstone, granite and rhyolite. The plant communities growing on these hills



are grouped under mixed xeromorphic thorn forest because the communities are largely dominated by thorny and spiny species, which include some evergreen non-thorny species as well. The soils of such habitats are skeletal, yellowish brown to brown, loamy sands. Low hills and rocky areas of 150 to 350 mm of rainfall zone are largely dominated by *Acacia senegal* community which under protection attains density of 72 plants per ha and 100% frequency. The *Anogeissus pendula* -*Acacia senegal* community occurs in 350-500 mm rainfall zone whereas in 500-700 mm zone *Anogeissus pendula* community is predominant with *Acacia catechu* as the chief associate. But on higher elevations, *A.pendula* combines with *Boswellia serrata*. The density of 15-35 cm DBH group ranges from 200 to 500 plants per ha.

The chief shrub associates in 150-350 mm rainfall zone are *Commiphora wightii*, *Ziziphus nummularia*, *Grewia tenax*, *Euphorbia caducifolia*, *Grewia tenax*, *Mimosa hamata*, and *Sericostemma acidum*. The associated trees that are short with crooked boles include *Salvadora oleoides* and *Maytenus emarginatus*. The associates of *A.senegal* community in the medium (350-500 mm) rainfall zone include *Wrightia tinctoria*, *Moringa cocanensis*, *Azadirachta indica*, *Bauhinia racemosa*, *Cordia gharaf* and *Acacia leucophloea*. In the higher rainfall regions (500-700 mm) the associated species are: *Securinega leucopyrus*, *Dichrostachys cinerea*, *Grewia villosa*, *Barlaria prionites*, *B. acanthoides*, *Cassia auriculata*, *Abutilon indicum* and *Dipteracanthus patulus*.

The ground flora in the low rainfall zone is poor and includes a few species of grasses and forbs such as *Cymbopogon jwarancusa*, *Aristida funiculata*, *Eleusine compressa*, *Eleusine hirtigluma*, *Tragus biflorus*, *Oropetium thomaeum*, *Melanocenchrus jacquemontii*, *Enneapogon brachystachys*, *Indigorera cordifolia*, *Lepidagathis trinervis*, *Blepharis sindica*, *Tephrosia purpurea* and *Tridax procumbens*. In the higher rainfall zone (350-700 mm), some more species are added viz., *Eremopogon foveolatus* *Heteropogon contortus*, *Brachiaria ramosa*, *Bothriochloa pertusa*, *Hackelochloa granularis*, *Sehima nervosum*, *Indigofera tinctoria*, *Tephrosia petrosa*, *Boerhavia diffusa*, *Pupalia lappacea* and *Achyranthus aspera*.

### Mixed xeromorphic woodlands

This formation, largely having spiny species mixed with non-spiny and evergreen species, occurs on the flat older alluvial plains and lower piedmont plains with deposition of sandy loam or clay loam or clay soils underlain with a hard *kanker* pan at 25 to 100 cm depth.

The plant community encountered in the desert plains are 1. *Salvadora oleoides*- *Prosopis cineraria*, 2. *Prosopis cineraria*- *Ziziphus nummularia*-*Capparis decidua*, 3. *Salvadora oleoides*-*Capparis decidua*-*P.cineraria*, 4. *Salvadora oleoides*, 5. *Capparis decidua*- *S.oleoides*-*P.cineraria*, 6. *S.oleoides* - *C.decidua*, 7. *P.cineraria*- *S.oleoides* - *Z. nummularia*, 8. *S. oleoides*-*Cassia auriculata*, 9. *P.cineraria* - *C.decidua*, 10. *P.cineraria*- *Z.nummularia*, 11. *C.decidua*, 12. *Z.nummularia*, 13. *S.oleoides*-*P.cineraria*-*Z.nummularia*, and 14. *P.cineraria* - *Acacia nilotica*.

The above plant communities, by the inclusion or exclusion of any one species, affect the association significantly, therefore these may be regarded as phases or "Facies" of the climax community, largely indicating the extent of degradation reflected in the preponderance of *Tephrosia purpurea*, *Crotalaria burhia* and *Indigofera oblongifolia*.

The common shrub associates of all the above communities include *Calotropis procera*, *Balanites aegyptiaca* and *Acacia jacquemontii*. The forbs and grasses are *Aerva persica*, *Tephrosia purpurea*, *Crotalaria burhia*, *Convolvulus microphyllus*, *Heliotropium subulatum*, *Pulicaria wightiana*, *Celosia argentea*; *Eleusine compressa*, *Dactyloctenium indicum*, *Desmostachya bipinnata*, *Cenchrus ciliaris*, *C. setigerus*.

### Mixed xeromorphic riverine thorn forest

The Jawai, the Sukri, the Mitri and the Luni rivers and their tributaries in the western Rajasthan form a narrow belt of younger alluvium having deep sandy soils without a hard pan. There is a good density of trees viz., *Acacia nilotica*, *A. cupressiformis*, *Salvadora oleoides*, *S. persica*, *Tamarix auriculata*, *Tecomella undulata*, *Tamarindus indica*, *Albizia lebeck*, *Ailanthus excelsa*, *Ficus religiosa*, *F. bengalensis*, *Moringa oleifera* and *Ziziphus mauritiana*.

*Acacia nilotica* - *Prosopis cineraria* community is predominant in the irrigated fields along the river courses and represents the climatic climax of this region. On medium heavy soils, *S. oleoides* and *P. cineraria* dominate. Degradation beyond this stage rapidly gives way to *Tamarix*, *Ziziphus*, *A. jacquemontii* and finally to grasses and sedges viz., *Desmostachya bipinnata*, *Cyperus arenarius* and *C. biflorus*.

The plant communities on the terraces of the river banks are 1. *Acacia jacquemontii*-*Cassia auriculata*, 2. *A. jacquemontii*-*Aerva pseudotomentosa*, 3. *Salvadora persica*-*Tamarix auriculata*, 4. *Salvadora oleoides*-*C. decidua*. The grasses and forbs in these communities are: *Cenchrus ciliaris*, *C. setigerus*, *Aristida adscensionis*, *Digitaria adscendens*, *Dactyloctenium aegyptium*, *Chloris virgata*, *Cynodon dactylon*, *Tephrosia purpurea*, *Solanum surratense*, *Vernonia cinerascens*, *Heliotropium subulatum*, *Crotalaria burhia*, *Boerhavia diffusa*, *Digera muricata*, *Pulicaria wightiana*, *Volutarella divaricata*, *Xanthium strumarium*, and *Indigofera cordifolia*.

### Lithophytic scrub desert

Eroded rocky surfaces, gravelly plains and pediment plains with shallow soil deposition in depressional pockets support stunted, multi-stemmed shrubs and trees which are cushion-shaped pillow-forms due to heavy grazing.

*Capparis decidua*-*Ziziphus nummularia* is the most prevalent shrub community on eroded rocky surfaces and piedmont plains. Stray plants of *Acacia senegal* and *Prosopis cineraria* also occur along the deep tunnels. Associated shrubs, undershrubs, forbs and grasses are: *Leptadenia pyrotechnica*, *Crotalaria burhia*, *Sericostoma pauciflorum*, *Bonamia latifolia*, *Tribulus terrestris*, *Orygia decumbens*, *Cleome papillosa*, *C. brachycarpa*, *Boerhavia elegans*, *B. diffusa*, *Mollugo*

*cerviana*, *Indigofera cordifolia*, *Dactyloctenium indicum*, *Oropetium thomaeum*, *Elusine compressa*, *Eragrostis* sp., *Aristida hirtigluma*.

### Psammophytic scrub desert

This formation has woody vegetation, predominantly of shrubs, on aeolian deposits viz. stabilised sand dunes, undulating hummocky older alluvial plains and interdunal hummocky plains with very deep loamy sands, often calcareous. Typical psammophilous species are *Aerva persica*, *A. pseudotomentosa*, *Crotalaria burhia*, *Panicum turgidum*, *Cyperus laevigatus*, *Calligonum polygonoides*, *Clerodendron phlomoides*, *Cenchrus biflorus*, *Aristida funiculata*, *Citrullus colocynthis*, *Dipterygium glaucum* and *Haloxylon salicornicum*.

Sand dunes with moderate sand deposition support the following communities: 1. *Calligonum polygonoides*-*Clerodendron phlomoides*. 2. *C. polygonoides*-*Panicum turgidum* 3. *Acacia jacquemontii*-*Acacia senegal*, 4. *Maytenus emarginatus*-*Calotropis procera*, 5. *M. emarginatus*-*A. senegal*, 6. *A. senegal*-*Calligonum polygonoides*, 7. *Crotalaria burhia*-*Aerva pseudotomentosa*, 8. *C. burhia*-*Sericostoma pauciflorum*-*Leptadenia pyrotechnica*. Sprawling grasslands of *Lasiurus indicus* cover substantial area in this low rainfall zone in the extreme west.

The sand dunes in the moderate rainfall zone (250-400 mm) are more stabilised and bear a larger number of small trees and a few shrub species, such as *Prosopis cineraria*, *Salvadora oleoides*, *Balanites aegyptiaca*, *Tecomella undulata*, *Maytenus emarginatus*, *Lycium barbarum* and *Acacia jacquemontii*.

The sand dunes in a higher rainfall zone (300-400 mm) are highly stabilised and support mixed xeromorphic woodland instead of psammophytic scrub desert.

### Halophytic scrub desert

This formation is localised in low-lying saline basins and depressional areas called ranns or playas wherein the salinity decreases towards the periphery and succulent halophytic nanophanerophytes and chamaephytes, generally of *Chenopodiaceae*, *Zygophyllaceae*, *Aizoaceae* and *Portulacaceae* grow more towards the periphery.

The plant communities recorded in various ranns are:

1. *Suaeda fruticosa*-*Aeluropus lagopoides*, 2. *Haloxylon recurvum*-*Salsola baryosma*-*Sporobolus marginatus*, 3. *Sporobolus helvolus*-*Cyperus rotundus*, 4. *Peganum harmala*-*Eleusine compressa*-*Sporobolus marginatus*, and 5. *Desmostachya bipinnata*-*Eleusine compressa*.

Other halophytic species common to the above communities are *Zygophyllum simplex*, *Cressa cretica*, *Euphorbia granulata*, *Portulaca oleracea*, *Fagonia cretica*, *Trianthema portulacastrum*, *Echinochloa colonum*, *Chloris virgata*, *Schoenfeldia gracilis*, *Dactyloctenium aegyptium*, and *Dichanthium annulatum*.

## Multivariate Approaches

The stereotyped IVI based approach continued even though there has been upsurge of multivariate approaches on classification, ordination and gradient analysis in different research centres of vegetation ecology in the post 1975 era. These multivariate and digital approaches effectively summarise redundancy, reduce noise, are unaffected by outliers and reveal relationships between sites, between species and between sites and species. In India there have been very few attempts to use multivariate methods. Kumar *et al.* (1980) for the first time used monothetic classificatory technique in studying Sal forests of outer Siwaliks (published later in Kumar, 1990a) followed by Tewari (1982) who used polar ordination in studying pine-oak communities around Nanital in western Himalayas. In the Indian arid zone, standardised computer programmes were used for the first time to classify desert shrubland communities by Shankar (1982) who employed four polythetic agglomerative classificatory programmes developed by Goldstein and Grigal (1972). He identified major shrublands of each landform in the Indian desert. A major breakthrough was achieved by Kumar (1987) when he accomplished an extensive computerisation of vegetation data of Jaisalmer. This work was aimed at studying spatial arrangement of species for identifying community types and to determine changes through direct or gradient ordination in species population and community characteristics as influenced by changes in environmental factors (Kumar, 1990b). It was desired to finally derive from this exercise, some directions for site management (Kumar, 1992a). Using advance ordination technique, Detrended Correspondence Analysis, Kumar (1996a) described trends in structural compositional attributes in the Indian Desert alongwith their edaphic relations. *Aerva pseudotomentosa* was clearly brought out as an indicator of vegetation degradation. The sites could be

organised along an axis of increasing degradation and hence, provided an idea about the site management. Secondly correlation between vegetation and edaphic factors was statistically established. This was thus, a pointer towards mathematically sound integration of soil-vegetation parameters in the ultimate scheme of vegetation management.

## Vegetation Succession

Succession is the march of vegetation on a particular habitat. The composition of plant assemblage changes with time and finally attain the climax formation which is in dynamic equilibrium with the environment. Knowledge of succession and its climax is important as it helps in determining the successional status of a particular piece of land and also how it can be brought to the desired status of succession which is not always the climax.

## Approaches to Study of Succession

The studies of succession can be carried out by 1. Comparing vegetation of different sites representing different stages of development, at one point of time; or 2. by closing a representative

habitat and recording changes in vegetation until it shows minimal changes in structure and composition. Both types of approaches have been followed in the Indian arid zone. In the former are the studies by Satyanarayan (1963, 1964) in central Luni basin and the entire Indian arid zone. Braun-Blanquet's (1932) system was combined with climatic attributes to arrive at dynamic successional trend of vegetation of two semi-arid areas in Jodhpur and Ramanathapuram by Meher Homji (1965). It was predicted that most degraded grass covers like *Aristida* will ultimately developed into "tall grasslands of *Lasiurus hirsutus* (now *L. indicus*) and may eventually lead to a savanna vegetation dominated by *P. spicigera* (now *P. cineraria*). The differences in community development at two places were related with rainfall, temperature, length of dry period and season of occurrence of drought. Verma (1964) studied changes in successional status of Kailana closures (210 ha) after four years of protection

in terms of six communities. Gupta and Saxena (1972) proposed a scheme of ecological succession in potential grassland types of Rajasthan. Saxena (1977a) further enlarged upon the scheme of succession proposed by Satyanarayan (1964) and proposed succession in woodlands and grasslands in respect of various habitats. The only climatic climax of grassland vegetation in India is the temperate alpine meadows which are largely dominated by festuoid grasses. The tropical and subtropical grasslands are "derived tertiary seral communities" (Whyte 1974) where the successional processes are arrested due to continued biotic interference viz. grazing and/or burning (Champion 1936). The flora of the grazing lands in general, is dominated by therophytes, hemicryptophytes and chamaephytes (Pandeya 1964; Singh and Yadava 1974). The preponderance of therophytes results from strong periodicity in tropical monsoonic climate, whereas hemicryptophytes dominate due to grazing pressure. Trees and shrubs are usually associated with grassland.

## Temporal Limits of Succession

Effect of long term closure on dune vegetation near Udairamsar were studied by Shankar and Dadhich (1977). Shankar (1983) reported changes in different vegetational attributes of exclosures of Kailana area, Jodhpur over time and recognised temporal limits to development of vegetation (Table 2). In addition, studies on retrogressive succession have thrown light on the process of degradation and desertification (Shankar, 1977). Thorny, bushy, unpalatable species assume dominance in place of the *Prosopis cineraria* - *Salvadora oleoides* - *Ziziphus nummularia* - *Capparis decidua* complex dominating a large variety of situations and is replaced by *Prosopis juliflora*, *Euphorbia caducifolia* and *Tephrosia purpurea* of little value (Saxena, 1977c; Saxena and Kumar 1991). The important forage grasses like *Dichanthium annulatum*, *Cenchrus ciliaris* and *Lasiurus indicus* occurring respectively on clayey, loamy and sandy soils are replaced by *Oropetium thomaeum*, *Cenchrus biflorus* and *Aristida-Eragrostis* species (Gupta and Saxena, 1972). Consequently their cover also declined (Kumar 1994). In addition to composition and

cover, a group of 25 parameters were identified for measuring degradation of vegetation (Kumar, 1992b) which also included dominance diversity relations.

Table 2. Time sequence of vegetation development on various habitats in arid region

Habitat	Duration of enclosure (year)	Grass cover	Tree/shrub cover
Hills	7	<i>Chrysopogon fulvus</i> , <i>Eremopogon foveolatus</i> , <i>Heteropogon contortus</i>	<i>Acacia senegal</i> , <i>Maytenus emarginatus</i> , <i>Ziziphus nummularia</i>
Rocky gravelly pediments	10	<i>Eleusine compressa</i> , <i>Acacia senegal</i> , <i>Dactyloctenium indicum</i>	<i>Balanites aegyptiaca</i> , <i>Maytenus emarginatus</i> , <i>Z. nummularia</i>
Rocky gravelly pediments with contour bunding	6	<i>Eleusine compressa</i> , <i>Acacia senegal</i> , <i>Dactyloctenium indicum</i>	<i>Balanites aegyptiaca</i> , <i>Maytenus emarginatus</i> , <i>Z. nummularia</i>
Flat buried pediments (high rainfall, heavy soil)	6	<i>Dichanthium annulatum</i>	<i>Salvadora oleoides</i> , <i>S.persica</i> , <i>P.cineraria</i> , <i>Z.nummularia</i> , <i>C.decidua</i>
Sandy undulating buried pediments (low rainfall)	6	<i>Lasiurus indicus</i> , <i>Panicum antidotale</i>	<i>Z.nummularia</i> , <i>Leptadenia pyrotechnica</i> , <i>Haloxylon salicornicum</i>
Flat aggraded older alluvial plain	4-6	<i>Cenchrus ciliaris</i> , <i>P.cineraria</i> , <i>C.setigerus</i>	<i>A.nilotica</i> , <i>C.decidua</i> , <i>Z.nummularia</i>
Sandy undulating aggraded older alluvial plain	4-6	<i>Cenchrus ciliaris</i> , <i>P.cineraria</i> , <i>C.setigerus</i>	<i>A.nilotica</i> , <i>C.decidua</i> , <i>Z.nummularia</i>
Sand dune	12	<i>Panicum turgidum</i> , <i>Cenchrus prieurii</i>	<i>Calligonum polygonoides</i> , <i>Sericostoma pauciflorum</i>
Shallow saline depression	6	<i>Sporobolus marginatus</i> , <i>Dichanthium annulatum</i>	<i>Prosopis juliflora</i> , <i>Acacia nilotica</i> , <i>Capparis decidua</i>

Source: Shankar, 1983

### Experimental Studies on Succession

Study of succession after rehabilitation involves monitoring of same rehabilitated plots at regular intervals. There have been two such studies both initiated in the year 1992. In one study, rocky rhyolite sites of Kailana catchments in Jodhpur were monitored after plantations and rehabilitation. Results revealed that 3-5 years after rehabilitation, sub-climax or climax species start gaining dominance over early successional species. Density of woody perennials increased by over

25 percent. Cover of vegetation increased by four times. The self regeneration of planted species indicated that habitats are becoming stable. These aspects were further proved by richness, evenness and dominance diversity trends (Kumar, 1997). These changes in vegetation have also been monitored through remote sensing (Kumar, 1996b).

In another study in the Indo-Japan Collaborative project on desertification, retrogressive changes in vegetation of arid and semi arid grasslands as induced by different grazing intensities of sheep were monitored. It emerged from these studies that the impact of grazing on arid vegetation was more than that on semi-arid one. In fact steep decline and peaks in vegetation cover in arid regions were related with rain induced germination and growth of annuals, mainly leguminous annuals, i.e., three species of *Indigofera* which accounted for 93% of total variance in coverage. Semi arid grasslands in contrast showed less of such changes and were hence stable. (Narita *et al.*, 1997).

Use of advanced multivariate analysis, i.e. Non Metric Multidimensional scaling has been made in studying succession in rehabilitation of mine spoil at gypsum areas in Barmer, (Kumar *et al.*, 1997). However, advance modelling for prediction of succession is yet to be attempted.

## **Vegetation Mapping**

It is thus, apparent that not only structure - compositional studies but even successional studies of vegetation are being attempted using most modern state-of-the-art computerisation strategy. These developments in the knowledge of structure and composition also resulted in parallel advancements in vegetation mapping.

### **Conventional Ground Survey Based Mapping**

Some of the earlier maps showing primary attributes of presence and density of vegetation were the stock maps of the rangelands. The secondary attributes of the vegetation formation, were mapped for entire Rajasthan by Gausson (1971) into 52 type of mapping legends at one million scale. UNESCO's Comprehensive Scheme was followed for preparing international map of vegetation of India showing 30 series; of which those which covered western Rajasthan (Puri *et al.*, 1983) are (i) *Calligonum* series, (ii) *Prosopis-Salvadora-Capparis-Ziziphus*, (iii) *Acacia - Capparis* and (iv) *Acacia senegal-Anogeissus pendula*. These were based on physiognomy and had their boundaries not so accurate. The dominant indices became the basis of mapping grass covers of Rajasthan (Gupta and Saxena, 1972, Saxena, 1972, and Saxena (1977a), wherein it was shown that grassland distribution is governed by habitat, rainfall and landform. In the low rainfall zone (100-250 mm) in the extreme western Rajasthan, the sandy terrain supports *Lasiurus sindicus*, with various associates depending upon degree of degradation. Likewise, in 250-400 mm rainfall zone, the *Cenchrus* type dominates on sandy terrain and in 300-450 mm rainfall zone, *Dichanthium annulatum* dominates. The specific habitats like saline playas support *Sporobolus* type, flood plains have *Desmostachya bipinnata* as dominant and hills have *Sehima nervosum* as

the dominant type. Sand dunes are occupied by *Panicum turgidum*-*P. antidotale* type. In their map, grassland types were correlated with the sheep breed type.

In the resource appraisal of Bikaner district, vegetation map of Bikaner showed tree-shrub cover by numerals and grasscover by alphabets. Nine communities of tree-shrub cover and nine of grass covers were depicted on map (Anonymous, 1974). Thus, in this map too, vegetation has been shown as a reflex of landform and degradational stages have been shown to some extent.

### **Potential versus Existing Vegetation Maps**

With each tree shrub cover, a specific grass cover has been shown. In conclusion, specific plant cover is correlated with a particular landform (Saxena, 1972). But Kumar and Shankar (1985) argued that "there is no denying the fact each landform might have supported a specific plant community in the beginning; but the spate of biotic interference which later followed on each landform resulted in degradation of site (Saxena, 1977b). Such degraded land forms therefore, became the ideal niche for species which are known to occur in early seral stages or in deflected successional seres". Since, these degraded sites are important in view of their priority in management, their depiction on the map is rather more important. Depending upon the kind and severity of biotic pressure coupled with variation of landform, soil depth and soil texture, the existing vegetation of Guhiya catchment represented a bewildering combination of trees, shrubs and grasses in the form of a mosaic (Kumar and Shankar, 1985). The existing vegetation, thus does not show exact specificity to a particular habitat and landform. It was, therefore, resolved to group sites according to their existing grass cover types (Dabadghao and Shankarnarayan, 1973). This type of grouping based on grass cover type was followed in vegetation mapping of Guhiya and Bandi catchment, wherein seven major grass covers were recognised and mapped, but tree shrub cover varied on each site according to soil texture, depth and landform (Kumar and Shankar, 1985, 1987).

The basic philosophy is that grasses being surface feeders are immediate indicators of the quality of site (Shankar and Kumar, 1983). Thus, ecological status of the site became apparent from the type of grass cover it had. That this fact is true was tested in survey of vegetation of Bandi catchment (Kumar and Shankar, 1987a). It was concluded from this study that as the grass cover improves, the perennial vegetation also recovers and stabilises. The approach to group sites on the basis of grass cover was shown to have sound rationale as it throws light on ecological status of vegetation, site quality and inter alia suitable directions of site management.

### **Vegetation Mapping on Aerial Photos**

In addition to ground based approaches, aerial photographs have also been used in resource surveys of arid areas (Ghose and Singh, 1966) but their use in identifying plant communities in relation to edaphic factors has been made by Gupta and Abichandani (1968). Photo elements of each dominant tree and shrubs were standardised and communities were mapped on physiognomic basis taking into consideration type of crown, plant height, distribution and spread



on each landforms. Though boundaries of types are delineated accurately on aerial photos, the structure of vegetation within these delineations is poorly understood (Gupta, 1971).

## **Vegetation Mapping Using Satellite Data**

### **Use of primary attributes in vegetation mapping**

With the advent of satellite data, the first serious attempt in arid lands was made by Hielkema (1977) in a FAO sponsored study on application of Landsat data in desert locust survey of the region from Arab to west India.

Simply comparing separate black and white multispectral bands at 1:1,000,000 containing information on vegetal growth with those imageries having same area under dry condition representing zero growth, revealed that such a comparison of band 5 scenes with and without vegetation gives a better and quick idea as to how widespread a rainfall event has been for inducement of vegetal growth. This helps in selecting areas for detailed digital analysis. This can be enhanced by diazo printing by exposing the two (wet and dry) relevant bands to diazo colour film. The two diazo films are superimposed and the area where radiance has changed shall appear in different colour than rest of the scene. However, inconsistency in photographic processing is a bottleneck in obtaining the accurate results.

Additive colour viewing of the scene through the false colour coded combination of the band 5 (veg. absorptive) and band 7 (veg. reflective) gives a qualitative assessment of location of areas with vegetation, the aerial extent and the coverage of vegetation in few classes e.g. high, medium, and low. Minimum area that can be identified is 5-15 ha with 25-40% cover. However, if one band is too dense it may hamper additive colour viewing.

### **Use of secondary attributes**

Visual interpretation for mapping vegetation through secondary attributes has rarely been attempted, less so in the arid zones. The reason could be that when delineations themselves obtained after visual interpretation suffer from less fidelity, the ground data could be as well physiognomic or purely floristic and need not be secondary in nature.

However, a small exercise on this aspect was done for Siwalik forest vegetation of India (Kumar, 1990a). Similar work can be done in arid zone where FCC are available and ground data can be analysed through multivariate technique.

### **Prospects of visual interpretation**

One of the limitations for achieving desired accuracy in visual interpretation of satellite data is that of lack of its stereoscopic vision, besides poor resolution. The problem of resolution is being gradually tackled with thematic mapper (TM) data becoming available at a resolution of 30 m and French satellite "SPOT" data at a resolution of 10 m in panchromatic mode and 20 m in multispectral mode. In fact, wastelands of India have been mapped using TM sheets enlarged to 1:50,000 (NRSA, 1986, Kumar. *et al.*, 1995). Experience has shown that visual interpretation of

FCC and black and white scenes enlarged to 1:50,000 scale can help in mapping dense, moderately dense and sparse vegetation and bare areas. Species groups or communities cannot be identified in arid situations. These proved to be excellent for detecting change in the extent of grazing lands over a period of time in Jodhpur district by Sharma *et al.* (1989). Thus, in visual interpretation, effective demarcation of large as well as homogeneous stands is possible such as that of *Lasiurus syndicus* in the Indian desert (Kumar and Saxena, 1989). Microlevel mapping is not possible.

In Indian desert, Landsat capability was demonstrated by Shankar and Singh (1983) in central Luni basin. Kumar and Saxena (1989) showed amenability of Indian Remote Sensing Satellite (IRS) IA data to identification and mapping of sevan grasslands in the western Rajasthan.

### Prospects of digital image analysis

In arid regions representing sparse plant population environments, vegetation detection and mapping through digital image processing becomes quite different. In fact standardisation of different ratioing, slicing and proportioning techniques seems to hold promise. McGraw and Tueller (1983) opined that on different components of vegetation i.e. trees, shrubs, grasses etc., different techniques of analysis could be combined. Such a combination resulted in 77.8% to 95.4% accuracy in Nevada rangelands of USA (McGraw and Tueller, 1983). In desert landscape with large open areas, it is also important to account for multiple intermingled green and senescent species and bare ground of variable canopies due to shadow, litter, gravel and moisture status.

All these studies discussed above employed physiognomic, floristic or primary vegetational attribute. It will be interesting to use synthetic attribute of vegetation derived from classification and ordination for mapping on digitally analysed satellite output.

### Single Species Maps

Besides mapping entire vegetation, there have also been attempts to map distribution and density of a single species.

The entire geographical area is criss-crossed and sampling sites are located on topographical maps. On each site density class can be marked with suitable symbols. Isolines can also be drawn to delineate sites of similar density to show different areas having varying density or absences. Such maps of *Prosopis cineraria*, *Ziziphus nummularia* and *Haloxylon salicornicum* have been prepared in Indian arid zone. Shankar (1980) mapped distribution and density of *Prosopis cineraria* and concluded that its density increases from western to eastern part of west Rajasthan. While edaphically, older and younger alluvium were its preferred habitats, lower pediments with thick soil deposits and hummocks also supported good density. The best and high concentration of *P. cineraria* was found in 250-400 mm rainfall zone. This ground data has been used to verify a NOAA satellite data after NDVI analysis for mapping its distribution in western Rajasthan (Dhir

*et al.*, 1991). But since this ground truth is over one decade old, the validity of mapped units at field level remains to be seen.

Similarly, the mapping of Bordi (*Ziziphus nummularia*) in western Rajasthan by Shankar and Kumar (1981) revealed that Jodhpur-Nagaur-Bikaner-Churu Zone broadly coming under 250-350 mm rainfall zone has its high density. Here also, alluvial plains with loam and sandy loam soils support its high density with high leaf fodder production. Charan and Sen (1985) mapped distribution of *Calligonum polygonoides*, alongwith its associates and found its relictual occurrence at five locations and correlated the distribution with the overall delimitation of arid zone.

Besides, these maps showing purely economic exploitation potential of a species, there can be ecological uses of these maps. In the distribution map of *Haloxylon salicornicum* for example, Shankar and Kumar (1984) convincingly demonstrated it as an indicator of buried courses of river Saraswati. Based on its distribution pattern, four abandoned courses of river Saraswati were reconstructed and certain courses suggested by other workers were confirmed. Thus, these single species maps have both economic and ecological value.

### Vegetation Maps of Future

Kumar (1992c) opined that accuracy in delineation and precision in determining structure of vegetation units in these delineated areas are the two foremost requirements for generating vegetation maps of applied value. Clearly, delineations will become increasingly accurate with increasing resolution afforded by satellite sensors. But with the state of technology available, even accurate

and full detection of vegetational signal from arid areas itself is faced with challenging issues. Since most of the established vegetation indices have not given satisfactory results in arid lands, more innovative approaches are desirable such as pixel modelling, band subtraction, possible use of mid-infra red and microwave band to take care of soil brightness, shadow attributes, path radiances, atmospheric haze, and variable canopies of arid vegetation.

But correctly delineating a unit is half the goal achieved. Determination of vegetation structure through multivariate analysis for derivation of mapping legend has been shown a distinct possibility in respect of aerial photographs. And it should be the endeavour to demonstrate its efficacy in respect of digital image analysis too. Since classification and ordination of ground data give vegetation classes of indicator value, its use should be widely adopted for generating vegetation maps which are not mere abstractions, but have ecological information for sound management of site. Then only, vegetation maps will be more application oriented (Kumar, 1992c).

Notwithstanding the superiority of these modern tools in mapping, they are costly and cannot be afforded by everyone. So, conventional maps will continue to be generated for variety of purposes. The important aspect here again is, to search for such a synthetic parameters of

vegetation which as succinctly as possible indicates habitat conditions. Derivation of this parameter and its use in mapping vegetation on topographical sheets will not only become basis of sound ecological management but will also generate interest among remote sensing specialists to increasingly adopt it in portraying this ground truth on satellite data.

Besides, information on allied aspects can be merged and efforts will have to be directed to standardise computer based vegetation resource information system such as one developed at St. Regis, USA (Singh, 1986).

### **Vegetation Biomass**

Whyte (1964) described grazingland types and supply-demand balance sheet of fodder and feeds. Five major grass covers, their aerial extent and existing herbage yield have been described by Dabadghao and Shankarnarayan (1973) in their book. The tropical *Sehima-Dichanthium* cover is the largest followed by subtropical *Dichanthium-Cenchrus-Lasiurus Phragmites Sacharum - Imperata* and *Themeda-Arundinella* and temperate and alpine meadows in the Himalayas and Nilgiris.

Some of the first studies on estimation of forage productivity in arid lands were carried out at CAZRI. These include aboveground productivity of grasslands at Jodhpur, India (Saxena *et al.*, 1974), forage potential of Jalore district (Gupta and Saxena, 1966), primary productivity and nutrient composition of desert grasses (Saxena and Aggarwal, 1983) Guhiya catchment (Kumar and Shankar, 1986a) production as affected by Khejri tree (Shankar, Dadhich and Saxena, 1977) or by *Albizia lebbek Prosopis cineraria, Tecomella undulata, Acacia senegal* (Ahuja *et al.*, 1978) or (Sharma *et al.*, 1980) by season and rainfall (Aggarwal, Saxena and Kaul, 1977, 1978, 1980). Much of this work was summarised by Saxena (1977c, 1988). These productivity studies in protected and unprotected range areas were carried out in detail by Shankar from 1975 to 77 in an MAB programme (Anonymous, 1976, 1977, 1978). These studies concluded that 60-70% of solar energy captured is partitioned into below ground part in degraded situations whereas in non-degraded situations reverse is the trend. Similar studies at Pilani revealed that turnover of underground biomass was higher and rate of production were 1.01 and 0.20 g/m<sup>2</sup>/day at two sites near Pilani (Kumar, 1975) All these have resulted (Table 3) in the decline in the forage yield (Shankar, 1983, Kumar, 1994). Of this low yield, the bulk is contributed by annual grasses, annual forbs, and perennial weeds (Gupta *et al.*, 1972), which are by and large, unpalatable. Studies on forage budgeting for Jaisalmer district (Shankar and Kumar, 1987a, b), entire Indian Desert (Shankarnarayan and Kalla, 1985) and in a cluster of six villages in Bikaner (Kumar, 1991) revealed that forage is in deficit at all levels - village, district and region, but can be enhanced upon protection and appropriate management. Such comparison of protected and unprotected sites alongwith habitatwise assessment continued in the normal vegetation survey work cited earlier. Based on these studies it emerged (Kumar, 1994) that upon protection, production can be increased 4-8 times (Table 3). Even then, a regional study concluded that with

the livestock increasing from 6.88 m adult cattle units (ACU) in 1956 to 9.09 ACU in 1977 and projected 10.02 m ACU in 1995, 11.28 m ACU in 2000 AD (Venkateswarlu *et al.*, 1992), the situation is really grim and serious in view of declining productivity over the years. Moreover, from 1960-61 to 1982-83, grazinglands area has declined to the tune of 14.2 % with forage supply being short of 62 % for entire arid zone in 1982-83 (Shankarnarayan and Kalla, 1985).

Table 3. Vegetation cover and yield in degraded and non-degraded conditions

Grass cover type	Herbage cover		Herbage yield (kg ha <sup>-1</sup> )	
	Non-degraded	Degraded	Non-degraded	Degraded
<i>Dichanthium annulatum</i>	4 - 8	0.5 - 2	4000	130 - 1100
<i>Desmostachya bipinnata</i>				
<i>Eleusine - Dichanthium</i>	3 - 9	0.5 - 2	1200 - 1500	100 - 600
<i>Desmostachya bipinnata</i>				
<i>Sporobolus marginatus</i>	4 - 7	1 - 3	1400 - 2600	300 - 500
<i>Dichanthium annulatum</i>				
<i>Sachharum spontaneum</i>	4 - 7	1 - 3	1400 - 2600	300 - 500
<i>S. benghalense</i>				
<i>Cenchrus ciliaris-C. setigerus</i>	4 - 6	1 - 2	2000 - 2500	300 - 400
<i>Eleusine compressa -</i>	3 - 4	0.5 - 2	800 - 1000	175 - 450
<i>Dactyloctenium</i>				
<i>Lasiurus indicus</i>	5 - 14	2 - 4	4000	400 - 500
<i>L. indicus - P. turgidum</i>	5 - 8	2 - 3	1500 - 2000	300 - 450
<i>Aristida - Eragrostis</i>	2 - 3	0.1 - 1	500 - 800	100 - 200
<i>C. biflorus</i>				

Similar studies on biomass estimation have been carried out at Kutch district by Pandya and Sidha (1987, 1989 a, b). They reported more below ground biomass in all the situations with efficiency of energy capture being 0.71% on yearly basis and 1.01% for monsoon season (Pandya, 1995).

In a series of papers emerging from Rajkot school under the stewardship of Prof. S.C. Pandeya, primary productivity system transfer function, ecotypic differentiation in grasses of arid grazinglands have been studied in arid and semi arid India (Pandeya, 1974, Pandeya and Jain, 1979; Pandeya and Jayan, 1969; 1970, Pandeya, Mankad and Jain, 1974, Pandeya *et al.*, 1977, 1986). Much of this information alongwith that from rangelands from other parts of the country has also been reviewed by Pandeya (1988) in his presidential address to the III International Rangeland Congress in New Delhi. The salient findings pertaining to arid part are as follows: (1) Slight increases upto 50% in dominance shoots up production whereafter production becomes static, (2) Production in monsoonal climate increases upto October and then declines, rather

sharply in arid areas, (3) Ratio of above ground to belowground net production is less than 1 in arid, dry atmosphere. Similar have also been the conclusion of MAB study at the Plant Ecology Unit of CAZRI (Mann and Shankar, 1979, Anonymous 1976, 1977, 1978) and Harsh and Sen (1975).

Efficiency of solar energy capture by various grasslands types of India has been reviewed (Shankar, 1984) and it has been found that semiarid grasslands have the higher energy use efficiency (Shankar *et al.*, 1977; Shankar and Kachhwaha, 1978). Naik (1973) and Pandeya (1974) ascribe this to the preponderance of C-4 plants in arid and semiarid tracts.

Most of the studies on estimating productivity have been based on harvest quadrats at a limited scale of sampling. Use of succinct estimator such as rain use efficiency though tried at village level (Kumar, 1991) needs confirmation at district and regional level estimates. Further these estimators need to be combined with satellite parameters to have biomass estimate on seasonal basis so that then contingency plans in the event of both surplus and scarcity could be envisaged well in advance.

## **Vegetation Use**

Economic importance of plants found in this region has long been recognised and documented in a series of papers from CAZRI. Gupta and Saxena (1968) assessed the potential of *Salvadora oleoides* and *S. persica* for non edible oil in western Rajasthan. Prospects of developing agro-industries in western Rajasthan were identified by Gupta and Saxena (1978). Plant foods, part used, season of availability were listed by Saxena (1979) and was further enlarged to include fuel, fodder, gums, oilseed yielding plant in another publication by Saxena (1981). It has been documented that 40 species belonging to 21 families yield leaves that can be used as vegetables; 27 species coming from 10 families yield edible fruits; 8 species yield fibre; 3, crude rope; 8, oils and 7, gums or resins. Besides, many of these are source of medicines. (Saxena 1979, 1981). Eleven grasses of fodder value were described by Oza (1972) from Kutch area of Gujarat. Many of these plants have medicinal value also (Saxena, 1984). Recently, this information has been updated on the form of a database (Kumar and Parveen, 1997 b) in order to prioritise families needing search for newer medicinal plants.

The important issues needing further research are (1) possibility of domestication of wildly available plants, (2) determining safe exploitation levels without affecting the stability of the system and (3) standardisation of agro techniques and post harvest processing for value addition, especially in respect of medicinal plants.

## **Epilogue**

Forty five years ago, Biswas (1952) in the Symposium of Rajputana Desert had remarked that "very little work has been done with regard to the Desert vegetation of this country" and outlined

the future lines of work in this field. It would now be worthwhile to examine achievements in these major areas and set agenda of work for future. The first target of thorough botanical survey of this area stand achieved by Bhandari (1978, 1990) and Botanical Survey of India. Knowing actual areas and exact spots covered by xerophytic, psammophytic, halophytic and lithophytic plant communities was identified as the second target by Biswas (1952). We know from the foregoing account that 90% of the area is now surveyed and mapped by the Plant Ecology unit of CAZRI. The third target of accurately delineating dry zones on map of India is fairly well accomplished. Establishment of small stations at each centre for recording meteorological data and studying environment factors was another desired line of action. Many centres of CAZRI, RAU, AFRI, GAU, HAU have come up in the recent years to accomplish these studies. The focus on life history of different plants of particular natural surrounding has, however, received much less attention. This aspect is now gaining momentum with newer uses of these plants being increasingly discovered and hence necessitating an urgent attention to understand biology of these plants.

Thus, beginning with simple listing of plants on different habitats, this century has seen progress in methodological tools so much so that nearly all aspects of vegetation resources are being studied now in greater detail and with increased precision in order to reach at the threshold of predictive management. Future developments in software technology, satellite sensors and sampling strategies would surely go a long way in understanding finer aspects of vegetation of arid zone for its better management.

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## PRODUCTS OF ECONOMIC IMPORTANCE FROM ARID ZONE PLANTS

Hamid A Khan

The importance of plants as treasure-house of renewable natural resources besides being the protector of environment has become greatest ever in the modern socio-economic scenario. In addition to firewood and timber, plants provide a number of other non-wood products which are termed as *minor forest products* and find wide application in domestic and industrial uses. These products include fibres and flosses, essential oils, oil seeds, tans and dyes, gums, resins, oleo-gum resins, drugs, spices, insecticides, leaves, edible products, lac and other products. Some of these products earn valuable foreign exchange and have good export potential. Arid zone flora also provides a number of plants which yield products of economic importance and hold promise to play a vital role in the economy of arid and semi-arid regions. Among the economic plants, exploration and survey of medicinal plants of the Indian arid zone, however, received the attention in 60's (Chopra *et al.*, 1960; Kaul and Ganguly, 1965). Some interesting observations have also been made on the ethno-medicinal and other uses of the plants endemic to this region (Gupta *et al.*, 1966). Separation of products of economic importance from plant matrix employs complex procedure of processing the plant material for analysis. solvent extraction, fractionation, chromatography, pH separation, sophisticated instrumentation, etc. which is time consuming and tedious. Modern instrumentation and advanced analytical techniques have, however, proved to be quite handy. An effort towards systematic study on products of economic importance from arid zone plants, however, started at CAZRI, Jodhpur, in 70's, as a result of which useful information has been generated.

### ***Plants of Industrial Importance***

*Balanites roxburghii*, locally known as Hingota, has been found to be a potential source of diosgenin and oil (Ghanim *et al.*, 1980, 1988; Chandrasekharan *et al.*, 1984; Ghanim, 1991). Diosgenin is used as a raw material for the production of steroid hormones and oral contraceptives by the pharmaceutical industry. Diosgenin from the pulp of Hingota fruits has been found to conform to the specifications of pharmaceutical industry. There is lot of variation in diosgenin content in the fruit samples collected from different locations in western Rajasthan and the fruit samples have afforded upto 3.7 per cent diosgenin (based on weight of fruit pulp). The kernel of the seed of Hingota fruit has afforded 45 per cent oil. The oil has been found suitable for use in the manufacture of soaps. Short term edibility tests carried out by National Institute of Nutrition, Hyderabad have shown that the oil was comparable to groundnut oil. However, long term feeding

trials have to be carried out before Hingota oil is recommended as an edible oil. According to an estimate based on existing natural stands of Hingota trees at the National Park, Bharatpur, it is easy to achieve per hectare production level of 30 kg of diosgenin, 129 kg of oil, 159 kg of animal feed and 1,772 kg of hard coat for use as a fuel or charcoal. *Balanites roxburghii* (Hingota) is, therefore, a potential plant for inclusion in afforestation programme which will not only provide much needed vegetative cover but also improve the economic conditions of the local people.

*Euphorbia antisyphilitica*, a shrub of Mexican origin is well adapted to Jodhpur and Pali conditions. Accordingly to the study, for optimum yield (4%) of candelilla wax, plantation should be harvested at the age of 3.5 years. Candelilla wax isolated and purified at the Institute has been found suitable for end use in the manufacture of explosives by Cordite Factory, Nilgiris, under Ministry of Defence, Govt. of India (Ghanim *et al.*, 1988). The wax is also an excellent substitute for carnauba wax and finds use in shoe polishes, chewing gum, lipsticks etc. Indigenous production of candelilla wax can easily substitute its import and also the import of carnauba wax which alone is to the tune of 3 lakh kg per annum. The need, however, is to develop cheaper extraction process for candelilla wax.

Other plants of industrial importance belonging to arid and semi-arid regions are Jojoba (*Simmondsia chinensis*) for oil (liquid wax) equivalent to highly prized sperm whale oil and Guayule (*Parthenium argentatum*), a rubber yielding plant.

## Medicinal Plants

Senna (*Cassia angustifolia*) is an important drought hardy medicinal plant. Its performance was studied by growing the plant under rainfed conditions at Jodhpur from seeds procured from south India. Analysis of dry leaves for sennoside content revealed a favourable yield varying from 3.0 to 4.8 per cent which is more than the desirability limit of 2.5 per cent prescribed in British Pharmacopocia (Amalraj and Khan, 1989). Senna leaves earn about Rs. 11 crore per annum in foreign exchange. Primarily grown in Tamil Nadu, farmers in western Rajasthan have also recently started taking up cultivation of this valuable medicinal crop which may prove to be a boon to the people of arid and semi-arid region.

*Datura innoxia* (EC 34404) raised at Jodhpur was found to contain 0.3 per cent total alkaloid whereas the same seeds grown at IARI, New Delhi afforded 0.12 - 0.14 per cent total alkaloid (Chandrasekharan *et al.*, 1984). This is alkaloid content in Jodhpur grown plants was, thus higher than those grown at New Delhi which is in agreement with the report that the active principle content is more in plants grown under arid zone conditions. Medicinal plants which show marked enhancement in active principle content when grown under arid conditions can be a source of additional income to the people of this region.

The roots of *Arnebia hispidissima* have afforded five isohexenylnaphthazarins which are considered to be a new class of drugs. These are alkannin acetate, alkannin, alkannin isovalerate, alkannin  $\beta$ -hydroxyisovalerate and arnebin-7 (Khan *et al.*, 1983). All isohexenyl-naphthazarins

are biologically extremely potent compounds, because they have pronounced antibacterial, antitumour and wound healing activities. The wound healing activity of all members of this class of compounds has probably the most important clinical significance. It is of interest that extracts of *Boraginaceous* roots (*Arnebia hispidissima* belongs to the family *Boraginaceae*) have been used for centuries as folk remedies for a variety of disorders such as eczema, keratoderma, dermatophytosis, corns callus, acne vulgaris, burns and even hemorrhoids.

Other important medicinal plants which are potential source of income to the people of this region are Isabgol (*Plantago ovata*) and Aswagandha (*Withania somnifera*).

### **Plants Yielding Gums and Oleo-Gum Resins**

*Acacia senegal* occurs widely in the arid and semi-arid regions of Gujarat and Rajasthan. The tree is a well known source of highly valuable gum-arabic in Sudan. The tree, however, produces little or no gum in India, as such. Gum arabic finds widespread use in various important industries. Besides its use in pharmaceutical industry, gum arabic is an important constituent of paper, textile, adhesives, minerals, fertilisers, explosives, cosmetics, soap, ceramics, food, beverages and confectionary industries. India is annually importing about 5000 tonnes of gum arabic worth 7.3 million rupees from Sudan. It is possible, however, to tap gum upto 1 kg per tree from indigenous stands of this tree by ethephon treatment. The ethephon solution is introduced into the holes made in the main trunk of the trees. The gum exudation generally occurs within 10 to 15 days. The gum samples so obtained have been found to conform to the physico-chemical characteristics prescribed in pharmacopoeia of India for Indian gum (Khan and Harsh, 1992, 1984). The tapping of ethephon induced gum from *Acacia senegal* has great potential.

Another important oleo-gum yielding plant found in arid and semi-arid region is *Commiphora wightii* commonly known as Guggal. Guggal is also the name given to its exudation. Guggal is widely used as an incense in religious ceremonies and as a fixative in perfumery. It is also considered astringent, demulcent, expectorant, alterative, stomachic, carminative, aphrodisiac and antiseptic. A preparation called Guglip is developed from guggal by the Central Drug Research Institute, Lucknow. The preparation is reported to possess hypolipemic activity. Injurious tapping methods generally followed by tribals has led to extensive depletion of the natural population of *C. wightii* and consequently the species has been listed as a threatened plant of India. The trade potential of guggal is quite large and promising. The need, therefore, is to evolve improved method of tapping to achieve optimum production of guggal on a sustained basis without adverse effects on plants.

### **Essential Oil Yielding Plants**

The essential oil extracted from the leaves and inflorescence of *Cymbopogon martinii* var. *motia* (Palmarosa or Rosha grass) grown at Jodhpur has been found to conform to ISI specifications (Amalraj and Khan, 1984). The oil also known as Palmarosa oil is in great demand

in the perfumery industry especially for its high geraniol content and contributes to the export trade. The essential oil content in Jodhpur grown plants of *Eucalyptus viridis* was found to be 2.1 per cent which is around one and half times higher than reported from Australia from where the seeds were procured (Ghanim and Jayaraman, 1979). Cineole content in the oil was found to be 93 per cent. The oil was thus superior both in quality and yield compared to *E. globulus* oil which is currently the chief source of medicinal oil in the country.

## Others

There are arid zone plants which contain various other products of economic importance. Triaccontanol - an effective and commercial plant growth regulator has been found to occur in *Tephrosia falciformis* (Khan *et al.*, 1984), *Prosopis cineraria* (Khan *et al.*, 1987), *Prosopis juliflora* (Khan *et al.*, 1992), *Cordia myxa* and *Acacia senegal*. The presence of triaccontanol (0.012%) in the leaves of *P. cineraria* explains better grass yield under and in the vicinity of this tree. Triaccontanol is a constituent of wax part of the plant extract. Since nature provides most of the arid zone plants with a coating of wax on their leaves or stems to minimise moisture loss, a systematic chemical examination of arid flora may lead to identification of new economically exploitable sources of triaccontanol. Amongst other compounds, a new flavanone, falciformin has also been reported from *Tephrosia falciformis* (Khan *et al.*, 1986).

Rotenone - the most effective rotenoid among rotenone group of compounds has been found to occur in *Tephrosia villosa* along with 6a, 12a-dehydrorotenone and stigmasterol (Chandrasekharan *et al.*, 1983). A new prenylated flavanone, 7-methyl glabranin has also been isolated from the roots of this plant (Jayaraman *et al.*, 1980). Rotenone is effective contact poison against flea beetles, aphids, apple suckers, caterpillars, etc.

There is a great demand of edible as well as non-edible oil in our country for various purposes. There are species like *Citrullus colocynthis* (Tumba), *Citrullus lanatus* (Mateera), *Salvadora oleoides* (Mithajal), *Salvadora persica* (Kharajal), *Azadirachta indica* (neem) and *Pongamia pinnata* (Pitpari) which grow in arid region and are oil/fat yielding.

Henna (*Lawsonia inermis*) is another important dye yielding plant which is gaining popularity in western Rajasthan. A part of the total production of Henna is consumed within the country whereas the rest is exported in the form of dried leaves or powder. *Cassia auriculata* (Anwal) is used for tanning leather on a large scale.

There are still a large number of arid zone plants which are either unexplored or underutilised for active principles and other products of economic importance. The priority research need is, therefore, to fully investigate this flora taking advantage of advanced instrumentation and conduct studies on pilot and semi-commercial scale to develop commercial extraction techniques and perfect agro-practices for economically potential plants. A well designed research and development model will convert potential economic plants to characteristic economic plants of arid zone. Propagation of plants of economic importance should be intensified in the existing

forest area and wherever possible, fresh areas which are otherwise uncultivable or barren should be brought under vegetation cover incorporating such plants. This will not only improve the economic conditions of the local people by way of additional income and generating employment but also encourage them to conserve and propagate these plants.

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## LAND USE

Balak Ram and Gheesa Lal

Land use is a product of an interaction between a society's cultural background, skills and physical needs on the one hand and natural capability of land in form of its soil, climate and water resources on the other. Under hot arid ecosystem in our country low and erratic rainfall, extremes of seasonal temperatures, high evaporation loss, meagre ground water potential, absence of perennial streams, salinity and dune and rocky/gravelly terrain are the major factor affecting the land use. Agriculture, which is the most dominant land use of the region, is mainly rainfed and subjected to high risk and uncertainty. Before sixties studies on land use were primarily based on revenue and land records data giving only a quantitative description. Thereafter the use of topographical maps and aerial photographs made it possible to show the spatial distribution of different land use systems. After seventies the satellite remote sensing has virtually revolutionised the research on land use mapping and monitoring its changes over time and space.

### ***Evolution of Land Use***

Evolution of land use in north-west arid zone of India has been reported by Whyte (1960), Bhardwaj (1965) and Randhawa (1980). According to them the evolution of land use took place during Neolithic Period when man had taken up sedentary life and domesticated the animals. They first settled along the rivers and near water points and later on shifted to other marginal areas. James Tod's *Annals and Antiquities of Rajasthan* (1929) and Erskine's *Western Rajputana States Residency and Bikaner Agency Gazetteer* (1909) highlight the land use system that prevailed during British period but no systematic account has been given. Classical treatise of Nainsi Mohtu (Fateh Singh, 1969; Jain, 1974) on *Marwar-ra-Pargana-ri Bigat* gives an account of cultivated area and crops being produced in the 'Khalsa' villages which were directly administered by rulers. Thus no account was available for villages under the 'Jagirdars'. After the settlement of land holdings and abolition of Jamindari system and reorganisation of states, the maintenance of land record of the each holding was started.

### ***Land Use Classification System***

The land records office at tehsil or taluka level keeps land use record of each of the village under their jurisdiction using 44 column proforma. This record is maintained by the village *Patwari*. This classification system categorises fallow lands into three sub-classes separately under individual and government holdings; area irrigated by different sources and sub classes of unirrigated, double cropped and net sown areas. Based on this format the State level Economic

and Statistical Organisation compiles and publishes annually the land use data by adopting 16 points format and 12 land use classes. Irrigated area is not included in this classification system. It is separately given under irrigation. The Economic and Statistical Directorate publish district level data in the Statistical Abstract of the state and tehsil/taluka level data in the district-wise Statistical Abstract. At national level the land use data is published under nine fold classification system. The district Census Handbook published by the Directorate of Census Operations also includes land use data in five classes viz., forest, irrigated area, unirrigated area, culturable waste and permanent pastures and area not available for cultivation. After the establishment of Central Arid Zone Research Institute in 1959 and launching of integrated basic resources survey, the need to evolve land use classification system to show its spatial distribution was also felt. Sen (1978) has reviewed the land use classification system adopted by National Atlas Organisation (Sen and Chakravarty, 1958), Planning Atlas of Damodar valley region edited by S.P. Chatterji and All India Soil and landuse survey organisation (Anon., 1960, 1971). Sen and Gupta (1971) modified the land use classification system of Directorate of Economic and Statistics for Choropleth Mapping. Sen (1972a) carried out land use mapping to estimate wastelands of arid region using aerial photographs and also categorised land utilization units (Sen, 1974a). He had also analysed the land use pattern of sand dunes through interpretation of aerial photographs (Sen, 1977a). National Commission on Agriculture (Anon., 1976) published national level land use statistics in a precise form. Taking into consideration various land use classification systems, problems of arid zone and feasibility of mapping, Sen (1978) evolved a new land use classification system for Indian arid zone. It contains 15 land use categories. Besides settlement, forest, permanent pastures and oran and water bodies, the cultivated lands were classified into seven categories based on their intensity of cultivation. This was done to avoid repetition of land use survey for every year since the annual extent of cropped area vary and depend on the intensity, distribution pattern and amount of rainfall. Wastelands were classified into four categories viz., sandy, saline, rocky/stony and rocky and gravelly waste. This classification system was widely appreciated and Government of Rajasthan has assigned land use mapping of 3 districts (Churu, Ganganagar and Jaisalmer) in IGNP command area. During the course of survey each of the four wasteland categories was further classified into two classes i.e., with scrub and without scrub. Similarly during the land use survey of Kachchh and Bikaner districts three more wasteland categories viz., gullied waste, mud waste and waterlogged area were added. Mangrove forest were separately mapped. For National wide land use/land cover mapping the classification system was attempted by Gautam (1988) and thereafter it was finalised by NRSA (1989). It includes six level-I and 24 Level-II land use/land cover categories. The wasteland categories were same as adopted during wasteland mapping project (NRSA, 1986, 1991). After the launching of Integrated Mission for Sustainable Development (IMSD) project the land use/land cover classification system was further modified to have upto level-III classification (NRSA, 1995c) where evergreen and deciduous forest categories were further classified into dense and open classes. *Kharif*, *rabi* and double



cropped areas are also included in level-III and grassland/grazing land were classified into dense and degraded. In future, thus land use classification system may be further improved because of the availability of higher resolution satellite data and better interpretation and mapping techniques.

## **Land Use Mapping**

An account of land use in Rajputana desert was first reported by Kanitkar (1952). He estimated that out of 88597 sq miles area of 10 important states in Rajputana only 20694 sq miles area was available for cultivation while net sown area was 8124 sq miles. Irrigated area was nearly 1486 sq miles. Bajra occupies 22 per cent, jowar 16 per cent, wheat and barley 16 per cent, gram 7 per cent and rest area is occupied by sesamum, cotton and maize. Banerji (1952) while defining the role of vegetation in desert control estimated 320 sq miles of Khalsa area under forest department. Total khalsa area was 5545 sq miles. Thus forest area was only 5.8 per cent and area under culturable waste was 523 sq miles. Nearly 31000 sq miles was with Jagirdars in the Division. In Jodhpur state out of 36120 sq miles area khalsa land constituted 17 per cent, Jagir 83 per cent and forest area 1.3 per cent. Later on the information on land use and cropping systems was reported by Mishra and Kachchhawa (1962), Bose (1964), Sen (1966), Sen and Abraham (1966), Mishra (1967), Ahmed (1968), Singh and Krishnan (1968) and Qureshi (1969). Integrated basic resources survey though was started at CAZRI from 1961 first in the Central Luni Basin and then in the eleven development blocks but land use mapping was yet not initiated. Thereafter for integrating the natural resources and characterization of Major Land Resources Units (MLRUs) (Abhichandani and Sen, 1977), the importance of land use was felt and from the survey of Bikaner district in 1971 it had become an integral part of integrated survey. Aerial photographs were mainly used to map various natural resources. Sen (1972a, 1977b) developed aerial photo interpretation techniques to classify and map different land use categories. Sen and Tak (1965) has also evolved a new method of constructing block diagrams for showing the terrain and land use.

Land use mapping of Bikaner district was thus completed on 1:253,440 scale (Sen *et al.*, 1982). Their characteristics, geomorphic significance and spatial distribution were discussed by Sen and Singh (1977), Sen *et al.* (1982) and Malhotra *et al.* (1976). The detailed land use mapping on cadastral map scale (1:6336) was undertaken in 1972 in five villages for Daijar Operational Research Project area (Sen *et al.*, 1978). Semi-detailed land use survey and mapping on 1:50,000 scale was carried out in Jodhpur district in 1974 and Nagaur in 1978 by Sen and others and reconnaissance land use mapping of Mahendragarh district, Haryana (Anon., 1981). Sen and Lal (1974) have also compared the land use system of Shergarh and Bilara tehsils of Jodhpur district. At the same time Lal (1974) made detailed land use study of Borunda village of Nagaur district using aerial photographs. Vats *et al.* (1972) has also done detailed study of a village in Pali district. On the other hand, Singh (1972a, 1972b) has worked out land use efficiency of Haryana State at the level of assessment circles by taking a number of parameters.

Further, Singh (1976) brought out Agricultural Geography of Haryana which gives an over view of land use, cropping pattern, settlement pattern and agricultural production. For entire Rajasthan state, Sen (1972b) has brought out Agricultural Atlas of Rajasthan. It includes a number of thematic maps giving district level information on various aspects of agriculture and its development. During the same period studies on cropping pattern, crop production and the impact of climate and other factors were carried out by Patnaik (1977), Chatterji (1977), Tewari (1972), Vats (1977) and Ramakrishna (1978). Sen (1976) has linked up agro-demographic aspects with land use system. Sen (1984) studied land use pattern in arid Rajasthan. A quantitative account of population, land use and livestock was presented by Malhotra *et al.* (1972), Mann, Malhotra and Shankarnarayan (1977) and Malhotra *et al.* (1983). For Punjab region, Anita Aggarwal (1981) has discussed the cropping system, their characteristics and technological development. On the other hand, Temang and Jayaraman (1981) has pointed out the status and the problems of land use in Gujarat state.

At CAZRI semi-detailed land use studies on 1:50,000 scale were undertaken in Churu (Sen and Ram, 1980), Ganganagar (Sen and Gupta, 1980) and Jaisalmer (Sen and Lal, 1980) districts on the request of Rajasthan Government. Final mapping was done on 1:250,000 scale. In such study the results of land use mapping were correlated with the land use data of revenue department. Balak Ram (1981) has made an assessment of land distributed to the people of weaker section while Gheesa Lal (1981) applied aerial photo interpretation techniques for rural land use classification. During 1981-83 semi-detailed land use survey and mapping was carried out on watershed basis in 34440 sq km area of the upper Luni basin. Separate mapping was done for the Guhiya (Balak Ram and Gheesa Lal, 1983) the Bandi (Balak Ram and Gheesa Lal, 1988), the Jojri and the upper Luni catchments (Shankarnarayan and Kar, 1983). During this study the land use system were correlated with cropping pattern, crop production, climate, landforms, soils and vegetation. Relationship between land use and groundwater was studied in Siwana region by Chandrasekharan and Balak Ram (1985) and by Gheesa Lal (1987b) in Borunda area of Nagaur district. Besides the use of aerial photographs, Landsat satellite imagery on 1:250,000 scale were also used. Although Sen (1974) has prepared a land use map of western Rajasthan using Landsat imagery on 1:1000,000 scale. Application of remotely sensed data has now become a mandatory aspect for subsequent studies. In the similar way district level semi-detailed land use mapping was carried out in Jodhpur (Anon., 1982), Nagaur (Chatterji *et al.*, 1989), Barmer (Balak Ram *et al.*, 1989), Kaparda area (Balak Ram *et al.*, 1989), Jaisalmer (Chatterji and Kar, 1982), Kachchh (Balak Ram and Sen, 1988; Balak Ram and Chauhan, 1990, 1994), Jalor (Singh *et al.*, 1996), Sikar (Balak Ram and Chauhan, 1992, Balak Ram and Gheesa Lal, 1996), Abohar tehsil, Ferozpur district (Anon., 1992) and Jamnagar district (Balak Ram and Gheesa Lal, 1995). Study on cropping pattern in Jodhpur district was carried out by Gheesa Lal (1995c). Detailed study of land use and cropping pattern was carried out in Balesar village (Balak Ram, 1984) in relation with soils, Doli and Jhanwar villages for operational research project (Chatterji, 1987a, 1987b;

Balak Ram, 1987), six villages of Bikaner district under IFAD project (Gheesa Lal and Balak Ram, 1991), Kailana watershed (Anon., 1992), Sar Sarecha (Anon., 1993), and eleven villages with a total geographical area of 88 sq km under DDP/TOT project. These are Champasar and Pandit-ji-ki-Dhani (Jodhpur), Karnu and Pabusar (Nagaur), Barju and Lakhusar (Bikaner), Lawan and Bharamsar (Jaisalmer), Korna and Juna Mitha Khera (Barmer) and Rupawas (Pali) villages. Till now reconnaissance, semi-detailed and detailed land use mapping has been completed in 30458, 234511 and 827 sq km respectively using CAZRI's methodology.

### **Land Use/Land Cover Mapping Through Satellite Data**

Using IRS LISS-I data of 1988-89, the land use/land cover mapping of the entire NW arid zone (24 districts) was completed during 1990-91 on 1:250,000 scale as per the land use classification developed by NRSA. Nine districts of western Rajasthan viz., Jodhpur, Churu, Barmer, Sikar, Jhunjhunu, Bikaner, Jalor, Jaisalmer and Nagaur with a total geographical area of 175730 sq km was completed by CAZRI (Anon., 1990a to 1990i; Sen and Lal, 1990; Balak Ram and Singh, 1995), Pali district by Rajasthan State Remote Sensing Application Centre; Ganganagar and 4 districts of Haryana by RRSSC Jodhpur and Haryana Remote Sensing Application Centre, six arid districts of Gujarat by RRSSC Jodhpur and SAC, Ahmedabad and 3 districts of Punjab by RRSSC, Dehradun. The land use/land cover statistics for all the completed districts of India was published by NRSA (1992, 1995b).

### **Wasteland Mapping Through Satellite Data**

Wasteland is an integral part of land use/land cover. NRSA has coordinated this work for National Wasteland Development Board. Using Landsat-2 FCC imagery on 1:50,000 scale the wasteland mapping of Pali, Churu, Ajmer, Tonk and Jodhpur districts (Anon., 1988a to 1988e) were carried out by CAZRI and Surendranagar, Jamnagar, Rajkot, Hisar, Sirsa and Bhatinda districts by other organizations during 1986-88. Under phase II wasteland mapping of Sikar district (Anon., 1992) was carried out by CAZRI while Mahendragarh, Banaskantha, Mehsana and Nagaur districts by other agencies during 1991-92 using IRS LISS-II goecoded FCC. Wasteland of the Upper Luni basin was mapped out and quantified by Sen and Balak Ram (1986) and for Rajasthan desert (Sen and Balak Ram, 1988). Sandy wastelands of Rajasthan desert were also mapped through remote sensing techniques (Sen *et al.*, 1990). Wasteland classification system was also improved and delineation of watersheds and village boundary were also included.

For mapping both visual and digital techniques were applied. NRSA (1995a) brought out Wasteland Atlas of India showing the distribution and statistics of wastelands.

Under the Integrated Mission for Sustainable Development (IMSD) project land use/land cover mapping as well as transport network and settlement mapping are also being done on 1:50,000 scale using IRS-LISS-II data and using both visual and digital techniques. Such mapping has been done for Nagaur district in Phase-I programme by Rajasthan State Remote Sensing Application Centre and for Bhiwani district by HARSAC. Under phase-II mapping in

Table 1. Changes in land use (in %) in arid Rajasthan (1958-59 to 1993-94)

Year	Total reporting area in 000 ha	Forest	Area under non-agri. uses	Barren and uncultivable land	PP & OGL	Misc. tree crops and groves	Culturable waste	Fallow land other than current fallow	Current fallow	Net area sown	Area sown more than once	Total cropped area
1958-59	20842	0.73	2.86	11.25	2.87	0.01	23.02	14.15	8.22	36.89	0.87	37.76
1963-64	20829	0.59	3.09	11.63	3.51	-	21.56	10.72	7.50	41.40	0.75	42.15
1968-69	20860	0.79	3.17	11.27	3.76	0.02	22.09	9.14	12.27	37.49	0.92	38.41
1973-74	20861	0.82	3.21	11.17	3.79	0.01	20.48	6.90	5.06	48.56	2.47	51.03
1978-79	21291	1.29	3.27	4.63	3.92	0.01	26.46	7.34	6.65	46.43	3.01	49.44
1983-84	20823	1.50	3.51	4.92	4.18	0.32	21.81	6.72	6.97	50.07	4.00	54.07
1988-89	20827	1.84	4.20	4.97	4.05	0.07	22.04	8.29	5.15	49.39	4.88	54.27
1993-94	20820	1.96	4.28	4.87	4.05	0.02	20.35	7.01	8.19	49.27	5.28	54.55

PP & OGL: Permanent pastures and other grazing land

Note: Figures in percentage to total reporting area

Barmer, Hanumangarh and Sikar districts is being done by RRSSC, Jodhpur; Pali by IDS, Jaipur; Jhunjhunun by Institute for Environmental Studies, Jaipur; Jodhpur, Bikaner and Churu by SRSAC, Jodhpur; Jalor and Jaisalmer at CAZRI. Similarly all the six arid districts of Gujarat are being done by SAC, Ahmedabad, Sirsa, Hisar and Mahendragarh districts by HARSAC and Bhatinda district by Punjab Remote Sensing Application Centre. Thus, excepting Ferozepur and Faridkot all the arid districts are included.

### **Land Use Changes, Impact Assessment, Remote Sensing and Land Use Planning**

Unprecedented growth of human and livestock population has caused expansion and intensification of agriculture. In doing so the land resources were arbitrarily used far beyond their use and regeneration capability and hence land degradation and desertification has taken place over time and space. Sen and Gupta (1971) attempted to show the land use changes based on secondary data. Malhotra *et al.* (1983) have brought out land use statistics from 1956-57 to 1977-78. Jodha (1977) assessed land tenure problems in arid Rajasthan. Study on agricultural growth was attempted by Mruthyunjaya *et al.* (1983) and Chauhan (1984). Gheesa Lal (1987a) tried to formulate land use planning in Jodhpur district. Balak Ram (1988) has given spatial and quantitative account of land use changes in Siwana region between 1960-61 and 1985-86 at village, tehsil and regional level. Changes in land use in arid Rajasthan over the period from 1958-59 to 1993-94 is given in Table 1. Studies on the assessment of land use changes using remote sensing techniques have been taken up by Balak Ram and Chauhan (1992, 1993, 1994),

Balak Ram (1990), Balak Ram and Kolarkar (1992), Gheesa Lal and Balak Ram (1994), Balak Ram *et al.* (1993), Gheesa Lal (1995a, b), Balak Ram and Gheesa Lal (1996) and Chaurasia *et al.* (1996). Directorate of Agriculture, Government of Rajasthan has brought out district level trend in land use statistics from 1956-57 to 1990-91 (Anon., 1992a). Important work on land degradation and desertification was done by Sen and Balak Ram (1987), Sen and Balak Ram (1991), Dhir (1992), Singh *et al.* (1992), Kolarkar and Balak Ram (1993) Sen and Kar (1993, 1995). Studies on the impact assessment have been carried out by RRSSC, Jodhpur in irrigated area in stage II of IGNP 1989 and Narmada Canal Command area in 1994. Balak Ram and Chauhan (1992) studied impact of gullies on land use and further the shrinkage and degradation of common property resources (Balak Ram and Pathak, 1996). Kolarkar and Balak Ram (1992) suggested preventive measures on restricting land use. Balak Ram and Sen (1992) mapped out changes in irrigated area in Rajasthan desert. Important study on crop acreage estimation using satellite digital data was carried out for wheat in Haryana state (Ruhel *et al.*, 1991) and for cotton in Hisar and Sirsa districts (Yadav *et al.*, 1995). An overview of land use system and their changes over time and space was given by Balak Ram and Gheesa Lal (1997). Land use studies carried out at CAZRI ultimately suggest and map the alternate land use system for the region. Sen *et al.* (1980), Gheesa Lal (1987a), Balak Ram (1988) and Balak Ram *et al.* (1989, 1990, 1993, 1994, 1995) have worked out and mapped sustainable land use system for different study areas on semi-detailed and detailed scale.

Recommendation for sustainable land use have also been given for all the areas for which integrated survey has been carried out. This is done by formulating Major Land Resources Units (Abhichandani *et al.*, 1977). Various aspects and feasibility of sustainable land use were discussed at length in the International workshop on sustainable land use systems research held in New Delhi during 1990. Technical guidelines (NRSA, 1995) for IMSD project also laid down the criteria to prepare action plan for land resources and water resources development by integrating natural and socio-economic resources. But still most of the land use planning are theoretical and criteria to evolve viable and workable land use planning, needs refinement and serious thinking.

### **Future Thrust**

Land and its resources are limited while human pressure and uneconomic activities are constantly increasing. Thus monitoring of land use at an appropriate administrative unit and/or agro-ecological sub-zone wise on a fixed time frame using remote sensing and GIS technologies will be the major thrust area for coming years. All the existing maps will be digitized and spatial and non-spatial data base will be created in GIS. Development of appropriate and workable methodology and Special Decision Support System (SDSS) (MLURI, 1996) will be another important thrust area. Preparation and dissemination of agro-ecological based district-wise Digital Land Use Planning Atlas (with tehsil/taluka or development block level maps) will be the ultimate objective for the years to come.

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# DESERTIFICATION : CAUSES AND POSSIBLE SOLUTIONS

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Desertification is defined as land degradation in the arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities (Anon., 1995). It ultimately leads to reduction or loss of production potential of the land and is a major environmental problem in the Asian countries. In India the drylands, comprising the hot arid, semi-arid and the dry sub-humid climatic zones, account for 203 million hectares or 61.9 per cent of the total geographical area. Ironically these regions are undergoing a steep rise in population, with attendant demands from the limited land and water resources, and are attracting many new industries which release toxic elements into its atmosphere, soil and water. The net result is desertification/degradation of more land, as well as a gradual deterioration of the production potential of these climatically handicapped fragile regions. According to a recent estimate by Government of India, 32.7 per cent of the country's land area (107.43 million ha) is affected by different land degradation processes (Anon., 1994) and needs a serious consideration for meaningful control.

## ***Causes and Manifestations of Desertification***

In order to understand desertification processes in the Indian context it is necessary to know the geomorphic processes under natural set up. Some studies have been carried out at Central Arid Zone Research Institute, Jodhpur, to understand the processes and their manifestations in the arid western part of India, using remote sensing and field information (Faroda and Singh, 1997). The region is dominated by two climate driven processes : fluvial and aeolian, although a few other processes, like the fluvio-marine along the coasts and weathering have also played significant roles in evolution of mega landforms like the hills, rocky plannar surfaces, vast alluvial plains, high sand dunes, etc., as well as smaller transient features like barchans, shrub-coppice dunes (nebkhas), other sand streaks, rills and gullies, new flood plain deposits, scalding, etc. Some of the smaller, recently formed features are good indicators of desertification.

## **Water Erosion**

Soil erosion through fluvial processes affects large areas in the Saurashtra and Kachchh uplands, and along the eastern margin of the Thar desert where the average annual rainfall varies from 350 to 500 mm, but has very few occurrences to the west of 250 mm isohyet in the Thar (Kar, 1996). The manifestations can be deciphered from the pattern of sheet, rill and gully erosion

features. Increased ploughing and destruction of vegetation cover for fuelwood, overgrazing and other destructive uses must have accelerated the erosion in recent decades, but in the absence of specific data it is difficult to suggest how much of the gullying activity is due to human activities alone and how much due to the natural processes. In Kachchh region a part of the problem is related to a slow natural upliftment of the terrain over the centuries, which leads to a change in base level and increased erosion.

### **Wind Erosion/Deposition**

Wind erosion/sand drift and deposition of sand is one of the most important factors causing desertification in arid Rajasthan. Gupta and Aggarwal (1980) and Gupta *et al.* (1981) quantified wind erosion under different land use conditions and reported maximum sand drift from bare cultivated lands without vegetation. The western limit of dryland cultivation was found almost co-terminous with the 240 contour of wind erosion index (Kar, 1996). To the east of this limit the sandy terrain is now increasingly put to tractor ploughing. This leads to more of sand blowing than earlier (Ghose *et al.*, 1977; Dhir *et al.*, 1992). Moreover, the traditional practices like keeping the land as fallow for long or short durations, rotational grazing, etc., are not popular now. Lands which earlier used to be reserved as common grazing lands have been encroached upon for cultivation. As a result more land is being subjected to sand reactivation (Singh *et al.*, 1978; Kar and Joshi, 1992). This is happening even in the wetter eastern margin of the desert which is potentially less vulnerable to wind erosional hazard (Kar, 1993). This is because, there is a limit to the capacity of sandy landforms to maintain a balance with the exploitative enterprises of man. The sandy landforms in the eastern part of the desert, including the high sand dunes, are largely inherited from a past major dry climatic phase (~18,000-10,000 years before present), as is the case with the high dunes elsewhere in the west. This is why some parts of eastern Thar (e.g. Pushkar near Ajmer; Sikar near Jaipur) with high cultivation and grazing pressures, suffer from high sand reactivation in spite of higher rainfall and better vegetation status of the sandy terrain there. The sand mobility is restricted to the areas of high human interventions only (Kar, 1986, 1992). Deep ploughing of the dune slopes and interdune plains, destruction of the traditional pasture lands and wanton destruction of the vegetation cover of the sandy terrain have loosened the structure of the sandy soil in its top few meters and have reactivated the erstwhile stable surface in many areas of the desert (Gupta *et al.*, 1997). Since human pressure is very high, people have no choice but to use their land continuously and suffer some degradation of their land. Dhir (1977) brought out that continuous sharp increase in population with a parallel increase in incidence of arable farming have resulted in the increased component of loose sand and hummocks formation, reduced soil fertility and loss in productivity. Raina (1992) and Gupta and Raina (1994) observed that in the soils of degraded fields of cultivated, pasture and oran land use in sandy terrain, there was decrease in the organic carbon, available P and available K content in comparison to the soils of non-degraded sites.

## Waterlogging and Salinity/Alkalinity

Increase in soil salinity/sodicity due to brackish water irrigation, seepage from earthen embankments/canals and waterlogging and salinisation in command areas leads to desertification in western Rajasthan (Singh *et al.*, 1994). Joshi and Dhir (1991, 1994) have reported that as the result of irrigation with high residual carbonate water (15-20 meq l<sup>-1</sup> RSC) the soils are turning sodic which acquire unusual hardness, reduced infiltration and surface crusting. Because of very low and uneconomic yields the lands are abandoned. Several thousands hectares of such lands have been desertified in this region. Chatterji (1985) reported that 9600 and 6170 ha area in the command of Sardarsamand and Jaswant Sagar dam respectively has degraded due to salinisation. Similarly large area in the command of Nayagaon and Kharda tanks has also degraded due to high salinity build up. In IGNP command, large area has turned water logged and saline due to seepage from canal, over irrigation and hard pan at some depth (Dhir and Joshi, 1997).

Raina and Joshi (1994) have reported the effects of desertification processes on soil health. The natural soil bodies in equilibrium with its environment. As a result of desertification physical, chemical and biological properties of soils have been adversely affected. Reduction in nutrient availability, compaction of soil, surface crusting and loose sand deposition have created non-congenial environment in soil for growth of micro-organism and nutrient availability.

Accelerated salinity-alkalinity hazard is dominant in the medium to heavy textured alluvial plains, especially because of irrigation with saline ground water. In the seaward margin of the coastal alluvial plains of Kachchh and Saurashtra very high pumping of potable ground water has led to an intrusion of saline sea water into the aquifer at many places. Since the farmers have no other choice as regards watering the crops, they continue to use the groundwater, even after its quality has been adversely affected by sea water intrusion. In the Indira Gandhi Canal Command (IGNP) area in the Thar desert, the problems of waterlogging and salinity-alkalinity are increasing at a faster pace. In the area covered within the Stage 1 of IGNP, the critical areas for waterlogging increased from 742 sq km in 1981 to 1980 sq km in 1990. This is mainly because the sandy soil is followed at a shallow depth by a barrier of gypsum or calcium-rich formation. Such salinity build up has also been noticed in the command areas of small irrigation tanks in the south-central part of the desert and where the canals have crossed some salt-rich palaeochannels. Wrong drainage planning has also contributed to the process of land degradation. For example, alarmed by the increasing waterlogging problem in the canal-dominated dry valley of the Ghaggar (Saraswati) in Ganganagar district a diversion was constructed linking eighteen fertile interdune plains between Jakhrawali and Suratgarh, in the naive hope that aeolian sand will absorb the excess water. The result is a very serious waterlogging and salinity-alkalinity problem in the area, leading to abandonment of land and settlement, with immense socio-economic problems to the dwellers.

## **Industrial Effluents**

In recent years industrial effluents have become a major source of land and water pollution/degradation in the arid Rajasthan. This is especially so in the vicinity of Jodhpur, Pali and Balotra towns where effluent discharges from the textile dyeing and printing industries into the ephemeral streams have contaminated the surface and ground water downstream. Use of such toxic water for irrigation has also degraded the land. According to the latest estimates, out of the 34500 ha land thus affected, 34 per cent is moderately degraded and 44 per cent is severely degraded (Singh and Ram, 1997). Efforts are being made to treat the water for disposal and reuse.

## **Mining**

In western Rajasthan about twenty major minerals and nine minor minerals are being mined. More than 90 per cent of the mine owners have open case mining. The rest are underground mines. The area occupied by the mine is increasing and by 2000 AD 0.05 per cent of Jaisalmer district and 1.15 per cent of Jhunjhunu district are expected to be under mining activities.

The surface mining activity causes immediate degradation of land. The mining sites are abandoned after the excavation work is over, without adopting any reclamation measure. The mining on agricultural land, either surface or underground, reduces the productivity of land by way of excavation, disposal of debris and tailing. The mineral processing like grinding of limestone for cement industry, calcite and soapstone for ceramic industry, have three-fold adverse effect. The fine dust, generated and released in the atmosphere, leads to surface scaling of the adjacent land after it settles down. Consequently the infiltration rate is reduced and the runoff increases.

Mining activity restricts the subsurface movement of water. With the removal of vegetation the rate of the evapo-transpiration is reduced as a result there is a change in the hydrological balance in the area. Due to this change the perched water table rises and causes salinity. When the mining debris of minerals like ball clay, china clay, Fuller's earth, bentonite and gypsum are dumped on the sandy plain, a semi-impermeable surface layer is developed. These areas get flooded during the monsoon and gradually developed salinity. Sodium salt mining activity increases the surface salt concentration, causing total loss of vegetation.

## **Degradation of Water and Vegetation Resources**

Desertification at its initial stage is manifested by vegetation degradation. Kumar (1992) has identified the parameters of vegetation degradation. These include changes in vegetation composition, changes in status of climax species, impact on plant density, plant vigour, bare area, biomass, carrying capacity palatability, mineral and nutrient composition of animal feed and impact on stability and equilibrium.

With increasing pressure on land vegetation degradation is increasing at an alarming rate. The common grazing lands around the villages are now some of the very severely degraded sites, as these are highly exploited and most neglected. Many good grazing lands have also been



encroached upon for agriculture. Some studies in the Rajasthan part of the desert suggest that vegetation cover in areas with good grass species in the less than 300 mm average annual rainfall zone has declined from about 7 per cent to 1 per cent, while in the more than 300 mm average annual rainfall zone the decline in tree and shrub cover is from 8 per cent to 1-2 per cent. As the useful plant species are selectively over exploited, their place is taken gradually by the unusable poor species, and by species with stunted growth. Biomass production from the system is then severely restricted. Consequently, it is becoming increasingly difficult to meet the forage demand from the grazing lands.

Sharma (1997) has developed hydrological indicators of desertification. For surface water these are: area covered and turbidity of surface water, changes in water flow and water courses, sediment load in water courses and sediment deposition in water reservoirs. For ground water these are sequentially lowering the depth of ground water and deterioration of water quality. Taking the case study of Jodhpur district, Sharma (1997) reported widening of stream bed by 1.8 times, decrease in water bodies area by 1.8 to 2.4 times and increase in sediment load by 30 million between 1958 and 1986. Due to over exploitation of the ground water there has been decline in water table in 16.4 per cent wells deeper than 12m and water quality in 54.6 per cent wells. This could be checked through cultivation of low water requiring crops, optimum use of water through conservation irrigation methods, water charges, etc.

Based on these studies, and using large-scale satellite imagery and ground-based information, it has been found that 32 per cent area in western Rajasthan is slightly affected by desertification, while 40 per cent is moderately affected and 21 per cent severely. The information has been mapped particularly with an objective of devising control measures.

### **Soil Degradation Mapping**

Delineation of kind and intensity of soil degradation is pre-requisite for planning desertification control. Kolarkar and Singh (1988) by adopting FAO (1979) methodology mapped soil degradation in Guhiya catchment (Luni basin). The methodology involved climatic aggressivity, soil characteristics and topographical factors. Very severe risk of degradation due to water erosion and salinisation was observed respectively in 1 and 19 per cent area and severe risk of degradation due to wind erosion, salinisation was respectively in 26 and 33 per cent area. Raina *et al.* (1991) with the help of Landsat Thematic Mapper subscenes have mapped the types and degree of soil degradation in the sandy plain. In an area of over 0.5 million ha, 42 per cent was degraded by wind erosion and 50 per cent by accelerated water erosion. Nearly 70 per cent area was slightly affected followed by 17 per cent moderately and 6 per cent severely degraded. In alluvial plain the Landsat TM FCC with ground verification revealed that out of 0.36 million ha, 52 per cent area was degraded due to soil stripping, sheet wash and gully erosion and 8 per cent due to salinity. Soil degradation due to combined effect of water erosion and salinization covered 33 per cent area.

This methodology of soil degradation mapping has been adopted for mapping soil degradation in Jalor and Sikar districts of Rajasthan and Jamnagar district of Gujarat. Raina (1994) reported that in an area of 0.41 million ha 51 and 30 per cent area has been affected due to water and wind erosion respectively and another 1.14 per cent area due to salinity. Nearly 44 per cent area has been moderate to severely degraded and needed desertification control measures. Raina (1997) observed that in Sikar district area degraded due to wind erosion, water erosion and salinisation occupied respectively 59.3, 18.7 and 3 per cent. Nearly 56 per cent area needed immediate attention for desertification control measures.

Singh *et al.* (1992) have reported that out of 20.88 million ha area in arid Rajasthan 68.3, 11.1, 3.1 per cent area has been affected by varying intensities of wind erosion/deposition, water erosion and salinisation respectively, out of which 20.6 and 0.2 per cent area has been degraded with severe and very severe intensities. Singh *et al.* (1994) have further discussed the desertification problem in different rainfall zones of arid Rajasthan as caused by accelerated and natural processes. In less than 300 mm rainfall zone wind erosion/deposition, salinisation and water logging due to IGNP are dominant processes whereas in more than 300 mm zone water erosion, wind deposition and sodification due to brackish water were major desertification processes.

## **Possible Control Measures**

### **Sand Dune Stabilization**

About 58 per cent of arid Rajasthan is under different types of sand dunes. These are grouped under two systems, old and new. Barchans and shrub-coppice dunes are newly formed and are the most problematic. The other dunes are of old system and are under various stages of reactivation. CAZRI has now developed appropriate technology for sand dune stabilization. It includes (i) protection of dunes from biotic interference, (ii) development of microwind breaks from crest to the base of the dunes in the form of parallel or chessboard pattern, and (iii) reseeding of grass and creeper seed in between the microwind breaks and transplanting of nursery-raised tree seedlings at the spacing of 5x5 m in between the microwind breaks. Most suitable tree and grass species for the purpose are : Israeli babul (*Prosopis juliflora*), Phog (*Calligonum polygonoides*), Mopane (*Colophospermum mopane*); Gundi (*Cordia myxa*), Sewan (*Lasiurus sindicus*), Dhaman (*Cenchrus setigerus*) and Tumba (*Citrullus colosynthis*) (Kaul, 1985).

Nearly 80 per cent of the sand dune areas belong to farmers and are mostly under monsoon cultivation. To stabilise such dunes, the technique is the same, but the whole dune should not be brought under tree cover. Trees should be planted in the form of strips. In between the two tree strips crop/grass can be cultivated. By adopting this model, farmer can get food grains and can stabilise his dune plot (Gupta, 1990, 1992).

## Shelterbelt Plantation

Considerable soil erosion takes place from the flat cultivated areas due to sandy nature of the soil and high wind velocity which during summer months is sometimes as high as 70-80 km hr<sup>-1</sup>. The soil loss is sometimes as much as 5 tonnes per hectare. If shelterbelts with 3-5 rows of trees are planted across the wind direction, soil erosion can be minimised (Bhimaya *et al.*, 1958; Gupta *et al.*, 1983).

The shelterbelts reduce wind velocity by 20-46 per cent on the leeward side of the shelterbelt at 2H to 10H distance and the soil loss is only 184 kg ha<sup>-1</sup>, as against 546 kg ha<sup>-1</sup> from areas without shelterbelts (Gupta, 1993; Gupta *et al.*, 1997). Moreover, soil moisture is 14 per cent higher in such areas as compared to the areas without shelterbelt and grain yield of pearl millet increases by 70 per cent. The fuel and fodder requirements can be met through lopping of trees which will also maintain the desired porosity of the shelterbelts.

## Aerial Seeding

Due to sandy nature of the soil the water holding capacity is very low, with the result that sowing of seeds needs to be completed within 2-3 days to favour germination. Conventional methods of afforestation are inadequate for revegetation of such a large and inaccessible tract having low moisture, erratic rainfall and loose sandy soil. Therefore, aerial seedling could be practised.

This technology has been used by different drought-prone states of India, like Gujarat, Rajasthan and Madhya Pradesh. The seeds of different trees and grasses are mixed and mass seeding is done from aircraft at the pre-monsoon as well as post-monsoon period. The seeds are pelleted using soil, clay, polymer (jalshakti) and farmyard manure. The germination of grasses and trees is about 70-80 per cent. However, due to severe grazing pressure and high moisture stress, the seedling mortality could be of a very high order. A study revealed that under such conditions only 1-2 per cent trees could establish themselves in the successive years. The grass population increased in the successive year, but again, due to grazing pressure, the grasses were uprooted. The process should therefore, be repeated continually for 4-5 years, so that in a good rainfall year there can be good establishment. The area should also be protected from biotic interferences.

## Silvipasture Systems

Indiscriminate cutting of vegetation for meeting fuel and fodder requirements is accentuating desertification. In order to control it there is need to follow a system approach. This helps in reducing solarization and wind and water erosion and thus increase productivity on long term basis, beside conserving resources and also to provide economic stability (Gupta and Sharma, 1997; Singh and Sharma, 1997). Various trees and grass combinations provide opportunities to suit different ecosystems. The promising trees and shrubs are: *Israeli babul (Acacia tortilis)*, *Nubica (A. nubica)*, *Kumat (A. senegal)*, *Angreji babul (Prosopis juliflora)*, *Anjan (Cenchrus*

*ciliaris*), *Mopane* (*Colophospermum mopane*), *Nutan* (*Dichrostachys nutan*) and *Lana* (*Haloxylon salicornicum*). All the above species are well adapted to arid and semi-arid regions.

## Suitable Agronomic Practices

### Minimum tillage

Tillage of agricultural land is necessary particularly from the point of view of seed bed preparation, moisture conservation and weed control. Excessive tillage under dry conditions, however, breaks unstable clods and exposes the soil to wind action. The common practice with the farmers of the region is to invert the soil after 3-4 years of cultivation, with an objective of capitalising on the fertilize sub-soil for crop production, particularly under non fertilizer use production systems. This practice, however, seems to accelerate wind erosion. The results of a study (Gupta, 1993) revealed that excessive tillage before monsoon lowers the percentage of clods of more than 5 mm size and also markedly increase the wind erosion. Reduced tillage, on the contrary, provides better clod size distribution and significantly reduces wind erosion. In vulnerable areas, therefore, summer tillage should be discouraged. Limited tillage after first showers and at optimum soil moisture content helps in clod formation, creation of rough surface and thus minimizes wind erosion.

Conservation tillage/farming for soil and moisture conservation and fuel economy are now practised in the developed countries. Type of tillage, however, depends upon soil, climatic conditions and the crops to be grown. On a loamy sand soil under unirrigated conditions and with an average rainfall of about 300 mm, reduced tillage of one disking and sowing has been found to be adequate in increasing the production of pulse crop of mung bean, clusterbean and cowpea. For sandy soils (highly vulnerable to wind erosion), however, further reduced tillage may be adequate (Gupta, 1993).

### Stubble Mulch Farming

Crop residues protect the soil against wind erosion during the periods between cropping. It is an excellent control measure if managed properly. The practice of using crop residues as stubble mulch began in North America as early as in 1910. Undisturbed residues in up-right position are normally more effective than grazed or fattened ones. Crop residues of 2 to 5 tonnes ha<sup>-1</sup> and pearl millet stubbles of 45 cm height were found very effective in preventing the blowing of sand from sandy soils of Bikaner. Crop residues like stubbles of coarse cereals, however, have generally been found to be more effective than equal quantities of short stubbles (Gupta, 1993; Gupta and Sharma, 1997). Crops with relatively more residues should be grown on the vulnerable soils. In arid areas, however, the availability of crops residues for mulch purposes is generally low. In such situations the perennial weeds could be killed and left over as organic mulch on soil surface.

## Strip Cropping

Strip cropping for wind erosion control is alternate plantation of erosion-susceptible and erosion-tolerant crops, perpendicular to the prevailing wind direction. The main advantage of the system is that the erosion tolerant strips reduce the velocity of the prevailing wind, trap saltating sand particles and thereby control soil avalanching. Therefore, narrow strips are more effective in reducing wind erosion in lighter soils. The width of the strip, however, depends upon the type of soil and the type of crops to be grown. It varies from 6 m in sand to 30 m in sandy loam. Establishment of strips of perennials like *Lasiurus indicus* and *Ricinus communis* at right angle to the prevailing wind direction in the CAZRI Farm at Jodhpur, reduced the impact and threshold velocity of wind to the minimum and checked the erosion. Consequently, crop grown in between the protective strips recorded increased production. Reduction in sand drift due to protective strips of grass at Bikaner and Hingoli (Jodhpur) was also reported by Singh (1989). Ley farming system of rotating grass and crop cultivation was found quite effective in resource conservation and improved production (Rao *et al.*, 1997). It has also been found that 18-20 years old cover of perennial grasses like *Lasiurus indicus*, *Cenchrus biflorus* and *Panicum turgidum* at Bikaner completely checked the movement of sand. The grass vegetation, besides reducing wind velocity and erosion, helped in forming surface crust and binding the sand particles. Agricultural lands can, therefore, be protected with strips and the marginal/degraded lands can be put under complete grass cover.

## Judicious Use of Irrigation Water

Irrigation plays a significant role in arresting desertification through its effect in promoting the establishment and growth of vegetation. In the highly sandy and dune covered areas sprinkler system of irrigation could be effectively used for raising crops and other vegetation. This has been found to economise water and increase the production of *Lasiurus indicus* in the extreme western part of Rajasthan. Excessive use of irrigation water, however leads to rise of water table and reduces crop yield particularly in low lying areas. The water table is reported to be rising at the rate of 0.3 to 3.0 m in the canal command area of north Rajasthan, the average being 1 m per annum. On the other hand, the ground water quality is deteriorating. Salt infestation could be a serious problem in near future, as there are substantial salts in various depths in the region.

## Control of Mining Activities

Presently these mine spoils are either barren or have sparse vegetation cover (5-8 per cent), but need to be vegetated. Some of the xerophytic tree species like *Prosopis juliflora*, *Acacia tortilis*, *Colophospermum mopane* and *Dichrostachys nutans* have adopted well under arid conditions and could be used in revegetating the mined wastelands.

## Extension Activities

As a result of efforts made by technologies have been developed for conservation of soil and water resources, sand dune stabilization, regeneration of degraded pasture lands and afforestation of arid lands. Contour bunding, bench terracing, gully plugging and integrated watershed development are some other techniques developed for water erosion control. Soil and water conservation and afforestation are some of the most important activities for the last few decades. Many of these programmes have been implemented under centrally sponsored schemes. Two major programmes of significance in this regard are Drought Prone Area Programme (DPAP) and the Desert Development Programme (DDP). About 35 million hectares of land has been treated at a cost of 22 billion rupees over the years. Yet this constitutes only about 20 per cent of the area in need of treatment. There are several reasons for the slow pace of progress like financial constraints, increasing biotic pressure, inadequate consideration for ground realities and people's participation, socio-economic conditions, small and unconsolidated land holdings, and poor maintenance of common property resources and soil and water conservation structures.

## Epilogue

From the above, it is clear that for sustainable development of arid Rajasthan desertification control is a must. Amongst other desertification processes soil erosion, degradation of common property resources, depletion of ground water, problems of introduction of massive irrigation and mining activity must be included.

Technologies are available today for control of most of the above processes. Further some need more attention. These include stabilization of private sand dunes, shelter belt in cultivated areas and rehabilitation of mined areas. Efforts are now being made to address these problems and find out simple solutions.

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# MANAGEMENT OF WASTELANDS FOR SUSTAINABLE PRODUCTION

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Though there is no universally accepted definition of a wasteland, it is generally defined as land which is degraded, depleted, eroded, spoiled, lying idle (singly or in combination) and so cannot be put to use. Wastelands may be idle due to inherent, environmental or anthropogenic factors. According to the National Wasteland Development Board, the total area under such category is 175 M ha, which is more than 50 per cent of the geographical area of the country. In western Rajasthan alone, about 7 million hectares area is classified as wastelands. This area is further increasing at an alarming rate because of over-exploitation and improper use of land, to meet the evergrowing grain, fodder and fuel wood requirements of the increasing human and livestock population. Also, culturable area is decreasing because of increasing urbanisation, mining and other economic activities, besides improper land use. In view of this, it has become essential not only to use the land according to its capability but also to manage the degraded lands for sustained and improved productivity.

## *Wastelands of western Rajasthan*

Wastelands of western Rajasthan occupy an area of about 7.0 M ha. which is about 33.2 per cent of the total land mass located in eleven districts. These wastelands have been mainly classified into four classes namely sandy, stony, gravely and saline. However, these have been further classified on the basis of their characteristics and problems of use (Table 1). Beside this there are lands wasted due to the mining activity and the use of industrial effluents.

Table 1. Wastelands of western Rajasthan

Wasteland category	Area (Million ha)	% of wasteland area
Sandy waste	3.43	48.7
Saline waste	0.20	2.8
Stony waste	0.15	2.1
Gravely	0.29	4.1
Rocky	0.02	3.1
Rocky and stony	0.11	1.6
Stony and gravely	0.06	0.8
Rocky and gravely	0.67	9.4
Sandy with open scrubs	1.00	14.1
Rocky and gravely	0.93	13.1
Waste with open scrubs		0.2

## **Sandy Wastelands and Technologies for Reclamation**

About 68 per cent of the area of western Rajasthan is occupied by sand-dunes and sandy plains predominantly in the districts of Jaisalmer, Barmer, Bikaner and Ganganagar. The productivity level of these lands is generally low because of the sandy nature of soils (clay 1.5 to 4.5% silt 1.2 to 5.5% and sand 90 to 97 %) and poor moisture retention and storage capacity (50 to 80 mm water/100 cm soil depth). Soil fertility evaluation of these sandy wastes reveal that a majority of these soils are very low in organic matter and nitrogen, low to medium in phosphorus, and medium to high in potassium. The soils are single grained, structureless and highly prone to wind erosion. In fact, sand movement is one of the serious problems of these regions which affect the establishment and growth of the plants. It has been observed that on an average 2 to 4 cm of the top layer of sandy soils and about 30 cm of the dune surface is generally blown away in Bikaner and Jaisalmer regions during hot dry months from mid April to mid June and is deposited along the obstructions particularly fences, houses, railway embankments, etc. (Gupta and Aggarwal, 1980; Gupta *et al.* 1981). The Central Arid Zone Research Institute (CAZRI), Jodhpur studied the problems of these lands for over three decades and developed technologies for their rehabilitation (Bhimaya and Ganguli, 1961; Kaul, 1968). Some details are discussed here.

### **Sand Dune Stabilisation**

The movement of sand dunes is a potential danger to productive lands, houses, roads and railways, canals, water courses, etc., and thus warrants stabilisation. The successful stabilisation of these dunes involve (i) protection against biotic interference either by fencing the area with barbed wire/thorny bushes or by digging trench around the area with an inward mound, (ii) sand-dunes fixation through mechanical or chemical means, to arrest the sand movement, and (iii) afforestation by vegetation like trees, grasses and shrubs preferably with the improved species of existing local flora (Gupta, 1990; Gupta, 1992).

#### **Sand dune fixation**

Sand-dune fixation is essential to check the movement of sand and protect the young planted seedlings from abrasive action of the moving sand. It can be achieved by constructing checkerboards or parallel hedge systems depending upon the direction of the wind. Locally available materials like *Calligonum polygonoides*, *Erianthus munja*, *Lasiurus indicus*, *Leptadenia pyrotechnica*, *Panicum turgidum* and *Ziziphus nummularia*, could be used for this purpose by burying them vertically downwards in rows 2-3 m apart. Mechanical (plant residues, plastic, etc.) or chemical (asphalt, latex sprays, etc.) mulching could also be used on sand-dune surface for arresting the sand movement.

#### **Afforestation**

After fixation, sand-dunes can be permanently stabilised with vegetation. It can be done by direct seeding, transplanting seedlings or cuttings of indigenous, or exotic species, adapted to the ecosystem. They may be planted in pits of 50 cm<sup>3</sup>. These can also be planted at 5m x 5m distance in strips of 10 rows at 50 m apart across the wind direction. The space in between the grass rows could

be used for planting grass slips or sowing grass seed. The success of sand-dune stabilisation depends upon choosing the right type of species, planting healthy seedlings, timely and deep planting, timely replacement of casualties and proper care of the plantation. Kaul (1985) reported *Acacia raddiana*, *A. tortilis*, *Prosopis chilensis* (syn. *P. juliflora*), *P. cineraria* and *Ziziphus mauritiana* among tree species, *Aerva javanica*, *Calligonum polygonoides*, *Crotalaria burhia*, *Ziziphus nummularia* (shrubs); and *Lasiurus indicus*, *Panicum antidotale* and *P. turgidum* among the herbs including grasses as the most suitable plant species for sand-dune stabilisation in the arid zone of western Rajasthan, India. *Calligonum polygonoides*, *Haloxylon aphyllum* and *Persicum* have been found to be excellent sand binders in arid areas of USSR.

#### **Aerial seeding of sand-dunes**

Another method of stabilising sand-dunes is through aerial seeding of a mixture of palletised (clay + sand + cowdung in 1:3:1 proportion) seeds of *Acacia tortilis*, *Citrullus colocynthus*, *Colophospermum mopane*, *Dichrostachys nutans*, *Lasiurus indicus*, *Prosopis cineraria* and *Ziziphus rotundifolia* @ 14 kg ha<sup>-1</sup> in selected spots. The technique was found viable. However, in the case of some failures, repeated sowing may be necessary.

After stabilisation, the sand-dunes should not be allowed for grazing. The biotic activity should not be permitted for 10-15 years. After the 10th year, the trees should be lopped for either fodder or fuel wood or both depending on the species.

#### **Shelterbelt Plantation**

Shelterbelts are multi-rows of trees and shrubs planted across the wind direction. These have been reported to protect the soils from wind erosion and the crops from hot winds in regions. It has been reported (Bhimaya *et al.*, 1958; Ganguli and Kaul, 1969) that shelterbelts planted across and on the margins of fields, protect crops effectively and control sand drifting in the arid areas. Shelterbelts of *Acacia nilotica* and *Dalbergia sisso* planted at the Central Mechanised Farm, Suratgarh and also along the roads and railways in early sixties were found highly useful in arresting the movement of sand (Bhimaya and Choudhary, 1961). Studies conducted at CAZRI, Jodhpur during early seventies with different shelterbelts showed that 8 years old and 5 metres tall three row shelterbelt of *Cassia siamea* in the outer rows and *Albizia lebbek* in the central row to be most effective in reducing wind speed and evaporative demand upto a distance of twice the height (2H) although the effectiveness was observed upto 10H distance in the leeward side during both summer and monsoon seasons (Gupta *et al.*, 1983, 1984; Gupta and Ramakrishna, 1988). The effectiveness was however, more during monsoon than summer season. Wind erosion is another most important factor which converts culturable lands to wastelands. All the three types of shelterbelts were found quite useful in reducing wind erosion by about 50 per cent. *Cassia siamea* type shelterbelts was however, found to be most effective. As there was reduction in wind erosion by shelterbelts, there was also reduction in nutrient loss associated with it. Consequently there was conservation of soil fertility also.

## Dryland Crop Production

### Soil fertility management

The soil fertility of dune soils is very low. Aggarwal and Lahiri (1981) reported that these soils contain total N in the range of 0.002 to 0.005 per cent, and organic carbon in the range of 0.02 to 0.03 per cent. Available P varies from 5.4 to 8.5 kg P ha<sup>-1</sup>. Although, nitrogen contents of sandy soils of these regions are low, but often half of it may be present as mineralised nitrogen. This soil nitrogen and that brought down through rains (Aggarwal and Lahiri, 1979) has been found to be sufficient to meet the requirements of grasses in this arid region. Aggarwal *et al.* (1978) reported that only 4 per cent of total soil nitrogen was involved in biological system of *C. setigerus* and *C. ciliaris* grass species of arid zone. Considering the requirement of nutrients of crops, this soil fertility is quite low for crop production.

The long term effect of the tree species on soil fertility regime in sandy plains showed that *Prosopis cineraria* and *Tecomella undulata* significantly improved the soil fertility status with respect to organic matter, total and available N, P and K and also the available micro-nutrients over the other tree species and field without vegetation (Aggarwal *et al.*, 1976). The response to applied N was also higher in soil beneath *P. cineraria*.

Under the given soil and climatic conditions, it is essential to develop low input technologies to make soil environment more congenial for sustainable crop production along with enhancing the soil productivity.

**Fertilisers and manure:** Effects of organic manure (FYM) on yield of pearl millet, efficiency of applied nitrogen and soil fertility were studied under rainfed farming for seven years (1983-1989) in Jodhpur. Application of fertiliser N along with FYM further increased yield. Yield with 40 kg N ha<sup>-1</sup> + FYM was nearly equal to that obtained with 80 kg fertiliser N ha<sup>-1</sup> alone (Gupta *et al.*, 1983; Aggarwal and Praveen Kumar, 1994). FYM significantly increased the utilisation efficiency of fertiliser N by crop and status of organic carbon, available N, P and micro-nutrients in soil. Residual N effects were observed for plots receiving FYM but no such residual effects were observed for fertiliser N. The efficiency of urea N could also be enhanced from 20 to 45 per cent by mixing elemental sulphur (Aggarwal *et al.*, 1987).

**Crop residues:** Leaving the crop residues in soil often have positive effect on the crop yield which is attributed to their beneficial effects like water conservation, soil erosion control and maintenance or enhancement of soil organic matter (Gupta, 1987; Rao *et al.*, 1997). These factors collectively often have favourable effect on crop growth and grain yield. The results of the studies undertaken on arid soils show the significance of crop residue incorporation on N-use efficiency, soil quality and crop yield (Aggarwal *et al.*, 1997).

**Crop rotation:** Growing one crop on same piece of land may have adverse effect even under good fertility management conditions. Some studies have indicated 62 per cent reduction in pearl millet yield in pearl millet-pearl millet rotation in contrast to green gram-pearl millet rotation. It has also been reported that green gram in rotation with pearl millet supplied with 20 kg N ha<sup>-1</sup> gave similar

yield as with direct application of 40 kg N ha<sup>-1</sup>. In other words, growing of legume had an effect equivalent to 20 kg N ha<sup>-1</sup>. Amongst kharif legumes, two years cultivation of clusterbean in rotation with pearl millet was found more beneficial for N saving, improvement of soil quality with associated 100 per cent increase in yield of pearl millet than yearly mung bean pearl millet rotation or continuous cultivation of pearl millet (Praveen Kumar *et al.*, 1996).

### Rain water management

**Water harvesting for crop production:** Water is single most important factor which affects growth and yield of crops. Its main supply through rain is not only low but highly erratic. The research efforts for over two decades showed the usefulness of on-farm water harvesting technology for field and orchard crops (Gupta and Venkateswarlu, 1994). Inter-row, inter-plot and micro-catchment techniques were evolved and perfected for different soil, topographic and rainfall situations. Runoff from micro-catchments was generally found to depend upon rainfall characteristics (amount, intensity, distribution), micro-catchment characteristics (size, slope, length, nature of the surface and antecedent moisture conditions) and water spreading properties of soil. The results of seven years field studies showed (Sharma *et al.*, 1986) that micro-catchments produced 13 to 32 per cent of rainfall as runoff at 0.5 per cent slope; and even higher amounts at 5 per cent (36 to 45%) and 10 per cent (26 to 44%) slopes. Runoff generally increased with decreasing slope length; runoff for 5 and 10 per cent slope were nearly equal but greater than for 0.5 per cent slope (Sharma, 1986). Apparently, there is a critical slope beyond which runoff is not affected by slope increases.

Catchment to cropped area ratios revealed 0.5 to be optimum with about 25 to 100 mm of additional water supply depending upon rainfall. Though no significant differences in yield of various crops were observed during normal rainfall years, the yields were generally higher with water harvesting system, particularly during drought years. A significant increase in yield of pearl millet and mung bean crops with higher water use efficiency was recorded during low rainfall years from 1982-1988 (Gupta, 1989). Pearl millet, mung bean and cowpea were generally found to be the best users of harvested water. Though the system was found highly useful, it has some of the inherent limitations like the use of 1/3 of land in constructing catchments, soil disturbance and earth movement, etc. In view of this, a micro-catchment technique involving 50 cm wide compacted catchment with 50 cm wide cultivated strip having paired rows of crop, was evolved. The technique was found to generate 20 to 80 per cent runoff depending upon the rainfall conditions. As a result of increased water availability, 50-100 per cent increase in yields of pearl millet, mung bean and clusterbean were recorded over control without water harvesting.

**Water harvesting for horticultural and other trees:** *Ziziphus mauritiana*, locally called 'ber' is an important horticultural plant which supplies fruit, fodder and fuel wood and could be raised under arid conditions. However, due to low rainfall and other harsh climatic conditions, it gives low fruit yield, bears stunted growth and its survival rate after planting is low. Therefore, a circular catchment technique was evolved for making more rain water available for successful establishment, growth and yield of the transplanted plants (Gupta, 1984). The technique involves the construction of

compacted circular catchment of 1.5 m radius with 5-10 per cent slope around the transplanted plants. During low rainfall years from 1986 to 1988, circular catchment technique increased the mean soil profile moisture storage by 10-30 mm m<sup>-1</sup> soil profile and improved the growth and fruit yield. Therefore establishment of tree seedlings with circular catchment technique seems to be one of the most feasible method under rainfed conditions.

**Micro-catchments and different lining materials:** A large part of the rainfall is absorbed by the sandy soil of the catchment, thereby reducing the total amount of runoff/harvested water. Various surface covers and sealant were, therefore, tried during the period from 1985 to 1996 for determining their relative efficiency for runoff generation. Plastic covered catchments were found to generate 95 per cent runoff while Janta emulsion (asphalt), pond sediment and compacted catchments yielded 91 per cent, 88 per cent and 66 per cent runoff, respectively. While the coefficient of correlation between precipitation and runoff was near unit (0.990 to 0.999), the threshold retention was 0.06 to 0.76 in plastic, 0.29 to 0.71 in Janta emulsion, 1.98 to 3.09 in pond sediment and 1.23 to 2.75 in earth compacted catchments (Sharma *et al.*, 1986). Uncompacted earth catchments were found prone to crust formation. As a result of this, after 7 years period of formation of these catchments, the threshold rainfall was found to decrease from 4.7 - 6.00 mm to 2.3 mm, thereby increasing the runoff efficiency from 22-36 per cent to 52-56 per cent. The results of the studies at farmer's field in Kalyanpur (Barmer) showed very high efficiency of moisture conservation with stone and sand filled used polythene bags with associated improvement in growth and establishment of *Ziziphus mauritiana* (ber) seedlings (Gupta *et al.*, 1997).

## **Alternative Landuse Systems**

### **Silvipasture System**

Silvipasture system is essentially a grass based system and is ideal for the rehabilitation of degraded lands with rainfall less than 200 mm. However, the choice of trees and grasses together conformed well with the soil and rainfall conditions. Trees like *Acacia senegal*, *A. tortilis*, *Azadirachta indica*, *Prosopis cineraria* and *Ziziphus nummularia*, have been found to perform well under extremely hot, dry sandy wastelands (Gupta and Venkateswarlu, 1993). Among the grasses *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum*, *Lasiurus indicus* and *Panicum antidotale* have been found to perform very well under arid conditions. *Lasiurus indicus* was found to perform exceptionally well under extremely arid conditions of Jaisalmer which is known as its natural habitat.

Silvipastoral studies conducted with *Acacia tortilis*, *Albizia lebbek*, *Azadirachta indica* and *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum* and *Panicum antidotale* showed no difference in dry matter production under different tree species. The results of some other studies, however, showed that *Acacia tortilis* in 10 m x 5 m spacing increased the grass production, over the control plants, (pure pasture) particularly during normal and above normal rainfall years (Gupta and Sharma, 1997). During low rainfall years, however, the yields were either comparable or marginally

decreased and the system has the advantage of providing continuous supply of fuel wood, and fodder besides, improving the environment conditions.

### **Agri-horticulture System**

Like *Prosopis cineraria* (Khejri), *Ziziphus nummularia* (Jhar beri), is an important top feed species commonly found in farmer's fields in arid areas. During drought years when crops fail, this plant comes to the rescue of the farmers and provide them fodder, fuel wood and fruits. However, it has been found to give low fodder and fruit yield. Budded 'ber' *Ziziphus mauritiana* has been found to grow very well with water harvesting system under arid conditions. Three years old plantation with budded ber (200 trees ha<sup>-1</sup>) was found to perform well in association with mung bean even during the low rainfall conditions of the year 1988 with 210 mm seasonal rainfall. The system was found to be economically profitable and technically feasible for greening the wastelands (Gupta and Venkateswarlu, 1994).

### **Soils Affected by Polluted Water**

In western Rajasthan particularly in districts of Pali, Balotra and Jodhpur effluents to the tune of about 22 million litres are discharged daily from textile units. In Jodhpur alone about 7 million litres day<sup>-1</sup> effluents are discharged which is equivalent to 8-10 per cent of the total water consumed by the city. The chemical composition of effluents show presence of dyes, alkali and other metals like zinc, manganese, copper, iron and little quantities of lead (Aggarwal and Praveen Kumar, 1990). These effluents along the course of their flow, pollute the soil as well as underground water.

Many fields along the river Jojri, Bandi and Luni were producing good irrigated crops, cereals, vegetables and few cash crops like chillies and condiments etc. but after the effluents were diverted in the river bed, the well water became injurious to the crops adversely affecting the seedling emergence and growth. The presence of carbonate and bicarbonate formed compact crust with high seedlings mortality. Most of the irrigation wells and the lands have been abandoned in the vicinity of the ponding. For instance in Salawas village of Jodhpur tehsil, about 60 wells along the river Jojri in which the effluents flow have been contaminated and water has become unfit for human consumption as well as for crops. In this way about 600 hectares of land have become unproductive. In general, there is about 25 per cent decrease in crop yields on soils irrigated from the polluted well.

### **Use of Affluents for Tree Establishment**

Out of fifteen tree species tested for tolerance in germination and seedling growth with effluent, nine species viz., *Eucalyptus camaldulensis* (Safeda), *Azadirachta indica* (Neem), *Acacia nilotica* (Desi Babool), *A. tortilis* (Israeli Babool), *Colophospermum mopane* (Mopane), *Hardwickia binata* (Anjan), *Prosopis juliflora* (Vilayati Babool), *P. cineraria* (Khejri) and *Tecomella undulata* were established in June, 1989 directly with this water. All these tree species established well showing good growth without any toxicity effect during the first three years.

## **Mined Spoiled Wastelands**

As per the mining and mineral department of Rajasthan only 1.13 per cent area out of the total area of the State is sanctioned for the mining lease basis. According to present statistics 66,000 ha (660 sq km) area of the Rajasthan state is estimated as mined wastelands.

The mining activity is carried out by open cast mining method except in Degana Wolframite mines. Some of the non-metallic minerals like gypsum, bentonite, fuller's earth, white clay, limestone, sandstone and granite are well spread over in the desert tract. The exploitation of above said minerals for the development and industrial purpose in the end leave the abandoned mined wastelands which contain low grade ore and other overburden deposits in the form of large heaps of irregular configurations. They are, by and large, devoid of any biological activity due to the lack of soil, organic matter and nutrients. In the true sense these represent completely desertized sites.

In order to carry out the rehabilitation of mined wasteland, CAZRI has selected two abandoned mined sites i.e. one of gypsum and the other of limestone. Here the major thrust is to standardise the techniques for the rehabilitation of mined wasteland and simultaneously make them productive. Gypsum mined wasteland at Kavas (Utterlai-Barmer) were under plantation using soil conservation methods and water harvesting techniques like development of micro-catchment area with 5 per cent slope to get the supply of run-off water to single row of plants, ridge and furrow system and half moon structure development etc. Seven species of trees, four species of shrubs and three species of grasses were planted with 93 per cent success.

Lime stone mined muck heaps at Barna (Bilara-Jodhpur) were reshaped providing a uniform slope of 5 per cent with inverted terraces at an interval of 5 m. Efforts were made to revegetate these lands with 89 per cent success.

## **Salt Affected Soils**

In Rajasthan salt affected soils occupy about 1 million hectare out of which nearly 70 per cent area is in arid region (Mehta *et al.*, 1970). Depending upon their genesis these have been classified as natural and secondary salt affected. The natural salt affected soils include vast stretches of barren degraded lands, saline water lakes near Sambhar and Didwana and a number of ranns scattered in the region. The secondary salt affected soils have developed due to irrigation with brackish water and also as the result of seepage from canal. Nearly 84 per cent of the area in arid Rajasthan has ground water with salinity of more than  $2.2 \text{ dS m}^{-1}$  and constitute 60 per cent of ground water source (Dhir, 1977). Ground water of EC up to  $10 \text{ dS m}^{-1}$  and those having high residual sodium carbonate (up to  $20 \text{ me l}^{-1}$ ) are being used for irrigation. Irrigation with such poor quality waters leads to salinisation/sodification of the soils. Because of non-availability of good quality waters reclamation of salt affected soils is beyond imagination. The approach has been to manage these problematic soils and water to improve productivity of land. Attempts have been made (a) to map the extent of salt affected soils, (b) to characterise nature of salt affected soils and (c) to evolve techniques for their sustainable management. Fortunately the problem has been tackled at all the fronts and now the



technologies are available for their management. Voluminous research work has appeared as comprehensive reviews on the afforestation of salt affected lands (Gupta and Prem Lal, 1993), effect of saline water on soils and plants (Joshi and Jain, 1993), technologies for amelioration of saline/sodic water irrigated soils (Joshi, 1992) and nutrient management in brackish water irrigated soils (1997). Following paragraphs deal with management of salt affected soils specific to north-west arid region of India.

### **Extent and Nature of Salt Affected Soils**

Mehta *et al.* (1970) after an exploratory survey gave a broad distribution of these soils. Later on with the development of more sophisticated technique of survey like aerial photograph and satellite imageries mapping of salt affected soils was further taken up. Kolarkar *et al.* (1980a) with help of aerial photograph reported that salt affected soils in the Luni basin generally occur along the river course and in localised micro-depressions. They could map five categories of salt affected soils viz., naturally saline, saline depressions, relict saline, secondary saline due to high water table and secondary saline due to saline water irrigation. Kolarkar *et al.* (1980b) observed that mapping of salt affected soils was possible with the imageries of band 5 and band 7 together. Singh and Kolarkar (1996) with the help of satellite imageries identified 5807 sq km salt affected area in Luni basin. Kalra and Joshi (1994) with help of ground radiometer observed highest reflectance of salt encrusted naturally saline soils followed by sodic soils due to high RSC water irrigation, natural saline soils and saline water irrigated soils. Using these information they (Kalra and Joshi, 1996) further observed that moderate and severe natural salt affected soils could be separately mapped by using Landsat MSS, Landsat TM, IRS LISS-I, IRS LISS-II and SPOT data of April and January. But the differentiation between the saline/sodic soils due to irrigation water was possible by the use of both the October and the January imageries.

### **Management of Natural Salt Affected Soils**

Natural salt affected soils have high concentration of salt distributed through out the profile. Sodium chloride is the dominant salt. The solum is compact with columnar structure and highly calcareous substrata. In spite of high salinity, the naturally salt affected soils are adequate with respect to available Fe, Mn, Zn and Cu (Joshi *et al.*, 1988a, b). High salinity considerably vitiated the available K (Joshi, 1993). Relationship of Q/I parameters with soil attributes and available K govern the dynamics and availability of K. Due to excess cations in the salt affected soils the inter-relationship of labile K with the K held on specific and the non-specific sites was viciated (Dutta and Joshi, 1992).

For management of these salt affected soils species of shrubs, grasses and trees tolerant to salinity have been identified and techniques for their establishment developed. Jain (1981) found *Prosopis juliflora* and *Tamarix articulata* to be most tolerant to salinity followed by *Acacia tortilis* and *Eucalyptus camaldulensis*. Similar observations have been reported by Shankarnarayan and Kolarkar (1988). Jain (1984) further reported the tree and grass species which can tolerate soil salinity in the

range of EC 4-8, 8-16 and more than 16 dS m<sup>-1</sup>. They have also described the ridge and furrow technique for plantation. However, Anon. (1985) reported failure of ridge planting technique as compared to flat pit planting in soils having salinity from 95-113 dS m<sup>-1</sup>.

### Management of Secondary Saline Soils

Secondary saline soils have developed due to Irrigation with saline water. High salinity in soil restrict choice of the crops and require specific management practices. Jain (1978) observed that salinity effects were more pronounced in soils of high silt and clay content. After taking one irrigated crop in rabi season, these soils have to be kept fallow during subsequent kharif and rabi season. Though there is appreciable leaching of the salts, yet build up of salinity/sodicity has adverse effects on the physical condition of soil and decline in crop yields.

Selection of salt tolerant crops and their varieties, balance fertilisation and application of amendments have been found to alleviate the adverse effects of salts on grain yield. Jain (1984) has suggested a number of crops and their varieties which can be grown on these soils. Kharchia, the salt tolerant variety of wheat, is responsive to soil fertility management. Dhir *et al.* (1975) and Garg *et al.* (1990) observed that upto 80 kg N ha<sup>-1</sup> there was increase in the grain yield of Kharchia wheat. Improved nutrient management led to higher chlorophyll and soluble protein and increased nitrate reductase activity in leaf tissues. The adverse effects induced by salt stress on growth, nutrient uptake and metabolism were markedly higher in sensitive than the tolerant varieties.

In situations of surface crusting application of gypsum at 2 t ha<sup>-1</sup> lowered sodicity, increased infiltration and decreased crusting and thereby increased the wheat grain yield by 5 to 10 q ha<sup>-1</sup> (Goyal and Jain, 1982). Application of gypsum at 100 per cent gypsum requirement of soil has been found very effective in improving infiltration, reduction in salinity and there by increased the yield of wheat crop (Joshi and Dhir, 1989, 1992).

### Management of Sodic Soils

In vast area of arid region the sodic soils have developed as the result of irrigation with waters of more than 5 me L<sup>-1</sup> RSC (Joshi and Dhir, 1989). These soils have developed high pH (9.2-10.5), surface crusting, unusual hardness, restricted infiltration and percolation of water in the soil profile. On these degraded lands soil working is difficult, seedling emergence is poor, crop is patchy and yields are very low. After growing rabi crops farmers have to keep the land fallow in the following rainy season and plough these fields after every shower of rain. High dose of FYM is also added before sowing next crop. This may help in reducing the soil compactness but there is progressive build up of sodicity. Many plant nutrients including phosphorus and zinc have been found below the critical limits (Joshi 1988, 1990). Puntamkar *et al.* (1972) reported that for improvement of these sodic soils application of gypsum alone was more effective than organic matter. Application of gypsum equivalent to 100 percent of soil requirement + quantity of gypsum required to neutralise RSC of irrigation water in excess of 5 me L<sup>-1</sup> has been found very effective in amelioration and rehabilitation of sodic soils.

## Shallow Gravely and Stony Wastelands

These lands occupy about 1.07 M ha of area mostly in Jaisalmer and Bikaner and to a lesser extent in Barmer and Jodhpur districts of western Rajasthan. The surface of these lands is generally covered with about 15-20 per cent gravel but at places the presence of gravel is as high as 70-80 per cent. The soil has a depth of 20 to 40 cm and is mixed with gravels. The underlying strata is generally gravely or concretionary in nature. The water retention and storage capacity of these soils is low due to the sandy nature of soil and the less soil depth. A greater part of the rainfall is lost as run off. These lands, therefore, generally support low vegetation. However, with contour furrowing, trenching and other management practices, grasses like *Cenchrus ciliaris*, *C. setigerus*, *Lasiurus indicus*, and trees and shrubs like *Acacia senegal*, *A. tortilis*, *Capparis aphylla*, *Prosopis juliflora* and *Ziziphus rotundifolia* could be grown.

## Rocky and Gravely Wastelands

These are mostly hill areas or foot hills devoid of vegetation. The rocks are exposed because of prolonged erosion and weathering. The hills are highly denuded and cannot be put under any economic activity. There are, however, spots with some soil (0-10 cm depth) which can be used for planting purposes. The pits of 50-60 cm<sup>3</sup> are dug out and planting is done. Various soil conservation measures like contour bunding, trenching, check dams and gully plugging are adopted wherever possible for successful afforestation. Various tree species recommended for such lands at Bhopalgarh are *Acacia senegal*, *A. tortilis*, *Albizia lebbek*, *Azadirachta indica*, *Cassia siamea* and *Dichrostachys stomerata*, etc. Grasses like *Cenchrus ciliaris*, *C. setigerus*, *D. annulatum*, and *Cymbopogon jwarancusa* are grown successfully wherever some soil is available. The productivity of such lands in terms of forage production could be increased by 100-150 per cent in 2-3 years period if properly protected and managed (Singh and Sharma, 1997; Shankamarayan and Singh, 1990). The percentage utilisation of herbage in rocky wasteland of Bhopalgarh was found to be 54, 65 and 76 per cent for natural, reseeded and sown pastures. Among different silvipasture systems tried (Singh and Gupta, 1997) for their performance on rocky stony wastelands, *A. senegal* and *C. mopane* along with grasses performed better than other. Fruit trees like *Ziziphus rotundifolia* (ber), Pomegranate and such other economic plants like *Lawsonia alba* (Mehandi) and *Cassia augustifolia* (Senna) also performed very well on such wastelands.

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Water is scarce commodity in the 11 arid districts of Rajasthan covering 1,96,150 km<sup>2</sup> area. Low and erratic rainfall, dominantly deep dry sandy soil terrain with dune bodies, total absence or disorganised natural drainage in major part, very deep and saline ground waters, very high evaporative conditions and frequent dust storms events makes the region most inhospitable for all in general and human in particular. Spatially, eastern margin of the desert receives more annual rainfall (500 mm) than the western international boundary (100 mm). Along with this decreasing rainfall gradient westward, there is increasing gradient of variability in rainfall as also evaporation. Thus, coefficient of variability in rainfall is 40 per cent in the east which increases to 70 per cent in western part of Jaisalmer district, while the annual evaporation is less than 1000 mm in east and it exceeds gradually 2000 mm in west. However, the rainy season is confined to a period June to September, when 90-95 per cent of the total annual rainfall is received.

Within this broad setting, there is again local spatial variability in rainfall events, even in the small areas. Under such conditions, considering the general water requirement, the availability of water resources is highly uncertain. In this backdrop of uncertainties that the rainwater management using is found to be valuable. There are some hilly, rocky, stony and gravely surfaces interspersed in this region, that generate good runoff which may be harvested and utilised for conjunctive use. Rainwater management has, therefore, to be looked into in the context of maximising water availability in the face of increasing demand for domestic consumptive and for biomass production on sustainable basis.

Rainwater management systems may be traced in the history of old Marwar civilisation. The native people used their local skill and developed many techniques for collection and storage of rainwater to thrive the population. However, since independent rainwater management approach was directed to suit the institutional and technological changes. Since then many researchers have worked and reported on various aspect of rainwater management which are described here.

### ***Management and Utilisation of Rainwater***

#### **Rainwater Management Using *Khadin* System of Runoff Farming**

In depressional area soils have developed from the silt load carried in runoff from adjoining uplands and hence are fine textured. In many situations, the base is rocky which restrict the deep percolation. This type of soil deposition with rocky catchment can be met in areas having as low as 150-350 mm rainfall. Such areas may be converted in productive table agricultural lands by

constructing earthen embankments at lower periphery of field with suitable spillway arrangement. Such farms are locally called as *khadins*. This system of water harvesting and landuse is very common in Jaisalmer district of Rajasthan, where average annual rainfall ranges from 100 to 225 mm.

Sehgal (1973) traced the history of *khadin* cultivation. He reported that *khadin* farms were first constructed by Paliwal Brahmin of Jaisalmer district in the fifteenth century and has a sound scientific basis. The Paliwals were vegetarian native of desert who left priesthood and became cultivator. They connected most of the local catchments into well knit system of *khadin* farms for assured crop production even in annual rainfall as low as 150 mm. Later Kolarkar *et al.* (1983) studied the physico-chemical characteristic of *khadin* soil. They observed 2 to 16 times lower electrical conductivity (EC) of soils of *khadin* farms compared to soils of outside of farms. Such a high variability in EC has been associated with leaching of salt of *khadin* soils through seepage water. The *khadin* soils hold soil moisture to last upto growing season. They also reported that even without specific agronomical practices and with no application of fertiliser the average crop yield ranges from 20 to 30 q ha<sup>-1</sup> of wheat or 13 to 25 q ha<sup>-1</sup> of chick pea. Tiwari (1988) has linked the *khadin* cultivation with the farming system of Kalibanga and Rang Mahal culture of the Indian desert which are presumed to be of Harappan age (3000 BC). In an other study Khan (1992) has suggested various options for structural improvement in *khadin* construction. He has optimised size and shape of *khadin* bunds surplusng arrangement and catchment to command area under different agro-climatological zones.

### Collection and Storage of Rainwater in Ponds/*Tankas* and Recycling

Collection and storage of excess rainwater in ponds and *tankas* (underground cisterns) and recycling, the traditional water harvesting system employed since ages for meeting domestic water requirements, speaks innovative wisdom of desert community. Till today, the most of the villages are depending on these structures as source of drinking water.

The *tanka* and village pond (*nadi*) system of water harvesting were not given much attention in earlier days. However, in recent years they have become an important component of integrated rural water supplies in western Rajasthan. They advocated that a circular *tanka* is economical and stable as compared to a rectangular *tanka*. Vangani *et al.* (1988) have observed that an individual family *tanka* is better managed than a community *tanka*. Later Khan (1992) suggested suitable designs and structural details of *tanka* for different agro-climatological zones. He developed improved designs of *tanka* for capacity ranging from 10,000 to 600,000 litres capacity each. He also worked out the economics of *tanka* system of water harvesting. It has been reported that cost of water in *tanka* is only 2 to 5 paise litre as compared to 75 paise per litre in hauling of water from long distance. In an other study, Khan (1995) emphasised the usefulness of *tanka* in developing fruit orchards. He observed that with supplemental irrigation (60 litres irrigation<sup>-1</sup> plant<sup>-1</sup>) the fruit yield of ber (*Ziziphus mauritiana*) and pomegranate increased substantially. As



compared to no irrigation increase in fruit yield with 2, 4 and 6 irrigations for ber was 46.4, 80.3 and 124%, whereas, in the case of pomegranate it was 69.8, 112.5 and 191.7%, respectively.

Rainwater management using pond (*nadi*) system of water harvesting is very useful both for domestic water use in villages as well as for crop production. However, the inherent limitations of this approach are high seepage losses in sandy soil situation and high evaporation losses due to hostile climatic conditions. Control of seepage and evaporation losses are not full proof and costly. Mann and Singh (1977) reported the usefulness of this approach in preventing complete crop failure. Singh (1983) suggested that in areas where *in situ* storage of runoff in soil is not possible due to soil depth and textural considerations, the practice of farm pond could be adopted to give irrigation to dryland crops. Singh (1986) observed that recycling of small quantity of water to field crops in sandy soil situations may not be practically feasible. It may be better option to use this water for raising nurseries, orchards and to support the initial establishment of trees. Chatterji *et al.* (1985) reported that in majority of the cases the stored water in ponds in Nagaur district are highly polluted due to free access of human and livestock in water for bathing and also local people clean their clothes in the *nadi*. This leads to the growth of many harmful bacteria and other water born diseases and therefore, not safe for human consumption. Sedimentation in pond is another major problem. Shankarnarayan and Singh (1979) observed that reduction in water surface area and drainage basin area upto 1.8 to 2.4 and 6 to 8 times, respectively, due to biotic interference, resulting in the desertification in large adjoining area. Khan (1989) listed the limitation of traditional *nadis* (ponds) and suggested measures to make the system economically viable and socially acceptable for drinking water on long term basis. The suggested measures involve use of LDPE for lining of side and bottom, minimum possible surface to volume ratio ( $<0.3$ ) to reduce evaporation losses, construction of silt trap at inlet point to arrest the silt entering in the *nadi* and withdrawal of water through handpump only, to protect the water from contamination. Development of *tanka* and ponds to store rain runoff is the only way to meet the requirements of desert ecosystem.

### **Water Harvesting From Roof Surfaces**

Roof water harvesting is an old practice in many parts of the world. In India this method is largely practised in north-eastern region and western Rajasthan. In the ancient time, houses in western Rajasthan constructed with stone and lime were so structured that they had a self contained roof water harvesting system. Rainwater from roof top was regulated through in-built drainage network in underground tank (cistern) constructed in the premises of houses. However, with the modernisation, like many traditional practices, roof water harvesting technique also has been neglected (Anon., 1989).

Rainwater yield from roof surfaces depend upon the type of roof and material used in its construction. Studies on runoff efficiency of different types of catchments were initiated for the first time at CAZRI, Jodhpur in 1993 by M.A. Khan. The results indicate that among the roofs,

the highest runoff efficiency of 85% was achieved from roof made of corrugated GI sheet, followed by stone slab and lime concretion roof (81%) and clay tile roof (56%). The traditional roof made of straw has the efficiency to generate less than 40% runoff during monsoon period. It was also found that the runoff generated from straw roof was of poor quality with heavy contamination and therefore, not suitable for domestic consumption (Khan, 1996).

### **Water Spreading to Improve Soil Moisture Regime**

Water spreading involves diversion of flood water from donor area to the command area to improve moisture regime. Crop is grown on stored soil profile moisture. Khan and Venkateswarlu (1993) reported that excess rainwater from 4 to 12 ha can be spread in 1 ha. This can be achieved by intercepting surface runoff and then led along to spread over the receiving area through staggered dykes and ditches. Deep tillage in the command area may be used to enhance the infiltration of water. In Rajasthan, this system is commonly practised in Jalor district, called locally as *rela farming*. The system also helps to induce ground water recharge. However, there is need to investigate the economic viability of this system on long term basis.

### **Rainwater Management through Stream Water Harvesting**

The ephemeral streams carry heavy flood during rainy season. This water either in part or full may be harnessed or diverted to help in either improving crop husbandry, recharge of ground water or for domestic water supply. This can be achieved by constructing anicuts, water harvesting dams or gully control structures. Dhir *et al.* (1978) reported that in Chinese arid lands by harnessing stream flow through small dams the irrigated lands have increased from 40,000 ha to 400,000 ha. This has also helped in recharging ground water aquifers substantially. Khan (1995) has reported that in arid zone of Rajasthan with the construction of anicuts in Ujalian watershed, Jodhpur district, static water level in wells located downstream increased from 1.8 to 2.2 m as compared to only 0.5 m in wells located in adjoining area. In an other study in Pali district it has been observed that with the construction of anicuts the ground water charge has increased upto 38.5% in the zone of influence of anicut than only 5.2% in the adjoining area (Khan, 1996).

### **Water Harvesting to Induce Ground Water Recharge**

In arid and semi-arid regions where rainfall is scanty replenishment of ground water is not in proportionate to its utilisation. Under such situations, harvesting and inducement of rainwater in depleted aquifers may be highly useful. This can be achieved through percolation tanks, pondage in stock tanks with infiltration galleries or sub-surface barriers. These structures are constructed exclusively to recharge the ground water. Raju (1987) reported that the rate of percolation through percolation tanks in Noyil, Vittamalai, Karai (Amaravathy) and Ponnani river basins ranged from 10 to 50 mm per day. He also observed considerable reduction in rate of percolation when the standing water persists for a longer duration. Studies an artificial recharge in seven

percolation tanks in Sina and Man river basins in Maharashtra revealed that the average recharge was 50% of the capacity of tanks, provided desilting was done before monsoon (Phadtare, 1987).

Sub-surface barrier constructed across on ephemeral streams traps sub-surface flow to recharge the groundwater aquifer. Construction of two sub-surface barrier of 10 m length each, within 300 m from the water supply wells is enough to store runoff water required for a village with population of 500 (Anon., 1985). Phadtare (1987) reported that sub-surface dykes of 1 to 4 m height were found effective in augmenting the ground water resources particularly in hard rock areas underlain by fractured aquifers. In an other study Das and Batra (1993) reported that with the construction of sub-surface barrier at Kalawas and Charni Kalan village in Jodhpur district the annual rate of depletion of ground water has been reduced from 1 m to 0.13 and 1 m to 0.23 m, respectively.

Pondage of rainwater in ponds can be used to induce ground water recharge. A group of scientists of CGWD conducted artificial recharge study in alluvial area of north Gujarat. They observed that recharge from 2.25 ha area and storage capacity of 15000 m<sup>3</sup> was nearly 1000 m<sup>3</sup> are in rainy season (Anon., 1989). Khan (1996) reported that in a pond with six bore wells the initial rate of deep percolation was 48 mm/day during monsoon period when the static water head in pond was maximum (4.2 m) but reduced to only 5 mm/day in post monsoon area (March). He associated the reduction in percolation rate to deposition of fine particles on the wetted area and reduction in hydrostatic pressure in pond.

Sand filled dam/tank is another novel method of water conservation and recharge of ground water prevalent in South Africa. In this method a situation is created by constructing a low head masonry dam across a ephemeral stream to check part of flood water and to restrict sub-surface flow. The stored water is used for domestic water supply. In India for the first time Khan made an attempt to study the performance of sand-filled tank in water conservation. Analysis of four year data revealed that evaporation losses from sand-filled tank was only 8% although the reduction in storage capacity was nearly half. Nearly 70 to 85% of evaporation losses occurred when the water in sand was between 0-20 cm from surface (Khan, 1992).

## **Water Harvesting Through Constructed Catchments**

Under this system, catchments are constructed to induce runoff. The principle involved is that rainwater falling over catchment slopes is induced to flow either to planning area to supplement the soil moisture profile recharge or to a reservoir constructed for storage and subsequent utilisation. Employing this principle, several techniques of water harvesting have been developed for conjunctive use in the arid zone.

Studies on *in-situ* inter-plot water harvesting were initiated for the first time at Central Arid Zone Research Institute, Jodhpur in 1969 by S.D. Singh and colleagues. It was reported that micro-catchments constructed with a 5% slope in the field in a ratio of 0.5 with crop area, resulted in 120% higher yield over control (Singh *et al.*, 1973). In further studies, it was found that such

catchments resulted in upgrading the soil moisture regime on an average by 20% throughout the season (Singh, 1976). The system can ensure a reasonably good yield even in drought years when many crops would normally fail due to prolonged moisture stress (Singh, 1985). The approach, thus, can meet the sustainability requirements.

Singh (1978) admitted the usefulness of micro-catchment farming for dryland crops that requires light to medium well distributed rainfall. On soils of sandy texture (sand, loamy sand) found over a large area in this region, heavy infrequent rainfall, one or two in the season, is get suited for tree crops like ber, because a lot of moisture from rainfall plus runoff may find its way in the sub-stratum (below 1 m depth) that may be used by tree crops.

Inter-row water harvesting using ridge-furrow has also been found useful in raising dryland crops. Under this technique, 50-60 cm wide ridges alternated with 30-40 cm inside furrows (15 cm deep) are constructed using a ridger equipment. Crops are planted in furrows adopting a paired row design. Ridges yield runoff to the furrows, thus enhancing the moisture regime in the root zone. Singh *et al.* (1973) reported 210% increase in the yield of pearl millet with this system. They concluded that ridge-furrow technique has better adaptability for small holders, as no area of the field is lost to catchment construction. Singh (1982) suggested maintaining the furrows and ridges as permanent structures. Thus, if the tillage is restricted to furrows only, the energy input can be substantially reduced. Application of manure and fertilisers in wet furrows can help realise a better utilisation efficiency.

### **Water Harvesting Through Treated Catchments**

The least expensive method of catchment is the natural or untreated catchment. Natural basement complex, rock outcroppings, exposed clay areas or iron oxide cemented sands make excellent natural catchments. In urban areas, roof tops and graded and paved streets are generally available for use at little or no cost. In areas, where good natural catchments are not available, runoff can be induced by treating the catchment surface.

The practice of watersheds to increase water yield for crop production is an old one as evidenced by ancient systems in the Negev desert in Israel (Evenari *et al.*, 1958; Anon., 1974). Sheet metal, butyl rubber, asphalt roofing, bentonite paraffin, fibre glass, reinforced asphalt, plastic sheeting with gravel cover, etc. have been used to cover the contributing area to induce large volume of runoff. Treating the catchment area with chemicals help in reducing infiltration and inducing large volume of runoff.

Attempts were made to find out a suitable water proofing material which may restrict infiltration and induce runoff (Murthy and Issac, 1980). They reported that *janta* emulsion, followed by sodium carbonate spray were most effective sealants and generated runoff 68% and 66%, respectively. Cost-wise sodium carbonate was cheaper than *janta* emulsion. Catchments treated with lime concretion, bentonite mixed with soil, mud plaster and mechanical stabilisation were also found effective and generated runoff nearly 56, 54, 54 and 37 per cent of rainfall,

respectively. However, the average runoff from plot covered with *Lasiurus indicus* grass was only 27 per cent of the rainfall.

### Management of Stored Water by Reducing Evaporation Losses

Evaporation accounts over two third of water losses from surface water bodies in hot arid regions. This component of water loss may be minimised by adopting suitable technology viz. by reducing wind velocity through developing shelter-belts of suitable tree species around water bodies or by artificially shading of water surfaces. However, shelter-belts have not been found very effective in evaporation control due to its limitations of partially shading of surface water.

Studies on artificial shading of water surface have shown encouraging results in controlling evaporation losses. Shading of water surface with polyethylene sheet successfully reduced evaporation by 91 per cent and cost of water saved was Rs. 2.54 per 1000 litres. Evaporation reduction with floating materials ranged from 37 per cent for *Saccharum munja* to 82 per cent for polystyrene sheet. Foamed rubber sheet, polyethylene sheet and bamboo reduced evaporation by 74 per cent, 66 per cent and 53 per cent, respectively. The floating polystyrene sheet and polyethylene covers were the most economical, saving water for Rs. 3.07 and Rs. 4.44 per 1000 litres, respectively (Khan *et al.*, 1990).

In Indian Thar desert, where water availability is meagre, the rainwater management technology may be an answer to improve water availability for the sustenance.

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About 15 per cent area in the north-west arid zone of India receives major input of water from more humid regions through an extensive canal network. This region comprises of the arid districts within the states of Haryana and Punjab and the north-western part of Rajasthan. The canal systems in this region are the Gang Canal, the Bhakra Canal and the Indira Gandhi Canal bringing water by diverting the flows of the Sutlej, the Beas and the Ravi in Punjab. The designed capacity of these canals are 314 (Murthy and Gulati, 1978), 510 (Uppal, 1978; Gupta, 1987) and 524 cumec (Kapoor and Rajvanshi, 1977), respectively. On the basis of average from 1982 to 1996, it has been calculated that the canal water available in the four districts of Ganganagar, Hanumangarh, Bikaner and Jaisalmer is at the rate of  $0.90 \text{ m ha}^{-1}$  (Anonymous, 1988; Anonymous, 1996), far more than the stipulated mean value of  $0.51 \text{ m ha}^{-1}$ .

About 52 per cent area in the north-west Indian arid zone comprises of sandy plains, dune systems, eroded rocky/gravelly surfaces and isolated hillocks. The channels emanating from these hillocks and rocky/gravelly surfaces get suffocated in deep alluvium and blown sand and form internal drainage basins. Jain (1968) estimated that approximately  $0.28 \times 10^9 \text{ m}^3$  surface water is available annually for utilisation in this region. Mehta and Kashyap (1970) estimated the surface water potential of this region as  $0.20 \times 10^9 \text{ m}^3$  out of which  $0.13 \times 10^9 \text{ m}^3$  is utilisable resource. Sharma and Vangani (1992) estimated the surface water potential of this region as  $1.33 \times 10^9 \text{ m}^3$  out of which 47 per cent was utilised till 1988.

Nearly 33 per cent area of the north-west Indian arid zone is occupied by the Luni Basin, the Sahibi Basin and a few smaller river basins. These are ephemeral drainage systems and convey runoff only in response to torrential rainfall during the monsoon season. The estimates of surface water resources ranges from  $518 \times 10^6 \text{ m}^3$  (Dhir and Krishnamurthy, 1952), to  $571 \times 10^6 \text{ m}^3$  (Dhruvanarayana *et al.*, 1964), to  $868 \times 10^6 \text{ m}^3$  (Mehta, 1970), to  $939 \times 10^6 \text{ m}^3$  (Mehta and Kashyap, 1970), to  $858 \times 10^6 \text{ m}^3$  (Anonymous, 1980), to  $1130 \times 10^6 \text{ m}^3$  (Sharma, 1991).

### **Management Needs**

Irrigation in the Indira Gandhi Canal Command area is being practised without adequate attention to long term side effects of waterlogging, soil salinity, depletion of natural pastures, increased soil erosion and environmental deterioration. Nearly 63 per cent of the Command area is having dominantly sandy soils. In these soils nearly half of the applied water goes as unproductive deep percolation losses and adds to the groundwater body. Out of about  $5250 \text{ km}^2$  area in the Stage-I,  $43.5 \text{ km}^2$  is waterlogged (Bithu, 1985; Anonymous, 1996). The mean rate of

water table rise varies from 1.1 m year<sup>-1</sup> in Stage-I to 0.81 to 0.85 m year<sup>-1</sup> in Ghaggar plain and Bhakra command, respectively and 0.64 m year<sup>-1</sup> in Gang canal command area. On the basis of annual rise in water table, it has been found that an area of 1456 km<sup>2</sup> has already turned critical (water table within 6 m of land surface) and nearly 3960 km<sup>2</sup> area is liable to become waterlogged by the year 2000 AD in Stage-I (Sharma and Mathur, 1991). However, a far more serious waterlogging problem awaits Stage-II. Owing to an underground hard substratum of gypsum, within 10 m depth, in about 34 per cent (1205 km<sup>2</sup>) of the gross command area of 3544 km<sup>2</sup>, water collected in low lying areas does not seep down (Rahmani and Soni, 1997). Due to capillary action, the water comes to the surface with dissolved salts and evaporates, leaving the salt behind, thus making the land saline. According to one study (Chouhan, 1988), if surface drainage is not introduced in the waterlogged area, thousands of hectares of land will be submerged and salinised in 25 to 30 years. In Haryana state, the Sirsa and Hisar districts have 148 (3.0 %) and 266 (4.0 %) km<sup>2</sup> area, respectively, within the influence of high water table (Rao *et al.*, 1986); the rate of water table rise is in the range of 0.14 to 1.0 m year<sup>-1</sup>. In addition to salts contributed by ground water nearly 2.0\*10<sup>6</sup> t of salts are added annually through canal irrigation. In the Punjab state nearly 1.05\*10<sup>6</sup> ha area is irrigated through canals in the arid districts of Faridkot, Ferozpur and Bhatinda (Sidhu *et al.*, 1991). As a result about 80 per cent of the total salt affected and waterlogged area of the state occurs in these districts; the water table is rising @ 0.52 to 0.75 m year<sup>-1</sup>.

The loose fine sand deposits over clay beds or massive calcium carbonate/gypsum/rock in the shallow substratum not only develop waterlogging or soil salinity on intensive irrigation, but also create conditions favourable for liquification and sinking on cyclic stress application by machines and walking cattle (Sharma and Vangani, 1992). The vast sandy plains have characteristic stratified soils with gypsiferous/calcareous/clay/rock/hard pan and an aeolian sand overburden. Indiscriminate alteration of the naturally grass covered sandy plains into intensively irrigated field crop areas in Stage-II may soon upset the ecological and hydrological balance of the region. The areas having hard pan or barrier at shallower depths may develop high perched water table in due course of time.

The stored water in reservoirs and small ponds (*Nadis*) is subjected to high evaporative and seepage losses. The highest evaporative losses were observed during the period March-June, i.e., in the driest season when the demand for water is the highest. High evaporation also occurred during October-November after the rainy season. On the other hand the seepage losses were greatest during the rainy season (July-September) when the storages were completely filled. Evaporative losses varied from 55 to 80 per cent of the total losses. The seepage losses were of the order of 20 to 45 per cent, the highest being in the sandy terrain. Annually the evaporative losses of stored water in the Indian arid zone varied from 1505 to 2473 mm whereas the seepage losses ranged from 666 to 1494 mm (Sharma and Joshi, 1983). Due to poor maintenance and improper utilisation, the stored water is highly polluted and contains health hazards in the form of guinea



worms, water hyacinth, mosses, algae, etc. (Chatterji *et al.*, 1985). Diseases of stomach, skin, infectious diseases and guinea worms are associated with the consumption of stored water.

In the Indian arid zone, the ephemeral flow in natural channels is accompanied by substantial transmission losses, to the tune of  $0.06 \times 10^6$  to  $4.73 \times 10^6$   $\text{m}^3 \text{km}^{-1}$  (Sharma and Murthy, 1994a), due to infiltration into the bed, the banks, and possibly the flood plain; the runoff volumes are reduced. Also large quantities of sediment are generated and transported in the ephemeral channels due to torrential rain spells, excessive weathering, sparse vegetative cover, aeolian deposits within the drainage basins and biotic interference. Absolute values of sediment concentrations range from 0.2 to 29.0  $\text{g l}^{-1}$  in the upland rocky/gravelly drainage basins to 1.0 to 453.6  $\text{g l}^{-1}$  in the downstream channel phase (Sharma, 1994). The sediment not only deteriorates the quality of water and may carry adsorbed chemicals but also reduces the storage capacity of reservoirs by 1.9 to 7.8 per cent annually due to sediment deposition and requires costly dredging operations (Sharma and Joshi, 1982). Further, the discharge of clear water from the spillway causes stream bank erosion downstream as a result of the increased transport capacity of the flowing water.

Reservoirs have also been constructed across the ephemeral channels. Seepage from canals, drainage impedance and granite basement have favoured waterlogging and salinity in the isolated pockets to the tune of 15,770 ha (Chatterji and Vangani, 1985). Also about 15,000 ha is affected due to high water table ranging between 3 and 5 m and saline water quality (Singh, 1992).

## **Technologies**

### **Command Area Development and Management**

A number of techniques which could be useful in mitigating the problems of waterlogging and salinisation or delaying the adverse effects have been discussed by Mann and Chatterji (1978), Chatterji (1985), Shankamarayan and Sarkar (1985), and Chatterji and Saxena (1988). These include construction of open drainage, horizontal sub-surface drainage, vertical drainage, soil management, artificial recharge, fish farming and growing aquatic cash crops. However, the vertical drainage, by way of construction of shallow skimming wells, is a technically feasible and economically viable solution to combat waterlogging (Rao *et al.*, 1986). Rana (1986) observed that continuous pumping from a vertical drainage well for 4 to 6 hours daily at a constant rate of  $0.77 \text{ m}^3 \text{min}^{-1}$  reduced the RSC from 7 epm to nil while the EC of groundwater increased from 1.9 to 3.3  $\text{dS m}^{-1}$ . After 36 h of pumping at a discharge rate of  $0.44 \text{ m}^3 \text{min}^{-1}$  maximum drawdown of 0.35 m occurred, thereby implying that the water table could be lowered immediately through vertical drainage and crops could be saved. In addition to the vertical drainage, Sharma and Mathur (1991) proposed efficient irrigation management practices and reduced water allowance for the Indira Gandhi Canal Command Area.

Boomans *et al.* (1988) controlled the rising water table in Hisar district through horizontal subsurface drains or by shallow, vertical, skimming wells. The horizontal drainage consisted of a system of laterals and collectors at a depth between 2 to 3.5 m from where the water is pumped into a surface drain or irrigation canal. Batta *et al.* (1990) used cavity wells to lower water table locally. Cavity wells are constructed by drilling into a sand layer lying below a layer of stiff clay. The discharge of these wells is about  $6 \text{ l s}^{-1}$  and the depth varies between 15 and 20 m. In the area where subsurface soil conditions prohibit gravity flow to the drains (Southwest Punjab), multiple well point system was found effective in lowering the high water table (Shakya *et al.*, 1990).

Extensive research work has been done in arid parts of Haryana and Punjab on reuse of drainage water for irrigating the cereal and vegetable crops. The saline drainage water is used either for direct irrigation, by alternating between fresh canal water and brackish well water and by mixing both waters. With increasing EC the yield of cereal crops reduced between 29 and 41 per cent (Boomans *et al.*, 1988). Lal *et al.* (1986) found that the yield of cabbage and cauliflower reduced drastically between 18 and 71 per cent with drainage water irrigation.

## Water Conservation

By far the conservation and utilisation of surface water should continue to be the chief method of development in the Indian arid zone (Khosla, 1949). In order to secure uniform soaking of the rainwater and to prevent the loss of rainwater by surface runoff, Kanitkar (1944) proposed universal contour bunding to be constructed by means of cattle drawn implements. Bunds of 0.30 to 0.60 m height were found to be sufficient for sandy soils. The bunds must be placed in a series from ridge to the bottom of a valley one below the other to form terraced slopes. However, the natural surface drains should be maintained and used for occasional overflow of water accumulated along bunds. It was observed that 25 mm of rainwater can penetrate 13-15 cm depth for future use of the growing crops. Tamhane (1952) observed that at certain places in the desert regions, i.e., in the south-eastern portion of Rajasthan, desert streams, rivulets and rivers carry a good deal of water in the rainy season often to waste. He suggested that the beds of such streams and rivers should be bunded with small dams and existing tanks should be deepened so that water might percolate through the sandy soils along the banks and supply waters to wells nearby. Wasi Ullah *et al.* (1972) conducted an exhaustive study on the performance of contour furrows and contour bunds on water conservation in grasslands in western Rajasthan. They observed that the contour furrows alone on an average stored 39 per cent more soil moisture than the contour bunds alone (27 %) and combinations of the contour furrows and contour bunds (26-32 %). The higher soil moisture resulted in 14 to 181 per cent increase in forage yield.

Contour furrows have been extensively used in the Indian arid zone as a measure of moisture conservation as well as economical and quick alternative for soil preparation for better establishment and growth of grasses. Verma *et al.* (1977) recorded the highest soil moisture at the centre of the furrow throughout the season. The mean soil moisture storage at the middle of the

ridge, top of the mound and at centre line of the horizontal spacing followed a similar pattern of moisture accretion and depletion, and were non-significantly different among themselves. Sharma *et al.* (1980) recorded the significantly higher soil moisture at the centre of furrow and at the middle of ridge than that of top of mound and centre line of horizontal spacing. Sharma (1983) observed the highest depletion and low peak retention at the centre of furrow and top of mound, respectively. The middle of ridge recorded the highest plant population, dry matter production and precipitation use efficiency over a period of two years in the arid regions (Sharma *et al.*, 1983).

Sharma *et al.* (1997) designed contour vegetative barriers (CVB) to replace the traditional soil and water conservation measures such as contour bunds in arid regions. In general locally adapted, native, fast growing perennial grasses with extensive root system such as *Cymbopogon jwarancusa*, *Cenchrus ciliaris* and *Cenchrus setigerus* transplanted 0.30 m apart on contours at 0.6-1.0 m vertical interval form a dense hedge in a two year period against soil erosion and conserve soil moisture. In a four year study the runoff volume was reduced by 28 to 97 per cent. Also the CVB fields stored about 2.5 times soil moisture than control. In CVB fields the grain yield of clusterbean and pearl millet increased by 37 to 51 per cent and by 19 to 40 per cent over control, respectively.

To minimise loss of rainwater or irrigation water through deep percolation in sandy soils an array of technologies have been developed. Some of these are: (a) use of sub-surface barriers of asphalt (22 mm layer), bentonite clay (5 mm layer) and pond silt/clay (5 mm layer) at 60 cm depth in the profile (Singh *et al.*, 1975; Singh, 1978; Gupta and Aggarwal, 1980; Gupta and Muthana, 1985), (b) use of amendments such as pond silt, vermiculite, etc. for increasing soil moisture storage (Gupta *et al.*, 1979), and (c) use of organic or inorganic mulches (Singh and Gupta, 1989). These techniques increased the moisture storage capacity of sandy soils by 50 to 60 per cent for pond silt, 60 to 70 per cent for bentonite and upto 100 per cent for asphalt. The mixing of pond silt upto 30-40 cm soil depth @ 76 t ha<sup>-1</sup> increased the available water storage capacity from 6.5 to 6.9 per cent, reduced the infiltration rate from 15 to 13.2 cm h<sup>-1</sup> and increased the yield of pearl millet by 40 to 50 per cent over control. Use of vermiculite @ 20 t ha<sup>-1</sup> increased the 0.1 bar moisture retention from 10.3 to 12.4 per cent, reduced the saturated hydraulic conductivity from 8.6 to 6.5 cm h<sup>-1</sup> and bulk density from 1.62 to 1.57 g cm<sup>-3</sup>. In some cases appropriate combination of these technologies yield good results and some of these have also been adopted for horticultural crops and forest trees.

## Runoff Farming

Studies on runoff farming/*in-situ* water harvesting were initiated during the year 1969. Singh (1973) compared constructed micro-catchments of 4 per cent slope, ridge-furrow system (60 cm : 40 cm) and flat regular planting with respect to soil moisture storage and yield of pearl millet. The ridge-furrow and micro-catchment systems resulted in 210 and 120 per cent higher yield, respectively than the regular flat planting. The Inter Row Water Harvesting System (IRWH)

maintained higher soil moisture storage throughout the crop growing season as compared to planting on beds and flat planting (Anonymous, 1979). The surface runoff varied from 7-15 per cent, being highest in flat planting system followed by bed planting and IRWH. Singh (1978) reiterated the importance of tree crops in utilising the moisture stored in sub-stratum and suggested the trees to be grown under runoff farming. The results of studies on runoff farming (Sharma *et al.*, 1982, 1986) for jujube (*Ziziphus mauritiana*) are summarised below:

- Catchment area of 31.5 m<sup>2</sup> with 5 per cent slope is adequate for optimum water harvesting in jujube orchards.
- In normal and high rainfall years receiving 300 to 500 mm monsoon rainfall, 2 m deep soil and sub-stratum profile with runoff catchment contained twice as much moisture as that under control. In low rainfall year receiving 200 to 250 mm monsoon rainfall, 1 m soil profile maintained 40 to 60 per cent higher moisture storage than control. Effectiveness of the micro-catchment water harvesting technique in all types of rainfall regime is thus revealed.
- Length of run-on catchment slopes should be kept as minimum as possible. This will give less opportunity time for rainwater infiltration within the catchment; the contribution of runoff to the planting zone would be greater.
- The runoff concentration results in the storage of bulk of rainwater within the deeper soil profile.

Further, it was suggested that conversion of only the canopy area into runoff catchment may serve the objective of obtaining the required soil profile recharge. Sharma (1986) observed that due to crust forming nature of the sandy soils, the natural catchments get sufficiently crusted and stabilised during 2 to 3 seasons. Thus, the use of artificial sealants for augmenting runoff from the natural catchments may not be required. Similar results were obtained by Singh (1988) also for the pond sediment treated catchments.

Looking to the high cost of construction of bigger catchments, Gupta and Muthana (1985) developed circular catchments of 1.5 m radius and 2 per cent slope as runoff areas. The technique proved efficient for improving the moisture regime in the plant root zone. Growth and establishment of tree saplings was significantly higher in the treated plots.

For imparting yield stability to crops, Singh and Gupta (1989) suggested the following runoff farming techniques: (a) *in-situ* water harvesting from artificial micro-catchment having a catchment to cropped area ratio of 0.5, (b) inter row water harvesting by ridge and furrow configuration, and (c) micro-catchment water harvesting from 50 cm wide catchment into cropped area of the same width. Singh (1988) found the catchment to cropped area ratio of 0.5 as optimum for the type of soil, climate and surface sealing pond sediment.

People in the driest part of the Indian desert practice a unique system of runoff farming known as *Khadin*. This technique requires a crop land in proximity to a rocky catchment, and is therefore site specific (Kolarkar *et al.*, 1980). The catchment to command area ratios vary from 11.27, 8.22 and 2.22 in 217, 240 and 310 mm rainfall zone, respectively. Bhati *et al.* (1994) harvested

rainwater in a badly eroded area by means of check dams. Besides, controlling erosion they recorded a remarkable regeneration of natural vegetation in the upstream of check dams. The tree and shrub density increased by 188 and 813 per cent, respectively from the original status.

## Modelling for Sustainable Management of Water Resources

The sustainable development of water resources is becoming increasingly critical in the Indian arid zone as more and more demands are placed on finite and threatened resources. Growing urban and industrial demands, decreased reliability for higher priority needs such as irrigation, the threatening of fragile desert ecosystem and the high costs associated with the development of new sources, have forced the planners to consider new water management strategies. Strategies for integrated and sustainable development of water resources include simulation modelling of runoff and sediment transport, comprehensive hydrological forecasting, upgrading and operation of hydrometeorological and water monitoring networks, environmental impact assessment of water resources development projects and water management through multi-objective planning, risk analysis and decision support systems for meeting the conflicting demand (Sharma, 1997).

There is a different mix of hydrological processes operating in the arid regions. Murthy *et al.* (1980) used eleven years rainfall data for estimation of runoff through Strange's method. Sharma and Murthy (1996a) developed a package of simulation models for rainfall-runoff modelling in the arid headwater region. The rising limb of the hydrograph is modelled through a regression analysis and the recession portion through a conceptual analog of discharge from a single leaky reservoir, which is described by a continuity equation and by discharge-stage and storage-stage relationship at the basin outlet. Within an error of 10 per cent between hourly discharges, all the 79 observed and simulated hydrographs match well in the headwater region of the Luni basin. The hydrological flow routing equations for the movement of flood waves in channels were modified by the inclusion of a nonlinear volumetric transmission loss rate term, which was estimated empirically from the observed inflow-outflow data for a channel reach (Sharma and Murthy, 1995). The values of the coefficient of determination for the hourly discharges between the observed and simulated ordinates for all the 79 hydrographs varied between 0.80 and 0.98, thereby showing a good fit. Sharma *et al.* (1994) have also developed a lumped model for streamflow routing in arid ephemeral channels. Infiltration and percolation from floods to the ground water table below alluvial channels is an important mechanism for recharging both local aquifers and regional ground water. Sharma and Murthy (1994a, b) derived transmission loss equations for estimating the ground water recharge from flash floods in arid regions.

A linear time invariant dynamic model was developed for predicting the sediment transport in the arid zone drainage basins (Sharma *et al.*, 1993). The sediment graph generated by memoryless models showed better fit with the observed data, thereby indicating the parsimony of sediment transport in the arid regions. The regression analysis of sediment yield with different morphometric characteristics indicated the constant of channel maintenance, relief ratio and

drainage density as better predictor (Singh and Sharma, 1994). Sharma *et al.* (1996) developed an upland sediment delivery model for estimating the sediment delivery rates in arid drainage basins. The model uses a steady state sediment continuity equation and a first order reaction model for deposition and predicts the sediment delivery rates within 10 per cent accuracy. For the channel phase, a conceptual model of an instantaneous unit sediment graph (IUSG), involving routing of sediment through a cascade of identical linear reservoirs, has been developed (Sharma and Murthy, 1996b). The predicted sediment graphs compared well with the observed values. The IUSG gives estimates of sediment transport that are better than those derived with the sediment rating curve as it takes into account the availability of erodible material within the channel bed (Sharma and Murthy, 1994c). Sharma (1995) also derived appropriate models to predict sediment transport at micro to meso to macro scale drainage basins and integrated through an equation based on transmission losses across the various scales in the arid regions. Ojasvi *et al.* (1996) used transcendental function for monthly estimation of runoff, change in soil moisture storage and evapotranspiration on a watershed scale by lumping the spatially varied parameters. The out come of this exercise was the amount of available surface runoff storage from a watershed with reasonable accuracy.

### **Remote Sensing as A Tool for Water Management**

In several studies remote sensing data products have been utilised for water resources management and hydrological modelling. Singh and Sharma (1979) utilised aerial photographs for morphometric analysis for estimating the runoff potential of twelve small drainage basins in the Jodhpur district. Water bodies upto 0.9 ha surface area were identified and mapped within 10 per cent accuracy by Landsat Thematic Mapper false colour composites for surface water inventorying (Sharma *et al.*, 1989). Singh *et al.* (1988, 1990) made extensive use of satellite remote sensing for detecting the temporal changes in surface water related features such as river courses, flood plains, uplands and gullied areas within desired accuracy. Sharma and Singh (1992, 1995) used hydrologic models for estimation of runoff potential and soil loss after combining the information of hydrologic response units including soil, land use and land cover derived from the Landsat images. Recently, Gupta *et al.* (1997) developed a water harvesting strategy for semi-arid area using a geographic information system (GIS) in conjunction with the satellite remote sensing. Information on topography and soils had been digitised to form the GIS data base and the land cover information was derived using satellite data in the form of the normalised difference vegetation index.

### **Looking Ahead**

A large number of need based, viable and cost effective water management technologies have been developed in the Indian arid zone over last fifty years. These have made tangible impact on the improvement and sustenance of water resources systems. Notwithstanding, a lot more still

needs to be done in terms of technology development, field level testing and refinement, transfer and adoption by the clients in light of meeting the future needs and challenges posed by environmental degradation and integrated catchment resource management. Some of the areas of future research are as follows:

1. Low and erratic rainfall, poor ground water resources and increasing demand of water have stressed the existing water resources to the limit. Over the years the study on arid zone hydrology and water resources development have been in piecemeal and incoherent. Frequent droughts and flash floods make it imperative to generate data on long term averages of water and sediment balances. There is need to take up research on various aspects of arid zone hydrology and limited irrigation.

2. Of late, hydrological models of the distributed system type have received greater importance than lumped system models. The distributed models are more physically based, have greater accuracy and can predict the effect of changes within the catchment area due to agricultural and pastoral activities, afforestation, urbanisation and mining. With the advent of GIS and satellite remote sensing including microwave, it is now possible to apply the distributed models efficiently.

3. Excessive emission of CO<sub>2</sub> and methane in atmosphere has set in green house effect and global warming. Climate change in either way may thus occur in the Indian arid zone; more rainfall and better water regime or poor water regime and accentuation of desertification hazard. Monitoring consequences of climate change on water resources may form an area of research.

4. In the Indian arid zone, in one year out of five years, rainfall is 50 per cent or more than the normal and may cause flash floods. On the other hand, two years out of five years experience drought, causing declining ground water. Also in many areas the ground water withdrawal exceeds normal recharge. Conservation and storage of excess water generated in a flood year may alleviate the water scarcity on drought years. Surface storages are costly and subjected to high evaporative losses. Studies on artificial recharge of ground water may be initiated.

5. The classical soil and water conservation measures such as bunding, furrowing, terracing, etc. are too expensive and difficult to maintain. The farmers need cheap, economically viable and easily implementable practices. With the growing interest in the protection of environment, vegetative measures for soil and water conservation gained importance. More so arid areas are prone to excessive wind erosion. In-depth studies are thus, warranted to develop solutions with regard to various plant species that can sustain prevailing land and water conditions and also are economic to the community.

6. Refinement in techniques of rainwater harvesting and runoff farming, tailoring the water use by crops and optimisation are some of the areas in which studies could be initiated.

7. In the canal irrigated areas of Indian arid zone indiscriminate application of water through surface irrigation methods has caused the problems of waterlogging and salinity. Sprinkler and drip systems of irrigation having 75 to 95 per cent application efficiency are more suitable for this

region having sandy soils and undulating topography. Development of low cost systems alongwith improved package of practices for high value crops is needed to facilitate adoption over large areas. Design of lateral line length, network and integrated procedure considering crop characteristics and soil properties for uniformity are the research issues for the immediate future.

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## MANAGEMENT OF LIMITED WATER RESOURCES FOR CROP PRODUCTION

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The arid Rajasthan, stretching over 31.7 million hectares area in north-western India, is a known site for finiteness of water consequent to scarce rain ranging from 100 mm in the extreme west (Jaisalmer) to 450 mm along the Aravallis. Uncertain erratic and scanty rainfall coupled with meagre irrigation facilities experiences heavy competition from other potential uses. Additionally, increasing human population (47 persons per km<sup>2</sup> in 1971 to 90 in 1990) and livestock (13 million in 1956 to 23 million in 1992) are mounting pressure on dwindling water resources. Land holding declined from 10.2 ha per capita in 1970 to 6.5 ha in 1990 and it would be 3.9 ha by 2020 AD. From such trends, it appears that the productivity of such area need special attention. Since independence, tremendous efforts have been done on the front of research and development to improve the crop production in this arid tract. Achievements made on efficient management of limited water resources till date are highlighted in this chapter.

### **Water Resources and Their Development**

Khan (1996) has given a detailed account of surface, canal and ground water resources. Thirteen districts of arid Rajasthan receive an average annual rainfall of 62623 million cubic metre (MCM) which constitute 89 per cent of the total inflow of water. The total surface water potential is 1361 MCM (Venkateswarlu *et al.*, 1990). As per 1984 assessment, it has been estimated that the total ground water resources was 4545 MCM in arid Rajasthan. The utilizable ground water resources for irrigation is 3355 MCM and 2957 MCM being gross recharge (Ground Water Department Statistics, 1984). About 1508.7 MCM (45%) is being utilised at present. It is also estimated that the buried course of Saraswati river to the west in Jaisalmer district have a reserve of 3000 MCM which is yet to be tapped (Venkateswarlu *et al.*, 1990). The number of pumpsets raised from 2464 in 1961 to 3,66,639 in 1988 in Rajasthan; of which 68204 pumpsets are existing in western Rajasthan (DOES, 1988).

The Indira Gandhi Nahar is the major canal network that passes through Ganganagar, Bikaner, and Jaisalmer districts of the region. The flow values of the main canal varies from  $1.727 \times 10^6 \text{ m}^3$  to  $2.961 \times 10^6 \text{ m}^3$  in different seasons (Khan, 1996).

The irrigated area increased from 0.79 million ha in 1970 (Mann and Singh, 1975) to 1.62 million ha in 1992 (DOES, 1992). Major portion of the irrigated area (56.42%) is covered under canal system. The tubewells and wells cater to the need of 40.7 per cent area while irrigation

through tank waters is only in 2.9 per cent area. With all possible development of surface as well as ground water resources, about 1.59 and 1.1 million hectare land will be under canal and tube-wells, respectively by 2010 AD which would be hardly 10 per cent of total cultivable land. In such situation, management of erratic and low rainfall in rainfed crops cannot be ignored.

## Problems

Rainfed farming is facing the problem of uneven and low rainfall coupled with high evaporative demand in the region. Frequent droughts, a recurring phenomenon, affect crop production adversely (Krishnan and Thanvi, 1971; Shastri *et al.*, 1981). The draft of ground water ranges from 0.14 m in Barmer to 1 metre per year in Pali while the recharge through splash rains is negligible. Indiscriminate use of irrigation resulted in 3-7 meter fall in ground water level since 1984 (Singh, 1997b). Besides, nearly 80 per cent of the ground water has the EC values more than 2.2 dS m<sup>-1</sup> (Dhir, 1985; Joshi and Dhir, 1997). Joshi and Dhir (1989) reported that in arid region low salinity groundwaters are generally associated with high concentration of residual sodium carbonate. Water quality of ground water resources is deteriorating due to over exploitation (Paliwal and Sharma, 1997).

In canal command area, water table is rising at an alarming rate of 0.5 to 0.9 m/year due to seepage and deep percolation. An unscientific use of irrigation water in the command area of IGNP has led to the problem of water-logging which is expanding slowly but steadily in the entire flow command. About 15000 ha area has become water-logged and salinised under IGNP area and about 26500 ha will not be useful for cultivation in due course of time (DOES, 1997). In IGNP stage II, 3541 km<sup>2</sup> area is vulnerable to water logging due to presence of hard pan layer within 5-10 metre depth. Choking of canal with sand drift and profuse growth of water hyacinth had affected the flow of water in canal (Saxena, 1991). These parameters indicate that desertification process in the region has enhanced due to improper management of irrigation water.

Water is not only scarce in the region, but the heavy competition from other potential water uses further threatens to reduce the volume of good quality water available for agricultural uses. On the face of it, the water use system will have to be highly efficient to justify the maximum production per unit of water. Technologies developed for managing rain and limited irrigation water to reverse the desertification process and stabilise the crop production are as below.

## Management of Water Resources In Rainfed Crops

Research and developmental work carried out in arid region on management of water resources in rainfed crops during last few decades is described here.

### Crop Planning Based on Rainfall and Moisture Availability

In dryland areas crop production depends on amount and distribution of rainfall. Dryland research was initiated all over India way back in 1970 (Singh, 1997a). Arid part receives rains in

between July to mid September. Ramakrishna and Singh (1974) analysed the rainfall data of arid tract of Rajasthan and reported that in good rainfall years (< 400 mm) moisture is available for more than 95 days. In years of normal (300-400 mm), sub-normal (250-300 mm) and low rainfall (250 mm), shortage of moisture adversely affect crop production. The relationship between rainfall intensity, duration and frequency showed that at the 80 per cent probability the maximum rainfall intensity was 22 mm h<sup>-1</sup> for 5 minutes duration and 17 mm h<sup>-1</sup> as the time interval increased to 10 minute (Singh, 1988a). He further reported that rainfall intensity pattern was such that 75 per cent of showers occurred as showers of advanced type, whereas 25 per cent of them occurred as showers of delayed type. Hence, pearl millet, clusterbean, moth bean, mung bean, sesame and castor are in cultivation since ages owing to short growing period and well matching with the rainfall pattern of the region. However, frequent droughts affect the growth and production of crops. Shastri *et al.* (1984) identified three common droughts viz., terminal, middle and early depending on cropping duration. The percentage of drought occurrence at terminal, mid and early crop stages was 62.2, 33.3 and 4.5 per cent respectively in 80 years. With the early onset of monsoon pearl millet and sesame get preference while with the late onset of monsoon clusterbean, mung bean and moth bean get preference (Shankarnarayan and Singh, 1985). In Jaisalmer and parts of Barmer and Bikaner rainfall occurs in between 100-200 mm, hence grass based cropping system dominates. Moth bean based cropping system is existing in Bikaner and parts of Nagaur districts where rainfall ranges from 200-250 mm. Ramakrishna (1986) suggested crops and cropping system and mid-season corrections depending upon rainfall variability.

Crops differ in their growing season, root system density, spacing, height, leaf orientation, reflection coefficients, photosynthetic efficiencies, etc. The C-3 plant type, particularly legumes, have a low photosynthetic rate, so they have low WUE. The C-4 (millet, sorghum) plants on the contrary, have a higher rate of photosynthesis and their WUE is twice as high (Singh, 1977a). Fast growing, responsive to fertilisers under favourable as well as unfavourable environmental conditions, genotypes/cultivars are preferred so as to check evaporation losses at the initial growth stage (Singh and Joshi, 1989). A variety may not be suitable in all the situation. For example, RSK and Chadi performed better in early sixties (Mehta *et al.*, 1970; Mishra *et al.*, 1966a), but later on hybrids like HB-1, HB-3 replaced it owing to better root system and responsive to fertiliser (Singh *et al.*, 1974; Daulay *et al.*, 1978; Mishra *et al.*, 1966a). Pearl millet cv. BJ 104 replaced all other recommended varieties (Singh, 1988b; Joshi and Kalla, 1986). Presently HHB 60, HHB 67, MH 179 are most commonly grown in western Rajasthan (Bhati, 1997). In early seventies, S-8 in mung bean, T-13 & Pratap in sesame, FS-277 & 2470(12) in clusterbean, T-16 in moth bean, GH3 & Aruna in castor were most commonly grown (Singh *et al.*, 1974; Singh and Prasad, 1977). Shankarnarayan and Singh (1985) reported that pearl millet cv. BJ 104, cowpea cv. FS-68, mung bean PS-16, clusterbean cv. Sona and Til cv. Pratap were the most efficient, evading drought by restricting growth when the water was scarce and allowed substantial cumulative benefits from the use of drought-combating practices. Bhati (1997) suggested K-851

& PS-16 for mung bean, FS 68 & K-11 for cowpea, RGC 1003 & HGS 563 for clusterbean, TC-25 & RT-46 for sesame, Aruna, Bhagya & Gauch-1 for castor and RMO 40 for moth bean for arid region. Shrotriya and Shekhawat (1969) found CSH-1 and CSH-5 better than local cultivars Mertia for Pali region.

Occurrence of drought is frequent in arid region. Although pearl millet is less susceptible to drought than legumes (Ramakrishna *et al.*, 1981; Shastri *et al.*, 1984) its yields are also affected by droughts (Rao *et al.*, 1984, 1986). Ramakrishna *et al.* (1985) reported that mild, moderate and severe droughts reduced the yield of pearl millet by 37.7, 72.5 and 82 per cent, respectively from normal average yield of 345 kg ha<sup>-1</sup> as base in western Rajasthan. Probability of late season drought is around 40-60 per cent (Shastri *et al.*, 1984). Misra and Daulay (1963) reported that variety JTR was more tolerant to drought than RSK and Chadi. Drought has adverse effect on nitrogen metabolism and enzymes (Lahiri and Singh, 1968; Garg *et al.*, 1981). The drought effects may vary with the age of crop (Lahiri and Kharbanda, 1965; Lahiri and Kumar, 1966). Adequate fertility reduce the adverse effect of drought on pearl millet (Lahiri *et al.*, 1973; Lahiri and Kathju, 1973). However, this part is discussed later on.

*Kharif* crops are generally sown with the onset of monsoon rains. Better results obtain if rain sets early in the season (Shankarnarayan and Singh, 1985; Shastri *et al.*, 1984). Late sown pearl millet produced low yield (Singh, 1988). Transplanting of pearl millet seedling has been advised for late rainfall situation by Singh (1978b). The most optimum time for sowing clusterbean was from July 1 to 20 and sowing done on 30th July or August 15 reduced the yield drastically (Singh, 1978c; Tiwana and Tiwana, 1992; Yadava *et al.*, 1992).

For having good stand of crop, the seed must be sown at proper depth. For local varieties of pearl millet 5 to 7.5 cm seeding depth was optimum (Misra and Kumar, 1963). For hybrid 4 to 5 cm depth and legumes 6-8 cm depth were found optimum (Shankarnarayan and Singh, 1985). A seed rate of 3 kg for pearl millet, 9 kg for mung bean, 10 kg for clusterbean, 2 kg for sesame and 25 kg for cowpea was most appropriate to have good stand (Shankarnarayan and Singh, 1985).

### **Soil Moisture Conservation Relative to Other Losses**

Besides precipitation variability, the efficiency of water use is limited by soil factors that affect runoff and infiltration, water distribution and retention in the soil profile, evaporation and deep percolation to absorb the soil water. Improving water storage involves increasing infiltration, reducing runoff, evaporation and transpiration and eliminating undesirable plants. Relationship between these factors are complex. The discussion here concentrated on several principles that are generally involved in the practices improving water conservation.

#### **Minimising evaporation losses**

Evaporation from soil surface cause considerable reduction in water availability to crops. Singh and Singh (1993) reported that average evaporation (E) fraction of ET (from ET maximum plot) values of 20 and 43 for wheat and mustard, respectively at Jodhpur. This difference is due to



high plant density and rapid growth of leaves which resulting faster canopy cover early in the season in wheat. Among *kharif* crops, E losses were 20, 23, 34, 38 and 40 per cent in respect of pearl millet, cowpea, mung bean, sorghum and clusterbean, respectively (Singh and Singh, 1993). Pearl millet and cowpea had better growth and fast canopy coverage of soil surface, hence evaporation was minimised. Comparing to vertisols of Hyderabad (semi-arid climate), evaporation losses of sandy soils were 20-30 per cent less. This is so because as the surface soils of loamy sand dries fast, soil conductivity for movement of water from lower depth declines to a very low value (Singh, 1977a).

The mechanism capable of restricting the availability of water to the evaporative site, reducing the availability of energy to the soil and limiting heat or vapour exchange between the soil and the atmosphere can minimise it, making water available more for transpiration which is most directly related to yield. Therefore, the best opportunity for saving water lies in methods influencing these factors of evaporation and relative proportion of evaporation to transpiration. Some of these factors are the elimination of weeds, the use of mulches, planting geometry and population, use of organic manure/fertiliser, biofertilizer and windbreaks and intercropping, etc.

**Elimination of weeds:** Weeds compete for water, nutrients and lights, especially during early stages of crop growth and cause considerable reduction in yield. Elimination of weeds makes water available for transpiration by crops. Weeding done in pearl millet conserved water and improved the yield (Singh and Singh, 1988a), however, the advantages were conspicuous in low rainfall years (Joshi and Panjab Singh, 1981). Gupta and Gupta (1982) found 2-fold increase in grain yield due to weed control measures. Mechanical weed control in clusterbean grown in arid part of Haryana in between 30-45 days after sowing has been recommended (Yadav *et al.*, 1992). Manual weeding is time consuming and often cause considerable loss to crops, therefore, use of weedicides is essential. Studies by Misra and Kumar(1962) revealed that 2, 4-D was more effective at early stages of growth, while 2, 4,5-T at later stages of growth in pearl millet. Joshi and Panjab Singh (1985) reported that pre-emergence application of atrazine @ 1 kg ai ha<sup>-1</sup> was as effective as one hand weeding 30 DAS. Pre-emergence application of Trifluralin, Alachlor, Nitrofen TCA and Dalapon in clusterbean and green gram were effective in controlling broad leaved weeds (Singh, 1978c; Daulay and Singh, 1982). The elimination of weed canopy early in the season, therefore, is one of the important practice to reduce water use per unit of yield and yield of commodity needed from a smaller total water supply.

**Use of Mulch:** Top surface of loamy sand soils acts as self mulch after drying. In such conditions, mulch may not be useful practice in arid region, however, many a times droughts occur early in the vegetative stage. In such situation use of mulch immediately after sowing delay the process of top soil surface drying which helps in promoting better plant establishment and results in higher yield. Polyethylene mulch was highly effective in controlling evaporation losses (Gupta, 1978, 1980). Daulay *et al.* (1979) also reported beneficial effects of mulch in pearl millet. Application of grass mulch (6 t ha<sup>-1</sup>) brought 200 per cent increase in the yield of green gram, dew

gram and clusterbean (Gupta and Gupta, 1983). Use of mulch on no-tillage plots increased the yield of cowpea by 50-150 per cent over no mulch in different years (Gupta, 1986). Gupta (1985) reported higher yield of tomatoes and lady finger with grass waste mulch. Increase in yield was owing to reduction in soil thermal regime evaporation and suppression of weeds (Gupta and Gupta, 1985). However, many of the workers did not find its utility in conserving soil moisture and improving yield of several winter crops (Singh *et al.*, 1977; Rao and Aggarwal, 1985). Mulch was also able to control the soil borne disease *Macrophomina phaseolina* of cowpea because the soil moisture content was more at early vegetative stage which helped in checking the multiplication of fungus and subsequent infection (Gupta and Gupta, 1986). Mulch may have desirable effects such as reducing runoff, increasing infiltration, and decrease in soil thermal regimes, but it may harbour plant diseases. Availability of suitable material and uneconomical operation restrict its adoption on large scale then kitchen gardening.

**Planting geometry and plant population:** Higher plant density has been a shot gun for enhancing transpiration relative to non-growth related evaporation losses in high rainfall areas or irrigated condition. One should not mistaken that two-fold increase in plant density will require twice as much water. Ram Niwas (1975) reported the similar consumptive use of water at optimal and higher plant densities in wheat. Higher plant densities do not allow deep percolation of soil moisture as observed in vegetables grown under drip irrigation (Singh, 1978d). In arid region, particularly rainfed condition, larger canopy growth may be disadvantageous as it may exhaust the available soil moisture from root zone during drought (Singh, 1977a). So in such areas, one has to be more cautious in deciding optimal plant population and row spacing for sustainable crop production. A spacing of 30 cm for local cultivars of pearl millet and 45 to 50 cm for hybrid have been found optimal (20 Years Research on Agronomy, Govt. of Rajasthan, 1971). A spacing of 45 cm with 1.45 lakh population gave optimal yield of pearl millet whereas wider row spacing was not significant (Garg *et al.*, 1993). Sorghum hybrid CSH-1 provided maximum yield at 45 x 7.5 cm spacing (Shrotriya and Sekhawat, 1969). In clusterbean, 30 cm spacing in late sown and 45 cm spacing in early sown condition gave better results in Hisar conditions (Yadav *et al.*, 1989; Rana *et al.*, 1991). While Tiwana and Tiwana (1992) found no differences in both the spacing in clusterbean. Shankarnarayan and Singh (1985) and Singh (1978c) reported 55 to 60 cm row spacing for pearl millet and kharif legumes to facilitate tractor operated weed control. Tomar and Saini (1979) observed 100 cm row spacing most advantageous for pearl millet in Hisar conditions. Sowing in paired (25 x 75 x 10 cm) was found more effective than 50 cm from spacing particularly in low rainfall years in most of the kharif crops (Singh *et al.*, 1978a; Singh and Singh, 1988a; Singh *et al.*, 1978d, 1978e). Conducive micro-climate for plant growth and development besides efficient use of water, better weed suppression within a row pair, greater root proliferation and reduction in soil thermal regime and evaporation were some of the reasons for better yield of paired row system (Ramakrishna *et al.*, 1982; Rao and Joshi, 1986). Singh and Singh (1988b) reported that fast canopy coverage in paired row systems at early vegetative stage conserved

moisture which was utilised by the crop at reproductive stage, hence drought at reproductive stage could not affect crop yields in low rainfall years.

**Application of fertiliser/manure:** Where soil nutrients are deficient for maximum growth of crops, application of fertiliser/manure may result not only in increased yield but also increased WUE (Singh, 1997b). Fertiliser may increase the water use, moisture use efficiency and grain/seed yield in many crops like pearl millet (Misra, 1964; Mehta *et al.*, 1970; Panjab Singh, 1977; Singh *et al.*, 1972; Singh *et al.*, 1981a; Kathju *et al.*, 1993), wheat (Ram Niwas, 1975; Singh *et al.*, 1976), mustard (Singh *et al.*, 1978b; Singh and Yusuf, 1979; Vyas *et al.*, 1995), sesame (Daulay and Singh, 1982). The principal effect of fertiliser/manure application is to allow more rapid growth of the canopy and a larger canopy that shades the soil surface and so reduces the proportion of the total water that is evaporated (Singh, 1977a, Singh and Singh, 1993). In low rainfall area, particularly arid climate, one has to be cautious in determining fertiliser use because early rapid growth may result in insufficient water being available later in the season. The nitrogen requirement of local pearl millet cultivars worked out to be 30 kg ha<sup>-1</sup> (Mehta *et al.*, 1970; Misra 1961), while the hybrids were highly responsive upto 80 kg N ha<sup>-1</sup> in good rainfall years and 40 kg N ha<sup>-1</sup> in subnormal rainfall years (Panjab Singh, 1977; Singh *et al.*, 1978c; Joshi 1984; Singh, 1995a). Joshi (1984) reported that varietal response to N was highly governed by distribution of rainfall than amount of rainfall. Application of N and P was more advantageous in pearl millet (Mann and Singh, 1977). The larger canopy where fertiliser was applied, apparently helped to reduce water loss by evaporation from the soil. Nitrogen losses in the form of volatilisation are very common in arid region (Aggarwal and Kaul, 1978). Therefore, split application of N, half as basal and half at tillering was highly effective in pearl millet (Mann and Singh, 1978; Singh *et al.*, 1973; Panjab Singh, 1977; Singh *et al.*, 1978a). Use of farmyard manure, besides improving yield also maintain soil fertility (Singh *et al.*, 1981b; Gupta *et al.*, 1983). Application of phosphorus to arid legumes improved the nodulation and seed yield (Singh and Singh, 1981; Singh, 1982; Singh and Ramakrishna, 1976; Singh, 1978c). The residual P from preceding year legume crops, boosted the growth of pearl millet (Singh *et al.*, 1981a; Singh *et al.*, 1985). Joshi and Rao (1989) reported 13 kg N saving and 39 per cent increase in yield when pearl millet was inoculated with azospirillum bacteria. Rhizobium inoculated mung bean provided 51 per cent higher seed yield. Hence, application of FYM/fertiliser/biofertilizer helps in early vegetative growth which led to faster canopy development and reduction in evaporation from soil surface.

**Stubble mulching/wind strip cropping:** Soil erosion and advection losses by hot and dry winds is very common problem in the region. One of the methods to overcome these problems could be the use of stubble mulching and wind break strips. Misra (1962) reported decrease in soil erosion and evaporation losses, etc. and increase in soil organic matter and yield of pearl millet, when pearl millet stubbles of 45 cm height were left in the field at harvest. Since, pearl millet stover meet the fodder requirement of livestock, it is not practical proposition in the region. Secondly

wild and stray animals may also graze the stubbles. Wind strips and wind breaks were found highly useful in controlling wind erosion and improving micro-climate by minimising advection losses (Misra *et al.*, 1966b; Ramakrishna, 1985).

**Intercropping:** Growing one or two legumes with pearl millet as mixed crop has been a traditional practice primarily to reduce the risk of complete crop failure in aberrant weather conditions. Clusterbean was the best associate of pearl millet in good rainfall years while cowpea was excellent companion crop during sub-normal rainfall years (Mishra., 1971). Green gram, dewgram, clusterbean grown in the space between two pairs of pearl millet provided additional yield of legumes (Panjab Singh and Joshi, 1980; Singh *et al.*, 1978c; Singh *et al.*, 1978b). Singh and Singh (1977) reported higher yield of sunflower and legume intercrops. Tomar and Saini (1979) reported that two rows of green gram grown with pearl millet (spaced 100 cm) provided 5.9 q ha<sup>-1</sup> additional yield of green gram seed. Singh and Joshi (1997) found that moderate population of 90,000 plants ha<sup>-1</sup> (equal population of pearl millet and clusterbean) was optimum for 1:1 intercropping system. Intercropping/strip cropping provided higher moisture use efficiency in moisture stress condition as it minimised the water losses at early vegetative stage (Singh and Joshi, 1994).

#### **Minimising runoff and deep percolation losses**

The another approach is to utilise the rainfall by means of appropriate land treatment increasing soil moisture (Singh, 1977a). Some of these include, tillage, contour bunding soil amendments, soil moisture barrier, *khadins*, anicut, etc. Mechanical structure like contour bunding, terracing are prerequisite on sloppy lands. Contour bunding of 75 cm height and 80 cm vertical spacing combined with contour furrowing of 10-15 cm depth and 100-125 cm vertical spacing generally improves the forage yield and increase soil moisture status as compared to control/bunding or furrowing (Singh, 1984). Studies on preparatory tillage showed that one sub-surface cultivation once in 3 years with a sweep at the onset of monsoon and one harrowing prior to sowing was conducive to good crop stand and higher yield of crops (Mann and Singh, 1978). However, Singh *et al.* (1973) and Singh and Singh (1988b) advocated that one tillage was enough for sandy soil as it controlled 73 per cent weeds population and increased the yield of pearl millet to the tune of 43 per cent. Gupta (1985) and Gupta and Gupta (1986) also reported that one discing helped in infiltrating rainwater in the soil and minimised the runoff losses.

Sandy soils, being coarse in texture, have low water retention capacity. In normal and good rainfall years 30 to 40 per cent of seasonal rainfall is lost as deep percolation. Thus, there is need to conserve water against deep percolation losses. Application of bentonite, vermiculite clay, pond sediments, organic amendment with *Calotropis* improved the soil moisture by retaining for longer time and enhanced the yield of rainy season crops (Misra and Bhattacharya, 1966; Gupta *et al.*, 1979; Gupta and Aggarwal, 1980; Gupta and Gupta, 1982). To minimise deep percolation, the Japanese Desert Development Institute has introduced a technique injecting 3 mm thick asphalt

layer at a depth of 45 to 90 cm. It has been estimated that deep percolation from asphalt barriered profile was 4 out of 54 cm rainfall (Gupta and Aggarwal, 1980). From the uniform profile the loss was 22 cm. The additional low tension water held in the root zone boosted the yield of pearl millet under rainfed condition and wheat under irrigated condition. Singh *et al.* (1979) reported that bentonite clay as sub-surface barrier was effective in reducing moisture losses due to deep percolation and resulted higher yield of round gourd. Similar observations has also been noted by Gupta and Aggarwal in 1980. Integration of subsurface barrier, water harvesting and farmyard manure increased the soil moisture 70-91 mm in 60 cm soil depth and increased the yield (Gupta, 1986). In Jaisalmer, water collected in *khadin* raised the production of rabi crops by 20-30 per cent (Khan, 1995).

### **Increasing Water Supply Available to Crop Plants**

Rain water harvesting, supplementary irrigation, cultivation to improve infiltration, crop and varieties with deep root system and drought resistant are some of the important agro-techniques which increase total water supply available to crop plants. Here, the discussion is concentrated on rain water harvesting and integrated dryland-supplemental irrigation approaches.

#### **Water harvesting**

Water harvesting is the harnessing of water from treated or untreated catchments to the field or ponds. It is advantageous in increasing total water supply available to crop plants during low rainfall years (Singh, 1985a). Two *in-situ* water harvesting system were devised at this Institute during seventies and eighties (Singh, 1988b). Interplot water harvesting, cropping 2/3 of the field and leaving 1/3 as catchment (1.5 m or 0.75 m catchment on one or both side respectively) with a slope of 5 per cent towards the cultivated area increased the soil moisture and yield of many crops (Singh *et al.*, 1973; Singh, 1988a; Singh, 1985b). The system resulted one third saving in inputs besides higher yield. The threshold rainfall to produce runoff from catchment with a layer of pond sediment is 4.5 mm (Singh, 1988a). Average of 85 year rainfall (1901-1985) shows that percentage of showers equal or less than 4.5 mm is about fifties, hence this technique is highly suitable for this region (Singh, 1988a).

In semi-arid part (Pali) catchment with 4-8 per cent slope provided 50-80 per cent runoff to the cultivated area and enhanced the yield of castor, sunflower, green gram (Jain and Singh, 1982). Later on covering these catchments with plastic, janta emulsion, pond sediment generated 98, 90, and 70 per cent runoff (Singh and Singh, 1997). Integration of paired planting arrangement (Singh and Singh, 1988a) or nitrogen fertilisers (Singh and Singh, 1997) into water harvesting enhanced the yield of pearl millet. Integration of crop husbandry, hybrid seed and fertiliser into water harvesting raised the yield of pearl millet from 4.0 to 27 q ha<sup>-1</sup> over local variety under conventional practices (Singh and Singh, 1988b). Interrow water harvesting system (ridge and furrow) was designed in modification of interplot water harvesting (Singh, 1988b). In this system no land is wasted for catchment purposes.

Another approach to water harvesting is collecting water in ponds and recycling at critical stages of crop growth (Mann and Singh, 1978). The increase in yield was 7-33 per cent depending on severity of drought, method of sowing and depth of water supplemented to crop.

### **Integrated dryland farming-supplemental irrigation**

The dryland crops may fail or give very low yield due to failure of rain. In areas having irrigation facilities or water collected and stored in ponds can be supplemented to crops during drought period. Studies conducted on supplemental irrigation in pearl millet showed that the yield of rainfed pearl millet was increased and a supplement of 14.5 cm to rainfall provided highest WUE (Singh, 1997b). This also opened the scope to bring larger area under irrigation and to increase the total production per unit of water. Singh and Singh (1993) also reported higher yield of kharif crops under integrated-dryland farming supplemental irrigation system. Kathju *et al.* (1993) reported that application of 40 kg N and one supplemental irrigation improved the yield of pearl millet over rainfed crop during drought years. Application of one supplemental irrigation in crops viz., barley, chickpea and mustard raised on conserved moisture enhanced the yield of these crops (Rao and Aggarwal, 1985). In sub-normal rainfall years, a single irrigation of 10 cm to cotton increased the yield by 76 per cent (Singh, 1997a).

### **Management of Limited Irrigation Resources**

The cropping pattern in arid zone has changed to a greater extent in the past, owing to creation of irrigation facilities in the form of canal and ground water. Cotton, sugarcane, groundnut, rice and sugarbeet are being taken in tubewell as well as canal operated areas.

Maximising production per unit of land was the basic water management strategy until seventies. For example, on loamy sand soil wheat required 79 cm of water in eight irrigations (Singh *et al.*, 1976). In light soils of IGNP command area, eight irrigations have been recommended for wheat (20 years Agric. Res. 1971). Yield of wheat with irrigation at 75 mm of CPE upto heading and 50 mm of CPE upto maturity provided maximum yield (Singh, 1978a). While Gupta and Aggarwal (1975) reported highest yield of wheat when irrigated at 25 per cent depletion of available soil moisture (ASM). Mallik (1974) obtained higher yield of wheat when irrigated at 50 or 75 per cent of available soil moisture in Hisar conditions. Singh *et al.* (1996) reported that mustard irrigated at 100 per cent of potential evapotranspiration provided the highest yield at 550 mm of consumptive water use. Irrigation scheduled at 50 per cent depletion of ASM from 1 meter soil profile required 30 cm water in mustard and 46 cm in sorghum (Singh, 1995b). Application of water at 0.6 ID/CPE to mustard gave the highest seed yield (Khan and Aggarwal, 1985). Daulay and Singh (1980) obtained maximum yield of wheat, barley, mustard, safflower, gram and peas with 7, 7, 4, 3, 3 and 3 irrigations respectively. Mallik (1974) reported higher yield of wheat with irrigation at 75 per cent available soil moisture in Hisar conditions. Mustard required 29 cm of water in 4 irrigations (Singh and Yusuf, 1979). On loamy sand soils maximum

yield of mustard was obtained with irrigation at IW/CPE of 0.5 (Bajpai *et al.*, 1981). With seasonal rainfall of 34 cm, cotton produced 2180 kg ha<sup>-1</sup> seed yield with 63 cm of water (Joshi and Saxena, 1997). In another study conducted in IGNP area, irrigation at 0.8 IW/CPE required 6 irrigations in cotton (Joshi and Saxena, 1997). Studies based on IW/CPE ratio conducted under AICRP on water management showed that mustard gave the highest yield with irrigation at 0.5 at Jobner and 0.3 at Hisar (Joshi and Saxena, 1997). In barley, irrigation at 50 per cent depletion of ASM provided the maximum yield on loamy sand soil (Mallik, 1971). Singh and Joshi (1989) reported that irrigation at 50 per cent depletion of ASM was adequate for satisfactory yield of barley. Studies conducted under AICRP on water management revealed that for higher yield on sandy to loamy sand soils of Jobner the barley crop required 9 irrigation of 4 cm each on the basis of IW/CPE of 0.8.

These studies reflected the importance of maximising production per unit of land. As we apply more irrigation to attain maximum yield, the relationship between evapotranspiration (ET) and applied water becomes convex (Singh, 1977a). Irrigation efficiency (ET as per cent of applied water) reduced due to increased non ET losses (Singh, 1977a). Deep percolation, moisture stored at harvest and evaporation at early growth stages are the major non-ET losses. Hence, no arid region can afford such wasteful use of limited water. This emphasised the need for minimising the non-ET losses in arid region. Since mid-seventies efforts were concentrated on minimising non-ET losses while managing limited water supply in arid region.

### **Minimisation of Evaporation Relative to Transpiration**

In field agriculture where the basic water parameter ET includes surface evaporation, any amount of technology, no matter how efficient can eliminate evaporation from the soil. The mechanisms that are capable of restricting the availability of energy to the soil, and limiting heat or vapour exchange between the soil and the atmosphere can minimise it, making water available more for transpiration which is most directly related to yield. Mulches related to moisture conservation, optimum leaf area concept and irrigation in terms of ground cover have been identified major practices to minimise evaporation losses. Much have been said about mulches under water management in rainfed farming, however, this practice has also been found suitable for winter crops raised on rainy season's conserved moisture (Gupta, 1985; Daulay and Singh, 1980).

Singh and Singh (1993) reported that ET started with a low figure and was independent of plant density upto 25 days in wheat when the ground cover was least. A large part of water use was in the form of evaporation and least through transpiration. Hence, the discussion limits to optimum leaf area concept and irrigation in terms of ground cover that influences the relative proportion of evaporation to transpiration. Maintenance of closer optimum leaf area at all times is difficult. However, a system if comes to this ideal situation is expected to be most efficient.

To ensure that the evaporation is less and less relative to transpiration it is desirable to have optimum density of vegetative cover by properly adjusting the row spacing and seed rate, by selecting the most favourable time of planting, and by a fast development of crop canopy through application of nitrogen early in the season. In wheat, LAI increases of crop (seeded at 125 kg ha<sup>-1</sup>) at its booting stage were found to be significantly curvilinear as season water increased in the 10 to 102 cm range, as also when water and fertiliser N were applied in a plot (Singh, 1977a). When water and seeding rate were set to 56 cm and 125 kg ha<sup>-1</sup>, application of 150 kg N ha<sup>-1</sup> maintained an optimal leaf area index at 3.4 (Singh and Mann, 1979). At this value, evaporation whatever value it had was a constant percentage of ET, and evapotranspiration exceeded the daily rate of evaporation (Singh and Singh, 1993). Maintenance of optimal soil fertility therefore is essential in managing relative proportion of evaporation to transpiration. Evaporation again contribute significantly when crop approached to maturity. Therefore, soil moisture should not be maintained at a high level during maturation in grain crops.

In case of mustard 22 cm of water combined with 50 kg N and 30 cm row spacing provided the optimal yield by keeping optimum leaf area to reduce evaporation losses (Singh and Yusuf, 1979). To obtain optimum yield of safflower a combination of 20 cm row spacing, 29 cm of water and 80 kg N ha<sup>-1</sup> resulted optimal crop growth yield (Singh and Yusuf, 1981). In coriander 490 mm water combined with 90 kg N provided the optimal yield (Singh and Rao, 1994a). Optimal water and nitrogen has also been worked out for cumin (Singh and Rao, 1994b).

Application of fertiliser, when water and seeding rate were kept optimal, increased the water use efficiency of many crops like mustard (Upasani and Sharma, 1986, Sharma and Kumar, 1989), pearl millet (Garg *et al.*, 1993; Singh *et al.*, 1995; Singh and Singh, 1997), wheat (Singh, 1981). While managing limited water, one thing is important to be kept in mind that restrict frequent irrigation early in the season until the maximum energy available is used through evaporation, on the one hand, and a wise use of water is made if applied during the period of complete ground cover, on the other. Using modified Pennan method (Joshi and Singh, 1994) worked out optimal water requirement of many crops for canal command area and suggested irrigation programming for efficient management of limited water. However, density and fertiliser have to be kept optimal as discussed above.

### Removal of Non-ET Water Uses

Irrigation water = ET + Non ET, and irrigation efficiency is the ET, expressed as percentage of irrigation water owned/purchased and applied. As we approached ET maximum to attain maximum yield, some deep percolation was inevitable, besides some available soil water remaining in storage at the time of harvest. A rainfall exceeding the size of soil storage also results in non-ET water disposition, and sandier the soil, the greater are the losses through deep percolation.

From the foregoing account it seems that the optimum water use policy in arid and semi-arid regions should apply the concept of modest irrigation, and to terminate irrigation at an appropriate



stage to ensure that losses due to deep percolation are minimal or even eliminated, and no available water remains in storage at harvest (Singh and Singh, 1993). However, termination of irrigation is specific to soil, climate, crop and irrigation system.

For achieving efficient management of limited water, the ratio of crop ET to applied water should approach unity to have maximum efficiency in water use. It is possible by applying less water than seasonal ET. Study revealed that when water application of wheat was limited to 56 cm below that required (84 cm) for maximum yield, the non ET water use was eliminated and 100 per cent irrigation efficiency could be achieved in wheat (Singh, 1977a). But optimum seed rate ( $125 \text{ kg ha}^{-1}$ ) and appropriate N rates ( $150 \text{ kg ha}^{-1}$ ) should be combined with modest irrigation. Singh and Singh (1993) reported no visible differences in ET of wheat crop at any planting density and may slight differences at peak growth stage. It seems that the plant density influenced ET through its effect on LAI. Optimal plant density may be helpful in improved water management also through a control on water flow below the root zone. For example in tomatoes grown under drip a plant population of 96 and 192 per 12 meter length using equilateral and hexagonal planting arrangement respectively, the soil was dry below 100 and 90 cm depth (Singh, 1978d). It means higher plant density restricted the deep percolation losses under drip irrigation.

Application of light and frequent irrigation also restrict deep percolation losses. Use of light and frequent irrigation 30 mm at  $E_0$  30 mm increased the yield of tomatoes and lady finger and soil was dry below 50 cm soil depth (Gupta 1985). High frequency (7 days interval) light irrigation (2 cm) gave more yield of cauliflower than low frequency (14 day interval) and heavy irrigation (5 cm) on a coarse sandy soil of arid region (Singh and Bhandari, 1984). It has minimised the deep percolation losses. Application of 700 mm water at 80 per cent deficit replacement combined with 80 kg N per annum provided the highest yield and WUE in sewan grass (Singh *et al.*, 1990). Singh (1985a) advocated low depth of water for cotton and chick pea grown on sandy loam soil with high water table. Singh *et al.* (1985) also reported favourable response of mustard to two irrigation with 2 cm rainfall at 6 meter water table on sandy soil of Hisar.

### Optimal Yield Concept

In arid tropics where water is limited and expensive, the objective may be to maximise production per unit of water. In this case, a lower average yield on a large area can result in higher total benefit than the most profitable yield from small area. Consequently, one may limit seasonal irrigation to a level that maximises WUE. In wheat 41 cm water provided the highest yield of HD 2009 wheat ( $46.7 \text{ q ha}^{-1}$ ) as well as maximum WUE (Singh and Singh, 1993).

Under water deficit conditions most field crops are known to have higher WUE. To verify, WUE of pearl millet, grain sorghum, cowpea, mung bean and clusterbean were calculated from the yield-water use relationship. Predicted WUE showed a general tendency for it to decline with decline in ET as intercept 'a' was negative (Singh, 1995a). With optimum combination of inputs

(150 kg N and 125 kg seed ha<sup>-1</sup>) in wheat, the WUE maximising level of irrigation was found to be 41 cm and yield was 3150 kg ha<sup>-1</sup> or 7.7 kg ha<sup>-1</sup> mm<sup>-1</sup>. Another approach is to achieve minimum acceptable yield. In wheat 48 cm of water use is the minimum level of water to obtain minimum acceptable yield, 4212 kg ha<sup>-1</sup> (Singh and Singh, 1993).

### **Optimal Irrigation Programme**

Optimal irrigation scheduling as per the stages of crop growth is essential for managing limited water supply in arid and semi-arid regions. To apply a volume of water smaller than ET requires that the loss in yield should be minimal. For that season, it requires to increase the ET from the least number of irrigation and the least depth of seasonal irrigation, provided the growth stage effects are controlled. Hence, a quantitative knowledge of the growth stage effects on yield is essential. Because, once the critical period in the life cycles of various crops are identified and sequenced in order of relative sensitivity, it would be possible to generate an irrigation programme which will improve an ET deficit within the limit of tolerance in stage (s) less sensitive to water and avoid, as far as possible, the occurrence of ET deficit during the critical stage.

Sharma (1984) identified six growth stages sensitive to water deficit in wheat (i.e. CRI, tillering, jointing, flowering, milk and dough). Experiments conducted at all India Coordinated Trial on Wheat that IW/CPE ratio of 0.9 is optimum for scheduling irrigation to wheat after irrigation at CRI on light texture soil. But this schedule may increase water losses in the form of Non-ET losses. Ram Niwas (1975) found booting to heading followed by flowering to grain development stage most critical in wheat. An early period of growth is least sensitive. The ET deficit, 10-18 per cent in the vegetative stage conditions the crop to tolerate 30-35 per cent ET deficit during the period of flowering to grain development in wheat (Singh and Mann, 1979). The flowering stage in mustard (Singh and Yusuf 1979), a week before flowering in sunflower (Singh and Mann, 1979) and branching, flowering to grain development in safflower (Singh and Yusuf, 1981) have been identified the most critical stages for water supply. With these considerations and limitations optimal irrigation programme have been developed for many crops grown in arid region (Singh 1978a; Singh and Yusuf, 1979; Singh and Yusuf, 1981; Singh and Rao, 1994a, 1994b). In Jodhpur condition, wheat require 84 cm of water in eight irrigation scheduled at different stages to produce maximum yield (5430 kg ha<sup>-1</sup>). The uses of 40 and 20 cm of water by irrigation optimally planned produced 4724 and 3668 kg ha<sup>-1</sup> of wheat respectively (Singh and Mann, 1979). This means that against 52 and 76 per cent reduced uses of water, the losses in yield are nearly 13 and 32 per cent. Here, the seeding and nitrogen rates were kept at optimal levels. Hence, optimisation approach seeks to fulfil this objective.

Rao and Aggarwal (1984) reported that application of 6 cm at tillering stage significantly increased the yield of barley over no irrigation at Hisar. While, Yadav and Singh (1985) advocated 2 irrigation at tillering and boot stage to attain maximum yield of barley at same location. In cotton, irrigation should be given at 30-35 DAS, 65-75 DAS, 90-100 DAS, 100-115

DAS, 125-130 DAS (Joshi and Saxena, 1997). In cotton, branching, flowering, seed formation are the most sensitive to water deficits in semi-arid region Pali (Singh 1977b).

### **Extensive Irrigation Concept**

Extensive irrigation approach seeks to apply a small quantity of water over larger area rather larger quantity of water on small area. In this, water supply is fixed and irrigation depth is applied as per the critical stages of crop from data generated under optimal irrigation programming experiments (Singh 1977a). For example, wheat, hybrid bajra, grain sorghum, sunflower and mustard required 84, 25, 28, 50 and 25 cm water per hectare to produce maximum yield. The same water if optimally applied at critical stages brought 3, 4, 2.5, 2, and 1.5 ha land under wheat, bajra, grain sorghum, sunflower and mustard, respectively. Though the production per unit land was less but total productivity per unit of water was more by bringing larger area under irrigation. Singh (1997c) also observed that under given water supply the area brought under irrigation in pearl millet was more in subnormal rainfall years than low rainfall years, however, the production enhanced in both the situation by bringing larger area under irrigation in pearl millet.

### **Partial Root Zone Wetting Concept**

Partial root zone wetting concept seeks that soil profile is recharged to field capacity at the time of sowing and subsequent irrigation were given to wet the partial root zone. This study was conducted in HD 2009 (wheat). Preplant irrigation of 7.6 cm was given just before sowing and subsequent irrigation 3.8 cm each were scheduled at CRI, late tillering, jointing, booting, flowering and milking stage, which resulted highest yield 4666 kg ha<sup>-1</sup> (Singh and Singh, 1993). Partial root zone wetting did not allow deep percolation losses. Similarly, in mustard 19 cm water applied (7.6 cm as preplant and three irrigation of 3.8 each provided the maximum yield (Singh and Mann, 1979). Low depth (2 cm) high frequency irrigation (7 days interval) provided the maximum yield of cauliflower in arid region (Singh and Bhandari, 1984). Rao and Aggarwal (1985) reported higher yield of barley, chickpea and mustard with one supplemental irrigation.

### **Crop Sensitivity Rating**

Relationship between reduction in yield v/s ET deficit is useful tool for managing limited water supply in arid region. The slope coefficient between yield reduction and ETD was found to be 1.20 for cowpea, 1.22 for pearl millet, 1.45 for clusterbean, 1.58 for mung bean and 1.68 for sorghum (Singh, 1995b). Study revealed that sorghum used 45 per cent of ET<sub>m</sub> in evaporation process without contributing to yield. Hence, it is not suited to arid environment as it is highly sensitive to ET deficits. Mung bean and clusterbean are well adapted to the rainfall pattern of the region. Pearl millet was the most efficient user of water as it produced as much yield from 20 cm water as sorghum produced from 35-45 cm water so, limited water should be given to pearl millet in hot arid environment.

## Irrigation Methods for Management of Water

Since the development of irrigated agriculture various irrigation methods have been developed and devised for efficient management of water at the farm. On sandy soils, extra care has to be given for improving irrigation methods as the infiltration rates are very high.

### Improvement in conventional methods

The check basin and border strip are the two commonly used methods of surface irrigation system in the region. Check basin is most suitable when flow rate are small while border strip is well suited for high flow rates. Murthy and Aggarwal (1970) suggested that time for water spread in a plot should be about 1/4 of infiltration time for desired depth of water. Yadav (1982) recommended a size of 225 m<sup>2</sup> for check basin (15 x 15 m) for stream flow of 14 l/sec for sandy loam soils of Hisar, while 25 m<sup>2</sup> (5x5 m) for stream size of 3.5 l/s for sandy soil of Rajasthan was optimum (Banarasi Lal, 1985).

### Sprinkler system of irrigation

Since the topography of sandy plains of western Rajasthan is highly undulating, proper land levelling is highly cumbersome and uneconomic for conventional irrigation methods. On such topography sprinkler irrigation is highly suitable technique. Sprinkler irrigation is gaining attention of farmers. Presently 19557 sprinkler sets are in operation in Rajasthan of which 11572 in Jaipur and 4073 set in Jodhpur divisions, respectively are existing (Singh *et al.*, 1997). Sprinkler irrigation resulted 38, 18, 33 cm saving of water in wheat, groundnut and cotton and provided the highest WUE as well (Kaushal and Pathak, 1977). Sprinkler irrigation gave higher yield and WUE of wheat and potato in Haryana (Aggarwal, 1985).

Yadav and Girdhar (1979) reported that sprinkler irrigation was more effective in reducing salinity in upper soil layers than surface irrigation. Sprinkler irrigation was more suitable for frequent irrigation. Studies conducted at CAZRI revealed that the yield of cucumber was 1 to 1.5 times higher over furrow irrigation (Singh and Singh, 1978). It also gave 33-37 per cent higher grain yield of wheat over check basin and border strip irrigation, respectively in arid region (CAZRI, 1979). The high wind velocity and saline water may restrict its wider application in the arid region.

### Drip irrigation

Drip irrigation neither influenced by high winds nor by uneven surface. This is highly useful for sandy soils where evaporation and deep percolation are very high. Drip provides water through a net work of pipes and tiny outlets at very low discharge and at low pressure. The discharge rate of drip is less than infiltration rate of sandy soil, hence deep percolation are minimised. Drip is able to save 30-50 per cent water in most of the high value vegetable crops besides giving perceptibly higher production (Singh *et al.*, 1978f; Singh *et al.*, 1997). It is highly suitable for saline water irrigation. Saline water 3 to 10 dS m<sup>-1</sup> were successfully used in potato and tomatoes

respectively (Singh *et al.*, 1978f). It has been observed that daily drip irrigation maintained higher moisture content and subjected the salts beyond active root zone, hence detrimental effects were minimised (Gupta and Singh, 1983; Singh *et al.*, 1978f). The high installation cost on drip lateral and emitters and clogging by salts are the major bottlenecks of drip system in its adoption on large scale.

Keeping one lateral in between two rows reduced the installation cost and water use by 50 per cent (Singh 1978d). Drip-fertigation provided gainful use of nutrient management with water and provided maximum yield of tomatoes and chillies (Singh *et al.*, 1989; Singh *et al.*, 1997). Plastic infusion sets used in hospitals have been reused on small scale area for raising vegetables (Kolarkar *et al.*, 1983). Keeping in view the scarcity of water in the region, drip irrigation has to be given proper attention for maximising the production per unit of water in the region.

### Management of Saline Water

Ground water in vast areas of arid region is of poor quality and use of such water caused deterioration of land in the district of Barmer, Jalor, Pali and Jodhpur (Joshi and Saxena, 1997). About 80 per cent of ground water has salinity more than  $2.2 \text{ dS m}^{-1}$  (Joshi and Dhir, 1997). Now farmers leave the land fallow during rainy season to leach down the salts with rains during rainy season. Salinity hazards will be impediment in canal command area with the passage of time. Since 1993 water table rose to 1.6 meter and salinity in water rose from  $0.17 \text{ dS m}^{-1}$  to  $0.4 \text{ dS m}^{-1}$  in IGNP area. In Ghaggar belt water table is within 0.3 to 3.9 m from soil surface due to water logging.

Salinity hazards of water increased with the increase in the content of silt and clay while sodic hazards lowered on such soil (Jain, 1978). Dhir *et al.* (1977) reported that the yield of wheat was reduced at irrigation with  $16 \text{ dS m}^{-1}$  salinity level in water, however, Kharchia 65 gave acceptable yield upto  $8 \text{ dS m}^{-1}$  of salinity level in water. Sharma *et al.* (1977) reported that irrigation at 10 days interval with saline water provided highest yield, however, salt accumulation was more. Higher moisture content with frequent irrigation was less detrimental than longer interval between irrigation. Sprinkler may prove hazardous to crop if salinity exceeds  $4 \text{ dS m}^{-1}$ . However, Yadav and Girdhar (1977) reported that frequent sprinkler irrigation minimised the salt content in soil. The water could have been of good quality in their study. In such situation, drip irrigation is highly efficient for managing poor quality water. Studies conducted at CAZRI revealed that potato yields of 26.4 and  $14.4 \text{ t ha}^{-1}$  could be harvested using saline water of 3 and  $10 \text{ dS m}^{-1}$ , respectively (Singh *et al.*; 1978f). Further, the yield of potato at  $3 \text{ dS m}^{-1}$  salinity was 31 per cent higher over furrow irrigation using good quality water. This suggests that it is possible to mix water of high salt content with good quality water in such a way so as to obtain conductivity of  $3 \text{ dS m}^{-1}$ . Poor quality water ( $10 \text{ dS m}^{-1}$ ) could also be used though drip in tomatoes without much deterioration in yield and quality (Singh *et al.*, 1978f). Minimisation of salinity hazard under drip irrigation has been attributed mainly to salt accumulation on the wetting front. Thus the use of

drip and sprinkler may improve the productivity and restrict the speedy rise of water table in canal command area and also provide check on waterlogging and salinisation in the area.

The problem of shortage of water to rainfed crops could be resolved either by increasing total available water to crop plants or restricting evaporation losses relative to transpiration by integrating various management options like soil moisture conservation practices, water harvesting, manipulation in planting arrangement, fertiliser application, eliminating weeds, etc. For managing limited water supply in arid region some concepts emerged like crop response factor as a tool to crop sensitivity rating, optimal leaf area concept, optimal yield concept, optimal irrigation programming, water-use efficiency maximising concept, partial root zone wetting concept, minimum acceptable yield concept, extensive irrigation system and use of modern irrigation like drip and sprinkler. Applicability of each of these concepts to managing a limited water supply in the arid region has been interpreted thoroughly.

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S. Kathju, N.L. Joshi, A.V. Rao and Praveen Kumar

The western Rajasthan which constitutes about 62 per cent of the Indian arid zone has been divided into four agro-climatic zones (Ia, Ib, IIa and IIb) based upon rainfall, topographical features and cropping patterns.

### ***Cropping Patterns in Arid Regions***

#### **Cropping Patterns of Zone Ia**

The zone Ia is Arid western plain, has a geographical area of 12.37 million ha covering Jaisalmer, Barmer, Bikaner and parts of Jodhpur districts. In this zone rainfall has imposed serious restrictions on arable farming. Despite rigorous ecological selection since ages, a few crops such as pearl millet, mung bean, clusterbean, dewgram (moth bean), sesame and castor are grown in various proportions. Among these crops pearl millet is the most important. The crop cultivation has essentially been subsistent. Monoculture of pearl millet or pearl millet-fallow rotation is common. Although monsoon food legumes are more suitable, besides their value in soil recuperation, yet the relative profitability of these crops does not fit into farmers' calculus, who are guided chiefly by security of subsistence rather than natural suitability and economic profitability.

Clusterbean, moth bean and greengram are legume crops of *kharif* season which usually show better performance. Wheat crop production is possible with irrigation. Wheat, barley, chickpea and mustard are important crops but yields are fairly low. Silvi-pastoral cultivation with production of pearl millet, moth bean, sesame, barley and chickpea can pay dividends and stabilise crop production in this zone provided wider spacing is adopted than has hitherto been followed. The commonly practised cropping patterns are given in Table 1.

Recent surveys conducted to understand farmers' perception of cropping systems (Joshi, 1996 unpublished data) indicated that significant number of farmers of zone Ia prefer mix cropping rather than sole cropping. The mixtures consist of pearl millet, mung bean, moth bean and sesame. The proportion of pearl millet in the mixture is reduced if sowings are delayed beyond first fortnight of July. The clusterbean is seldom put in mixtures and is preferred as sole crop.

#### **Cropping Patterns of Zone Ib**

The zone Ib has been classified as Irrigated north-western plain, has geographical area of 2.06 million ha comprising districts of Sri Ganganagar and Hanumangarh. This zone has much larger

Table 1. Existing cropping patterns of Zone Ia

I year		II year	
Monsoon	Post-monsoon	Monsoon	Post-monsoon
Pearl millet	Fallow	Fallow	Barley
Moth bean	Fallow	Pearl millet	Fallow
Pearl millet	Chickpea	Fallow	Fallow
Clusterbean	Fallow	Pearl millet	Fallow
Sesame	Fallow	Fallow	Fallow
<i>Pearl millet +</i> food legumes	Fallow	<i>Sesame</i>	<i>Fallow</i>
Fallow	Fallow	Food legumes	Wheat
Fallow	Mustard	Clusterbean	Fallow

irrigated area through canals than any other zone. Land development work has been complete in most cases and major cropping patterns revolve around cotton, wheat, peanut and chickpea. This area turns out 86 per cent of cotton crop from 74 per cent of the cotton area concentrated in this zone. Wheat also enjoys comparative advantage owing to dry winters. The most common cropping patterns of zone Ib are given in Table 2. The peanut-wheat rotation has been found to give maximum advantage, leading to efficient water use and ensure higher yield of wheat (Singh and Shaktawat, 1991).

Table 2. Cropping patterns of Zone Ib

I year		II year	
Monsoon	Post-monsoon	Monsoon	Post-monsoon
Rice	Wheat	Rice	Wheat
Peanut	Wheat	Peanut	Wheat
Pigeonpea	Wheat	Pigeonpea	Wheat
Pigeonpea	Chickpea	Pigeonpea	Chickpea
Clusterbean	Mustard	Clusterbean	Mustard
Pearl millet	Wheat	Sorghum	Chickpea
Cotton	Fallow	Food legumes	Wheat
Clusterbean	Wheat	Cotton	Fallow
Pearl millet	Chickpea	Fallow	Mustard
Cotton	Sugarcane	Ratoon	Fallow
Fodder	Berseem	Peanut	Wheat
Fallow	Wheat	Fallow	Mustard
Food legumes + pearl millet	Fallow	Fallow	Barley
Cotton	Wheat	Cotton	Wheat
Fallow	Chickpea	Fallow	Chickpea



Average yield of wheat is though high in this region, for the simple reason of water availability, yet been stagnant, and many farmers are switching on to chickpea and of late to mustard. Average yields of sugarcane and cotton crop, though grown as commercial crops, are low. Should we be able to maintain fertility of soil at high level it is possible to harvest at least 3000 kg ha<sup>-1</sup> of wheat and another 2500-3000 kg ha<sup>-1</sup> of peanut. Pigeonpea has not been found suitable for these command areas. Similarly irrigated chickpea is also not very successful. To increase efficiency in water use one has to plan balanced use of fertilisers and make best use of hardware investment in irrigation works. However, no serious effort has been put up to workout nutrient management of different cropping patterns adopted in this zone. Fertilisers are applied based on general recommendations made else where.

### Cropping Patterns of Zone IIa and IIb

The zone IIa is a Transitional plain of inland drainage, having 3.694 million ha geographical area comprising of Nagaur, Sikar, Jhunjhunu and parts of Churu districts. The zone IIb is classified as Transitional plain of Luni basin with an area of 3.01 million ha comprising Jalor, Pali, and parts of Sirohi and Jodhpur districts. Since these zones are transitional between arid to semi-arid, pearl millet, greengram, clusterbean and cowpea are principal *kharif* crops whereas mustard, chickpea, wheat and barley are *rabi* crops taken in many pockets. Our experience over several years shows that in the agro-climatic zone IIa and IIb only one crop can be grown. *Kharif* crops like pearl millet, greengram and clusterbean can be grown without irrigation if *in-situ* water harvesting techniques are adopted. Thus, so long as there is no arrangement for augmenting water supply during winter season, only one crop in the year can be taken. Intensity of cropping in zones IIa and IIb is also 100 per cent; it does not matter much so long as high yields are harvested from one crop. Thus, mustard-based cropping pattern, chickpea/barley-based pattern of cropping and pearl millet-wheat rotation in irrigated areas can give better prospects. Average yields of mustard, chickpea and pearl millet are of the order of 0.5 t ha<sup>-1</sup> and that of wheat is more than 2 t ha<sup>-1</sup> in this zone. The common cropping patterns in zone IIa and IIb are almost similar to those of zone I with relatively higher yields and lower risk of crop failures. Significant deviation in cropping of zone Ia and IIa is that the farmers of zone IIa prefer to take sole crops of pearl millet and other legumes rather than mixtures. Mix cropping of pearl millet with other legumes is taken only when sowings are carried out beyond third week of July (Joshi, 1996 unpublished data).

Most of the crops are adapted to most of sub-zones but poor yields are due to further depletion of already impoverished soil. Fertiliser use is hardly 15 kg ha<sup>-1</sup> year<sup>-1</sup> in some of the parts as against a net requirement of 40 kg ha<sup>-1</sup>. Most farmers at present are reluctant to use inorganic fertilisers in arid areas but use FYM to partly meet out nutritional requirement of crops.

### Cropping Patterns of Other Arid Areas

Pearl millet is grown either as sole crop or with legumes in intercropping systems. In Gujarat with medium textured soils and better rainfall, groundnut, cotton and sorghum assume

significance whereas in south, minor millets appear, in addition. Wherever irrigation facilities exist wheat, cotton and a variety of fodder crops are also grown in Gujarat. Under rainfed situations these cropping patterns are based on traditional subsistence farming. The varieties of crops are longer in duration with low yield potential and more often suffer from moisture stress in years of low rainfall or with terminal stress. The existing crop production systems are based on capitalising on the inherent fertility of soil without much use of fertilisers. However, the situation is changing after the introduction of high yielding varieties. The use of fertilisers is gradually increasing.

## ***Crop Management***

### **Tillage and Land Preparation**

Tillage is not only necessary to control weeds but also to bring about optimum tilth and soil physical environment conducive to proper germination and crop-stand establishment. Soil type is the main factor to determine the kind and the level of tillage operation for field preparation. Characteristics of soils of western Rajasthan have been studied in detail (Dhir, 1977). Light brown sandy soil (64.6%) was reported as major soil type in the arid region. Brown light loams, grey brown loams, soil with hard pan, sierozems, alluvial soil with dunes and other soil types occur in pockets and occupy 1.7, 13.6, 5.9, 1.6 and 6.8 per cent of the area, respectively.

Light soils require comparatively lesser tillage than heavier soils. Soils with hard pan may require deep tillage for proper crop growth. Studies on preparatory tillage showed that one sub-surface cultivation with a sweep at the onset of monsoon and again prior to sowing was conducive to good crop stand and higher yield of pearl millet (Mann and Singh, 1978). Almost complete control of *Cyperus rotundus* was achieved using plough board plough for seed bed preparation. Yadav and Singh (1978) recorded the highest yield of pearl millet (36 q ha<sup>-1</sup>) with one deep ploughing followed by one cross harrowing of the field. To evaluate the possibilities of minimum tillage for pearl millet, the plough plant seeding and bed preparation by varying degrees of tillage were compared (Singh *et al.*, 1973). Though plough plant seeding gave rain yield statistically similar to the plots with more tillage, yet, a trend of higher yield was shown by plots receiving two preparatory ploughings. Detailed studies confirmed that seeding after field preparation through harrowing was better than plough plant seeding (CAZRI, 1978). In plough plant method, higher weed population (344%) and more weed dry weight (243%) as compared to one shallow preparatory tillage caused intense competition for water and nutrients to the pearl millet and consequently resulted in low yields.

Tillage requirement for pearl millet production has been a rapidly changing concept. If weeds could be controlled through chemical means, the practice of plough plant seeding could be advocated or else, one preparatory tillage would be a minimum requirement for satisfactory harvests from pearl millet in light arid zone soils.

## Crop Stand Establishment

### Time of sowing

Pearl millet is generally sown with the onset of monsoon and seeding is the common practice. However, better results with seed sowing could only be obtained if the rain sets in time (from last week of June to mid-July). Drastic yield reduction has been reported in delayed sowing (CAZRI, 1978d). Under delayed condition (after mid-July), transplanting of 21-25 days old seedlings resulted in 22-36 per cent higher grain yield than direct seeded pearl millet (Singh, 1978). Transplanting, although labour intensive, has given reasonably good yield in the years of low rainfall and in good rainfall years also (Mann and Singh, 1978).

Misra *et al.* (1966), in a laboratory study, reported differential germination response of pearl millet varieties under varying temperatures. The cultivar JJN germinated better at higher temperature and, therefore, was suitable for pre-monsoon sowing. The dry sowing (pre-monsoon sowing) was reported to be practicable for soils which are not prone to crust formation (CAZRI, 1982). For normal sowing conditions, BJ 104 was found suitable while CM 46 was better for late sowing (CAZRI, 1980).

Plant population per unit area also depends upon the sowing conditions. Under normal sowing, grain yields were similar with different plant populations whereas under late sown condition (transplanted crop), significantly higher yield was obtained with higher plant population (CAZRI, 1977).

### Method of sowing

Two methods of seeding, i.e., *kerā* (sowing behind plough) and *pora* (drilling behind plough) are commonly practised for sowing pearl millet, and the latter has been found to be better as, in *pora* method, intimate contact of seed with moist soil and optimum seeding depth are ensured (Singh, 1984). Different makes of tractor-drawn seed drills found large scale adoption for sowing millets. Light planking after drilling the seeds is also a common practice. Use of packer was advantageous for adequate germination and crop stand establishment (Yadav, 1977). Sowing with seed drill having hoe type furrow openers and on-the-row press wheels has been found to result in a uniform stand leading to higher grain yield of pearl millet compared to using disc type furrow openers.

### Depth and rate of seeding

Adequate plant stand is the first requisite for successful crop production. The primary factors influencing stand establishment are depth and rate of seeding. In arid regions, proper moisture in seeding zone at times becomes the limiting factor for establishment of a good crop stand. Placement of seed at a proper depth would ensure environment conducive to uniform germination. A four-year study (Misra and Vijay Kumar, 1963) showed that the seed placement at 7.5 cm followed by 5.0 cm depth was optimum for seedling emergence and grain yield. Use of

3.36 kg ha<sup>-1</sup> was an optimum seeding rate (CAZRI, 1961). Misra *et al.* (1966) screened five pearl millet varieties (RSK, RSJ, Chadi, T55 and JN) for germination capability and concluded that the medium size seeds (with a mean test weight of 0.62 g per 100 seeds) gave the highest germination (93.1%) while the lowest germination (82.1%) was recorded with small seeds. The large and medium size seeds showed equal germination capability.

### Spacing

Spacing determines the areas available to each plant and the competition for resources between and within the plants. In arid areas competition for moisture is relatively more severe. A row spacing of 45 cm was found to be optimum (CAZRI, 1961). In another study, 30 and 45 cm spacing gave significantly higher yield than 60 and 75 cm spacing in a normal rainfall year (CAZRI, 1983). It is generally believed that a wider spacing may be more advantageous than narrower ones under moisture stress situation. In a closer spacing, manual weeding is easier than tractor mounted cultivator as operation of tractor is difficult in closer spacing.

### Control of surface crust

Formation of crust on the soil surface is common in arid soils. The impact of rain on exposed soil causes structural break down. The dispersed finer fractions of soil deposit on soil surface as well as move downwards with percolating water and impregnate the soil pores. The consequent rapid drying of soil, owing to high radiation intensities available in arid areas, results in surface crust formation. These crusts cause mechanical impedance to the emerging seedlings and often result in very poor crop stands or total crop failures. Crust is thus a serious problem in the arid zone. Some methods for minimising crust impedance to seedling emergence have been evolved at CAZRI. Application of farm yard manure (FYM) on the seeded row after sowing reduced crust strength from 0.74 kg cm<sup>-2</sup> to 0.33 kg cm<sup>-2</sup> (CAZRI, 1976). Joshi (1987) studied pearl millet seedling emergence under naturally crusted arid soils for four consecutive years. These studies revealed that application of FYM over seed furrows reduced the crust strength to 49 KPa on 3rd day and 69 to 74 KPa on 7th day after sowing as compared to 108-128 KPa on 3rd day and 162-172 KPa on 7th day under drill sowing. The lower crust strength with FYM allowed higher rate and ultimate emergence with low mean period of emergence. The FYM over seed furrows firstly reduced the beating effect of rain drops and thus caused lesser breaking of aggregates. Secondly, FYM being amorphous in nature, absorbed more rain water besides its mulching effect and kept 2.26 per cent higher moisture content in the surface layer. Other methods such as use of pearl millet husk as mulch (CAZRI, 1976) and mixing of legume (greengram) seeds with pearl millet seeds (Joshi, 1987) have also been found satisfactory for securing better plant populations and final yields in crusted soils.

Adverse effects of crust could also be minimised by sowing the crop in furrow in ridge-furrow system. Ridge-furrow system laid out in N-S direction or with 25° diversion either in west or east (NW-SE or NE-SW) was effective to combat crust problem as it reduced wind action and

lowered the soil temperature to result in reduced soil surface drying rate by 25 per cent to 35 per cent (Singh, 1984). Joshi (1987) reported that the success of ridge-furrow system of land preparation was largely dependent on compactness of ridges. The dislodging of loosely packed ridges on light arid soils due to high rain intensity after sowing resulted in poor emergence and low yields in two out of four years of study. Packing after sowing offers promise to overcome this problem. Yadav and Singh (1978) reported beneficial effect of packing wheels attached to seed rills on the emergence of pearl millet seeding when sowing was followed by rains.

## **Cropping Systems**

In conservation farming the crop rotation occupies an important place. A crop sequence that reduces loss of soil and gives more returns per unit area may be considered more suitable for adoption in arid areas. Growing same crop continuously on the same piece of land may adversely affect soil fertility. Mann and Singh (1977) recorded 62 per cent reduction in pearl millet yield in pearl millet - pearl millet rotation in comparison to greengram-pearl millet rotation. In traditional cropping, pearl millet is grown either after fallow in two year rotation or monocropped every year. Among single crop systems (Singh, 1980) pearl millet - fallow rotation and among double crop systems (Misra, 1971) pearl millet-clusterbean gave highest returns per unit area. Results of a long term study (Singh *et al.*, 1985) also support pearl millet - clusterbean rotation where 11 per cent higher pearl millet yields were achieved in comparison to continuous growing of pearl millet. The systems also improved soil organic carbon by 12 per cent and available soil P by 25 per cent.

## **Planting System**

Pearl millet is generally grown in uniform planting system. Possibilities of other planting systems were also explored at CAZRI. In a study, Singh *et al.* (1978a) reported 9 per cent higher yield of pearl millet in paired row than in uniform row system. Beneficial effects of paired row system were observed during drought year only (CAZRI, 1978). Conducive micro-climate for plant growth and development, besides efficient use of water, better weed suppression within a row-pair and greater root proliferation in paired rows were some of the reasons attributed for better yields in paired system (CAZRI, 1978 and Ramakrishna *et al.*, 1982).

Rao and Joshi (1986) examined the possibility of incorporating such beneficial effects. They tried border cropping by skipping every 4th row in uniform row system with a view to save nitrogen input in pearl millet production. These studies revealed that the border row system (with adjusted population on hectare basis) gave 14 per cent higher yields over uniform row system despite 25 per cent lesser inputs.

## **Intercropping**

Growing legumes with pearl millet as mixed crop has been a traditional practice primarily to reduce the risk of complete crop failure in aberrant weather. In the traditional practice, specific

row arrangements were not followed which led to low yields of both the mixed crop components. Growing pearl millet in association with clusterbean was better in a normal rainfall year while in subnormal rainfall years cowpea was a better associate (Misra, 1971). Singh *et al.* (1978a) did not see any adverse effect of intercropping greengram in the inter-row spaces of pearl millet. In a two-year study (Panjab Singh and Joshi, 1980), double rows of dewgram, clusterbean and greengram planted in the interspaces of paired rows of pearl millet (30/70 cm) yielded 381, 381 and 458 kg ha<sup>-1</sup> additional grain without adversely affecting the yields of the pearl millet. The land equivalent ratios (LER) of various intercropping systems were also studied. On the basis of LER, growing dewgram in double rows gave maximum advantage of 54 per cent owing to least competition offered by this crop. Growing two rows of greengram, though resulted in comparatively lower LER (1.19) and only 19 per cent better land utilisation, gave the maximum gross returns from the system. Singh *et al.* (1978b) observed that pearl millet could also be taken as an intercrop in greengram-pearl millet system with higher returns from intercropping than with sole crop of greengram.

Studies on planting systems for pearl millet - greengram intercropping revealed that paired planting (30/70 cm) of base crop was more efficient giving 7-24 per cent higher yield than uniform planting (50 cm) in subnormal rainfall years and as good as uniform planting in normal rainfall years (CAZRI 1984 and 1985a). These studies also showed that yield of principal crop increases with increase in levels of nitrogen but the yield of intercrop (greengram) gets adversely affected. Perhaps at higher nitrogen levels the increased vegetative growth of pearl millet suppressed the growth of intercrop. A three-year study on component populations of pearl millet - greengram revealed that closer spacing of 10 cm for both component crops offered severe competition to the principal crop and gave the lowest yield (202 kg ha<sup>-1</sup>). Keeping pearl millet plants at 15 cm apart with greengram (intercrop) plant spacing of 20 cm resulted in maximum grain yield of 1183 kg ha<sup>-1</sup> (CAZRI, 1985b).

## **Soil Moisture Conservation and Management**

With a few exceptions, about 500 mm rainfall is required in a growing season for good harvest. In the Jodhpur region the average seasonal rainfall during growing season is about 298 mm. There is, thus, a large gap between requirement and receipt. Low moisture retention capacity of soils, high infiltration rates and high evaporative demand further aggravate the situation. Dry land crops experience moisture stress during early or late stages of growth, leading to low yields or to complete failure of crops. Raising crops under such conditions is a challenging task and needs a good deal of management.

## **Surface Mulches**

In sandy soils capillary continuity is poor. Water stored in deeper layers, therefore, moves up very slowly in response to the evaporation pull unless conditions are very harsh. After drying, a

few centimetres of surface soil act as a mulch, hence, use of mulches may not be of any benefit in arid soils. But, many a times drought occurs just after sowing. In such situations covering of soil surface with mulch like grass waste, pearl millet husk and other organic wastes, immediately after sowing, may delay the surface drying, promote better establishment of crop and result in higher yields. Singh (1977b) has reported that mulches effectively conserved soil till the 50 per cent ground area was covered with canopy. Daulay *et al.* (1979) reported beneficial effects of mulch in pearl millet crop during drought years. Gupta (1980), while comparing the efficiency of organic and inorganic mulches, reported superiority of polyethylene mulch over organic mulch. The beneficial effects of mulches could be attributed to better moisture conservation and reduced heat load on the surface. Higher albedo and consequent lower soil temperature with the use of wheat straw mulch as against grass mulch was recorded (CAZRI, 1975). In another study, Gupta and Gupta (1985) observed that mulches not only conserved soil moisture by reducing the soil temperature but also considerably suppressed the weed growth.

### **Stubble Mulching and Wind Strip Cropping**

Wind erosion is a serious problem of arid regions. Low rainfall, high wind velocity, scanty vegetation and sandy soils are the causes for wind erosion. Wind speed may be as high as 20-27 km h<sup>-1</sup> in summer in western Rajasthan. Adverse effect of wind mainly occurs in summer as ground vegetation cover is minimum. Wind erosion causes damage not only to the area from where the soil is blown, but also to the area where it is deposited.

Use of stubble mulch farming and growing wind strips may minimise wind erosion. Misra (1962) reported decrease in wind erosion, and increase in soil organic matter and yield of pearl millet when pearl millet stubbles of 45 cm height were left in the field at harvest. The practice, however, has some limitations to its large scale adoption. The farmers of arid zones are reluctant to leave stubbles in the fields as these are used for animal feeding. Moreover, due to grazing by stray animals, it is difficult to maintain stubbles in the fields. Further, this practice is not so useful as it has nitrogen immobilising effect. Wind strips were found to help in controlling wind erosion (Misra *et al.*, 1966). Comparing the different materials for wind strips, they reported that perennial grass *Sewan* as wind strip not only increased the yield of pearl millet by 9 per cent over unprotected field, but also provided nutritious fodder for animals. This approach also has limited scope to its adoption in the arid zone.

### **Soil Amendment and Sub-surface Moisture**

Arid soils, being sandy in texture, have low water retention capacity. In normal and good rainfall years, about 30-40 per cent of seasonal rainfall is lost as deep percolation. Thus, there is a need to conserve water against percolation losses. Water retention capacity of light soils can be improved if amendments are mixed with these soils. Surface application of FYM and *Calotropis* amendments increased the yield by 30 per cent, whereas subsurface application (15-20 cm deep) increased the grain yield by 53 per cent and 58 per cent, respectively, over control (CAZRI,

1973). Singh (1973) reported higher soil moisture status and yield of pearl millet with the use of *Calotropis* as organic amendment. The increase in yield was due to more availability of soil nutrients with the application of *Calotropis* (Aggarwal and Sharma, 1980). Gupta *et al.* (1979) reported 40-50 per cent increase in the grain yield of pearl millet (BJ 104) with the application of 76 t ha<sup>-1</sup> of pond sediments. The increase in yield was caused by higher moisture retention, addition of nitrogen and organic matter through the amendments.

Use of asphalt as a subsurface barrier (2 mm thick of 60 cm depth) increased water and nitrogen retention by 100 per cent and pearl millet yield by 40-50 per cent (Gupta and Aggarwal, 1980). Large scale use of these barriers is limited scope due to non-availability of implements to incorporate the barriers at the desired depth, and higher cost of barriers. Availability of suitable implements and cheaper barrier material would enhance the prospects of this practice at least on a small scale.

### **Crop Energetic**

The commercial energy input, which largely depends on fast depleting non-renewable sources of energy, has immensely increased crop production in recent years. Despite modest energy use in rainfed agriculture, pearl millet productivity has also become highly dependent on commercial energy inputs. Some of the evolved technologies were, therefore, assessed from energy use efficiency point of view (Joshi, 1989). The efficient utilisation of inputs largely depends on the quantity and distribution of rainfall. The analysis of two typical rainfall (good and sub-normal) years showed that in good rainfall year, pearl millet gave as high as 126852 MJ ha<sup>-1</sup> total energy output was 25348 MJ ha<sup>-1</sup> for the same quantum of energy input (9246 MJ ha<sup>-1</sup>). This resulted in higher energy output per unit input (Eo:EI) value of 13.71 in good year compared to Eo:EI of 2.74 in sub-normal rainfall year.

In another study, application of 40 kg N ha<sup>-1</sup> with one manual weeding involving 8034 MJ ha<sup>-1</sup> total energy input resulted in total energy output of 39817 MJ ha<sup>-1</sup> compared to 27226 MJ ha<sup>-1</sup> output without nitrogen. The nitrogen accounted for 12591 MJ and the weeding for 21886 MJ ha<sup>-1</sup> energy output. Combined application of these resulted in complementary of 15.48 per cent over simple additive effects, thus marking integrated use of inputs as more efficient. The least specific energy of 1.76 MJ kg<sup>-1</sup> biomass, with the highest Eo:EI (7.45) was recorded by the application of 40 kg N ha<sup>-1</sup> together with herbicide application.

Energy output per unit of input varied with the cultivars and BJ 104 was the most efficient. The energy output could be further augmented by intercropping grain legumes with pearl millet. The intercrops clusterbean, dewgram and greengram, with only 91 MJ ha<sup>-1</sup> extra energy input resulted in 7938, 3810 and 2215 MJ ha<sup>-1</sup> additional energy output, respectively. The paired planting with 10 plants ha<sup>-1</sup> proved to be energy efficient system for intercropping as it gave significantly higher energy output over uniform row planting in sub-normal rainfall year and similar energy output in normal rainfall year.



Joshi (1988b) worked out radiant energy use efficiency (REUE) of pearl millet. The maximum REUE (1.77%) was recorded during 41-50 day period with an overall efficiency of 0.65 per cent.

## **Crop Responses to Abiotic Stresses**

### **Water Stress**

#### **Sensitivity to water stress**

The sensitivity of crops to moisture stress varies widely at different developmental stages. The crops are usually most sensitive to water stress at the onset and/or during the reproductive phase when the yield reduction is maximum (Table 3) (Lahiri and Kharbanda, 1965; Lahiri and Kumar, 1966; Vyas *et al.*, 1983; Lal *et al.*, 1990). Similarly Lal *et al.* (1990) have shown

Table 3. Growth and yield of sesame plants droughted at different growth stages  
(After Vyas *et al.*, 1983)

Stage	Plant height (cm)	Dry matter (g/plant)	Seed yield (g/plant)
Control	82.5	3.7	1.38
20	82.3	2.6	1.19
30	71.3	1.0	0.90
40	68.6	1.0	0.85
50	82.1	3.0	1.40
60	84.7	2.5	1.16

recovery of pearl millet plants exposed to water stress at anthesis stage was poor. In Thar desert terminal drought is frequent, and yields of rainfed crops are often low as the period of stress coincides with critical period of grain development and maturation. Wherever resources permit life saving irrigation at this critical stage, in the event of drought, may help in restoration of yield. Garg *et al.* (1984c, 1986) showed that on loamy sand soil significantly higher grain yields of pearl millet and clusterbean can be achieved if the drought at the critical stage is avoided through irrigation with saline waters (120 to 160 me/L). Water stress at other stages also reduces the grain yield. In this regard it has been reported that differences in yield between varieties of pearl millet were discernible when soil moisture varied between -0.03 to -0.8 MPa during the growing period but not under more acute stress (Lahiri and Singh, 1970). During 1969 when the total precipitation was only 76 mm no significant differences in dry matter and grain yield amongst pearl millet varieties were recorded (Lahiri, 1980). However, at Jodhpur during 1979 when the soil moisture in the profile progressively declined, the yields were generally low but the differences among varieties were significant (Garg *et al.*, 1981). In pearl millet two repeated cycles of moderate stress at flowering and grain filling stages brought about a significantly larger yield reduction as

compared to a single intense stress at these stages (Lahiri, 1990). Cumulative adverse effect of repeated water stress of high intensity is also reported in wheat (Garg *et al.*, 1984a; Kathju *et al.*, 1990) and sesame (Vyas *et al.*, 1987). Pre-sowing seed treatment like soaking and drying with chemicals has been shown to induce drought tolerance in crops. Misra (1962) evaluated effects of sodium sulphate, sodium chloride, potassium nitrate and ammonium sulphate on wheat and barley and concluded that sodium sulphate, sodium chloride and potassium nitrate effectively induced drought resistance in these cereals. Vyas *et al.* (1990) have reported benefits of water stress at seedling stage on the subsequent stress at critical stage. Sesame plants exposed to moderate water stress at seedling stage overcame the adverse effects of severe moisture stress at the critical stage of onset of flowering. Pre-stressed plants maintained higher levels of sugars, protein, amino acids and higher activities of NR, GDH and GS in the leaves. Earlier Lahiri and Kumar (1966) reported increase in the grain yield of pearl millet due to early drought. Thus it seems both complexion and intensity of drought may modulate the crop performance.

### Metabolic responses to water stress

Soil moisture deficits influence the metabolism, growth and yield of plants through changes in the internal tissue moisture status. In sandy soils, where moisture retention is poor, the development of stress is rapid. Study undertaken by Vyas *et al.* (1985) on sesame at critical stage revealed that during soil drying plant water potential not only remained higher than the water potential of soil, but this difference progressively increased with the increasing period of water deprivation. Furthermore, they found that diverse metabolic derangements increased with increasing stress intensity but all the perturbations were triggered-off simultaneously even under mild stress.

In pearl millet Lahiri and Singh (1968) reported water stress during the initial stages of tissue dehydration increased the soluble nitrogen contents in the tissue due to a decrease in protein synthesis while at a higher stress proteolysis occurred leading to increase in the levels of various fractions of soluble nitrogen. Intense stress led to the accumulation of ammonia in the tissue. But rewatering induced a fast normalisation and ammonia-N disappeared with an associated increase in amide-N suggesting quick incorporation of ammonia into organic acids as a measure against ammonia toxicity. In the absence of soil moisture deficit, hyperthermia may also cause almost similar derangements in nitrogen metabolism (Lahiri and Singh, 1969). Experiments undertaken on sandy soils on crops like pearl millet (Garg *et al.*, 1981, 1984c), clusterbean (Garg *et al.*, 1986), sesame (Vyas *et al.*, 1983, 1985) and wheat (Garg *et al.*, 1984a; Kathju *et al.*, 1990) have also indicated stress mediated changes in various metabolites and enzymes in the shoot tissue which modulated the growth and yield. Thus a substantial knowledge has been generated on the effects of water stress on plant metabolism. Study on loamy sand soil also indicated that the stomatal resistance increased from 1.1 to 14.1 S cm<sup>-1</sup> due to water stress at anthesis on wheat over 8 days when the plant water potential declined from -1.4 to -3.5 MPa. In a similar soil, a close

relationship has been noted between tissue water status and stomatal resistance of sesame irrespective of the soil fertility conditions (Vyas *et al.*, 1987). Thus an obvious effect of water stress on photosynthesis may be easily surmised. In this regard, fast normalisation of nitrate reductase activity on rewatering at post-drought stage has also been reported in both pearl millet and wheat (Lahiri, 1984).

Vyas *et al.* (1996) working on moth bean have concluded that under water stress the normal GS-GOGAT system of ammonia assimilation becomes ineffective, the GDH activity increases, as an adaptive mechanism to detoxify the accumulated ammonia and produce glutamine.

### **Water use and water-use efficiency of crops**

The water use may depend on the availability of moisture in the root zone, growing period of the crop, climatic and management conditions, etc. Water use and WUE of legumes is lower than that of pearl millet (Lahiri, 1977). In pearl millet (Lahiri, 1975) and also legumes (Kathju *et al.*, 1987) an even distribution of rainfall during the growing period rather than its quantum promoted the growth and water use. In pearl millet water use increased from 218 mm with no N to 268 mm at 120 kg N ha<sup>-1</sup>. The WUE increased from 3.54 kg ha<sup>-1</sup> mm<sup>-1</sup> at N<sub>0</sub> to 4.83 kg ha<sup>-1</sup> mm<sup>-1</sup> at N<sub>120</sub> with a maximum of 5.38 kg ha<sup>-1</sup> mm<sup>-1</sup> at N<sub>60</sub> (Krishnan *et al.*, 1981). In groundnut wider spacing increased the WUE during the low rainfall year while closer spacing increased it in high rainfall year (Bhan and Misra, 1970). Groundnut grown at 30 cm spacing rapidly depleted the soil moisture. In plots where plants were grown at 45 and 60 cm row spacing maintained soil moisture at high level and plants maintained favourable internal tissue moisture (Bhan, 1973). Similarly in low rainfall year water use and WUE were reduced to a very low values without any discernible effect of N fertilisation while in a good year the situation was completely reversed (Lahiri, 1980).

### **Root growth**

The extent of root growth may depend on the crop and the soil physical and moisture conditions. The differences in root growth have been studied in a number of crops (Yadav and Gupta, 1977) and water extraction from soil was closely correlated with the distribution and extent of root system (Joshi, 1988).

### **Drought fertility interaction**

Under conditions of sporadic drought, crop may experience intermittent dry and wet phases. Under such situations benefits of fertiliser are apparent, though the extent of yield improvement may be less as compared to well watered crop. Under stored soil moisture conditions, where soil moisture declined progressively, number of factors like initial soil moisture, root growth and moisture use pattern of crop may influence the effects of fertiliser. However, under situations where soil moisture remains perpetually low, the advantages of fertiliser application are uncertain. In groundnut application of 20 kg N ha<sup>-1</sup> and 30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> not only helped in better extraction of soil moisture but also HF plants maintained higher leaf water potential (Bhan, 1973).

Some of the factors conducive for fertiliser induced improvement in yield include: (a) a high transpiration rate at post-drought stage (Lahiri and Kharbanda, 1966) and as a consequence higher nitrate uptake, (b) fast post-drought normalisation of nitrate reductase activity particularly under high level of soil N (Lahiri, 1984), (c) fast restoration of N metabolism associated with fast normalisation of protein-N in the tissue during recovery from stress (Lahiri and Singh, 1968), (d) unaltered N uptake under different soil moisture regimes (-0.03 to -0.1 and -0.03 to -0.8 MPa cyclic soil moisture) except under acute stress (-0.03 to -0.1 and -0.03 to -1.5 MPa) and the unchanged two peak nature of the N uptake rate curve of pearl millet (Lahiri and Singh, 1970), and (e) the improvement of tolerance to drought imposed at different growth stages of pearl millet, clusterbean and mung bean and moth bean under improved soil fertility (Lahiri *et al.*, 1973; Lahiri, 1978; Lahiri and Kacker, 1985). It was observed that tissue hydrature was the not only index of metabolic efficiency because in desiccated wheat leaves of identical tissue water status, the activities of enzymes like amylase, acid phosphatase, ATPase and also the level of chlorophyll remained higher in plants grown under high soil fertility as compared to those grown under low fertility (Kathju and Lahiri, 1976). In wheat also soil fertility alleviated the growth and yield under two successive drought cycles at various developmental stages and this was related to larger root growth and greater post-drought nutrient uptake and not to any favourable tissue water modulations (Garg *et al.*, 1984a). In this context favourable moisture interlude after the stress and not the intensity of stress has been considered to have importance (Table 4). For example, in sesame and also wheat longer favourable wet period between two drought cycles lessen the cumulative adverse effects (Vyas *et al.*, 1991; Lahiri *et al.*, 1992). The benefits of fertiliser were also more when this wet period was longer (Vyas *et al.*, 1991). In sesame improved soil fertility increased the dry matter, seed yield and nutrient uptake under one or two cycles of drought compared to LF plants (Table 5), in spite of HF plants having lower plant water potential, RT and higher diffusive resistance (Vyas *et al.*, 1987). But these benefits of fertiliser applications were not apparent when crop experienced more severe stress. It thus appears that the metabolic efficiency may depend more on the nutritional status rather than on the water content of the tissue, at least upto a critical limit. The overall issue is rather complex as it is not known whether the adverse effects of drought are mediated through a deficiency of water or of nutrients. In mustard fertiliser N increased seed yield, WUE, nutrient uptake coupled with increased levels of chlorophyll, starch, reducing sugars, proteins and amino acids despite greater decline in plant water potential at all levels of soil moisture mainly due to the maintenance of ammonia assimilation (Vyas *et al.*, 1995).

In wheat maintained at -0.6 MPa throughout the growth period the nitrogen and phosphate application increased the dry matter accumulation and also absolute quantities of N, P and K in the tissue. Similarly in wheat grown from 20 DAS till maturity at a fixed soil moisture of -0.03, -0.3, -0.6 and -0 MPa, a progressive increase in N and P from 0-120 kg ha<sup>-1</sup> showed a progressively larger dry matter production and K uptake at all points of soil water potential (Lahiri and Kacker, 1985).

Table 4. Influence of favourable soil moisture between drought events on yield on yield of wheat

Favourable moisture period (days)	Grain yield (g plant <sup>-1</sup> )	Drymatter yield (g plant <sup>-1</sup> )
0 (control)	3.58	5.10
3	0.65	2.70
6	0.86	2.77
9	1.40	2.84
12	1.53	3.09

(Lahiri *et al.*, 1992)

Table 5. Effect of drought cycles on seed yield and dry matter production of sesame plants grown at low and high soil fertility

Drought cycle	Seed yield (g plant <sup>-1</sup> )		Drymatter (g plant <sup>-1</sup> )	
	LF	HF	LF	HF
control	0.55	0.51	3.65	3.65
1 cycle	0.43	0.61	2.40	2.40
2 cycle	0.31	0.56	1.85	1.85
3 cycle	0.21	0.81	1.70	1.70

(Vyas *et al.*, 1987)

Wherever available, application of life saving/supplemental irrigation, in the event of onset of water stress due to inadequate rainfall, may improve crop yield both under low and high soil fertility conditions. It is concluded that a conservative limited irrigation coupled with soil fertilisation may be beneficial in drought prone areas (Kathju *et al.*, 1993).

#### Plant growth regulators and water stress

Plant growth retardants have been known to influence the drought tolerance of plants. These growth regulators reduce plant growth, and also leaf area, thus reducing the water losses through transpiration. Studies have been conducted on the effects of growth retardants on plant growth, water use and WUE. Foliar application of morphactin did not improve the pearl millet growth and yield under low soil moisture regime and did not impart any efficiency of water use for grain production (Kackar *et al.*, 1978). Similarly cycocel (CCC) also did not improve yield of wheat crop both under adequate and low soil moisture levels (Kathju *et al.*, 1980). It seems that reduced growth and leaf area reduced the CO<sub>2</sub> assimilation, thus adversely affecting the yields.

## Salt Stress

Among arid legumes clusterbean has been reported to be relatively more tolerant to salt stress as compared to mung bean and moth bean. In clusterbean significant yield reduction has been reported only at  $6.0 \text{ mmhos cm}^{-1}$  and at higher levels (Table 6). The salts like NaCl,  $\text{Na}_2\text{SO}_4$  and  $\text{NaHCO}_3$  reduced the activity of nitrate reductase (NR) but activities of pyrophosphatases increased in these legumes (Garg *et al.*, 1996).

In clusterbean flowering stage was the most susceptible to salt stress and at this stage reduction in seed yield was the maximum (Table 7), however, dry matter was affected more due to salinity at the seedling stage (Garg *et al.*, 1997b). Critical salinity level at which clusterbean growth and yield is significantly reduced has been quantified to be  $6 \text{ mmhos cm}^{-1}$ . Although leaf metabolism is affected even at  $4 \text{ mmhos cm}^{-1}$ . Increasing soil salinity progressively increased the concentration and uptake of Na. It is concluded that clusterbean crop is suitable for cultivation in salt affected areas under summer fallow (Lahiri *et al.*, 1987). Working on wheat Garg *et al.* (1983) concluded that  $\text{Na}_2\text{CO}_3$ ,  $\text{NaHCO}_3$  and NaCl were the most detrimental for growth and yield of wheat while  $\text{Na}_2\text{SO}_4$  and KCl were less detrimental. Carbonate and bicarbonate influenced the activity of enzymes of nitrogen metabolism. In clusterbean NaCl has been shown to reduce growth and yield with decreased concentration of K and Ca and increased Na concentration in the tissue. These adverse effects have been shown to be ameliorated by Ca application (2.5 and 5.0 mM) due to enhanced Ca and K uptake and reduced Na uptake coupled with restoration of activity of enzymes of N metabolism (Garg *et al.*, 1997a).

Table 6. Influence of soil salinity on growth and seed yield of clusterbean

Salinity level ( $\text{mmhos cm}^{-1}$ )	Plant height (cm)	Seed yield (g plant <sup>-1</sup> )
0	54.6	4.50
2	53.6	4.26
4	49.9	3.90
6	47.6	3.66
8	45.1	3.50
10	43.6	3.00
LSD 5%	4.8	0.73

After Garg *et al.*, 1987

Nitrogen has been shown to improve the growth and yield of certain crops under salt stress. In wheat this fertiliser induced improvement under salt stress has been shown to be due to increased concentration of N, P and K and decrease in chloride in the tissue. Both under normal and saline conditions, nutritional improvement led to higher chlorophyll concentration and increased efficiency of enzymes like NR, ATPase, alkaline pyrophosphatase and amylase in the leaves

(Garg *et al.*, 1982). In another study Garg *et al.* (1990) reported significant increase in growth and yield under saline water irrigation both in salt tolerant (Kharchia-65) and sensitive (HD-2009 and HD-4502) wheat varieties. In mustard also detrimental effects of salinity were less in plants grown under HF condition (Garg *et al.*, 1993). Mustard plants grown at high soil fertility gave higher yields at all levels of salinity as compared to those grown under low soil fertility (Table 8). Significant salinity-fertility interaction has also been reported at biochemical plane in mustard (Sharma *et al.*, 1989).

Table 7. Effect of salinity at different growth stages on seed yield and dry matter production of clusterbean

Growth stage	Seed yield (g plant <sup>-1</sup> )	Drymatter (g plant <sup>-1</sup> )
Control	2.07	9.93
Seedling	1.75	6.30
Vegetative	1.77	7.53
Flowering	1.41	8.78

(After : Garg *et al.*, 1997b)

Table 8. Influence of soil fertility on grain yield of mustard grown under saline water irrigation (Garg *et al.*, 1993)

Salinity level (meq L <sup>-1</sup> )	LF	HF
0	2.13	2.47
50	1.81	2.23
100	1.30	1.94
150	0.81	1.09

Garg *et al.* (1984) while studying relative effects of salinity (NaCl) and water stress on growth, yield and metabolism observed that pearl millet suffers more from salt rather than water stress under a comparable osmotic condition. In another study it was shown that significantly higher dry matter and grain yield can be achieved if the water stress is avoided through irrigation with substandard waters (160 meq L<sup>-1</sup>). The metabolic derangements due to water stress were slow to normalise when plants were irrigated with saline water (Garg *et al.*, 1984c).

Similarly in clusterbean studies on plant water potential, leaf metabolism including levels of chlorophyll, carbohydrate, proline and activities of enzymes, revealed that the adverse effects were far greater in droughted plants revived with saline water as compared to those which suffered only salt stress. Based on these studies Garg *et al.* (1986) concluded that since drought

and salt stress had cumulative adverse effects it may be advantageous to irrigate crop with saline water before onset of severe stress at the critical stage.

### Shade Stress

Crops grown with trees or under intercropping are often exposed to shade stress. Vyas *et al.* (1996) have studied the effects of shade on clusterbean genotypes. Shade increased the internal tissue moisture, levels of chlorophyll, proline and amino acids and activities of NR, GDH, GS at 25 per cent shade. However, activity of GOGAT decreased under shade. Genotype Suvidha was benefited the most due to shade.

### Heat Stress

Plants in the arid region are often exposed to high temperature stress that influences the crop production adversely. Lahiri and Singh (1969) have studied the effect of high temperature stress on N metabolism in 3-week old pearl millet plants exposed to 48°C. High temperature stress triggered off proteolysis leading to accumulation of amino acid nitrogen. During hyperthermia initially ammonia formed was neutralised with organic acids, and accumulated only 12 to 24 hours after imposing treatment which caused injury. The authors have suggested increased organic acid production under hyperthermia to be a basis for heat hardiness in plants. Exposure of pearl millet leaves to high temperature (60°C) for 60 minutes inactivated the hydrolytic enzymes like phosphatases and invertase. The plants grown at high soil fertility have been shown to maintain higher enzyme activity despite temperature stress (Lahiri and Kathju, 1973).

## Integrated Nutrient Management

### Soils

Soils of the arid region have been classified in the 16 major series. Their important characters are given in Table 9.

Table 9. Major soil series of Indian arid region

Series/ FAO Classification	Surface Characteristics					LCS	PP	Area (000 ha)
	Texture	Structure	pH	OC%	Total N%			
Chandawal								
Eutric Cambisols	fsl	sbk	8.3	0.10	0.028	III	M	61.7
Chirai								
Calcaric cambisols	lfs, fsl	sbk	8.0	0.11	0.035	VI	L-M	eak
Dhabar								
Haplic Calcisols	sl	sbk	8.1	0.12	0.032	III	H	41.6
Dune								
Eutric Arenosols	s	sg	8.4	0.08	0.021	VIII	L	4283.3



Gajsinghpura								
Eutric Cambisols	siel	sbk	8.3	0.30	0.049	III	M	98.7
Jadan								
Eutric Cambisols	l,cl	sbk	8.3	0.54	0.063	III	M	392.0
Jaitaran								
Haplic Arenosols/								
Eutric Cambisols	sl	sbk	8.5	0.40	0.051	III	M	eak
Kolu								
Petric Calcisols	ls,sl	sg	8.2	0.18	0.042	IV	L	eak
Masitawali								
Eutric Fluvisols	fsl	gr	8.0	0.16	0.044	IV	M	eak
Molasar								
Eutric Arenosols	ls	sg	7.9	0.12	0.032	IV	L	654.8
Pal								
Eutric Cambisols	sl	sbk, gr	8.4	0.22	0.042	IV	L	136.9
Pali								
Calcaric Cambisols	l	gr	8.1	0.37	0.056	IV	M	58.3
Panchroli								
Calcaric Cambisols	ls	sbk	8.2	0.29	0.031	IV	L	99.9
Parbatsar								
Eutric Cambisols	sl	sbk	7.4	0.22	0.034	IV	M	99.7
Pipar								
Calcaric Cambisols	sl	sbk	8.1	0.23	0.029	IV	L-M	127.0
Shobhasar								
Eutric Cambisols	s	sg	8.5	0.08	0.016	III	M	eak
Thar Eutric	ls	sg	8.0	0.10	0.021	VIc	L-M	eak
Arenosols								

## Abbreviations

- Texture : s-sand, ls-loamy sand, lfs-loamy fine sand, sl-sandy loam, l-loam, fsl-fine sandy loam, cl-clay loam, siel-silty clay loam
- Structure : sbk-sub angular blocky, gr-medium granular, sg-single grain
- Land class : LCS-Land capability subclass
- Productivity : PP-Productivity potential; L-low, M-medium, H-high
- Distribution : eak-extensive but exact area not known

Source: Praveen-Kumar and R.K. Aggarwal (1997)

### Fertility status of soils

Fertility status of soils of arid region is low. N status in soils of most of the districts ranges from very low to low, P low to medium while K ranges from medium to high (Table 10).

Table 10. Fertility status of soils in arid districts of Rajasthan  
(classification as per nutrient index).

	Sharma <i>et al.</i> (1966)	Mehta <i>et al.</i> (1967)	Dhir and Singh (1985)
Barmer	LMM	LMH	VLMM
Bikaner	MMM	LMM	VLMM
Churu	LMM	LMM	VLMM
Ganganagar	LMH	LMH	VLMM
Jaisalmer	LLM	LLH	VLMM
Jalor	LMM	LMH	LMM
Jodhpur	LMM	LMM	LMM
Jhunjhunu	LMH	LMM	VLMM
Nagaur	MMH	LMM	LMM
Pali	MMH	LMM	LMM
Sikar	LMH	LMH	VLMM

VL - very low; L - low; M - medium; H - high

### Nitrogen

In arid soils status of N is low because of low clay content, hot climate and low rainfall (Jenney and Raychaudhury, 1960; Dhir, 1977). The mean organic carbon content in the arid soil ranges from 0.05 per cent to 0.2 per cent in coarse, 0.2-0.3 per cent in medium and 0.3-0.4 per cent in fine textured soils. Aggarwal and Lahiri (1981) reported higher soil organic C and narrow C:N ratio in stabilised dunes as compared to unstabilised dunes. Dhir and Gajbhiye (1973) observed higher humus content in the soil near the grass clump in the pastures lands, which decreased with increasing distance.

Soil organic matter is the largest reservoir of N in arid ecosystem. Vegetation contain 5-10 per cent of the total N found in the arid ecosystem as against nearly 15 per cent in deciduous forest and 2 per cent in grasslands (Wallace *et al.*, 1978). Joshi (1993) reported low N contents in the arid soil of Rajasthan. In the soils of Gujarat also the content of organic carbon and total N was reported to be low ranging from 0.16-0.34 per cent and 0.021-0.056 per cent respectively (Joshi *et al.*, 1989). Aggarwal *et al.* (1977, 1990) reported that the major part of N in the aridisols of Rajasthan was in organic form, of which the acid hydrolysable N constituted about 62-87 per cent of the total N. Amongst the different fractions the order of distribution was amino acid > unidentified N > amonical N > hexoseamine N (Praveen-Kumar and Aggarwal, 1997). Amino

acid and hexoseamine fractions often contribute more towards total hydrolysable-N in the fine textured soils than the unidentified fraction. Although absolute amount of hydrolysable-N decreases with depth, but when expressed as per cent of total N, it generally followed an opposite trend. Vegetation also alters the distribution of organic N fractions. Cultivation of field legumes or growing of leguminous trees increases the build up of hydrolysable N fraction (Aggarwal and Praveen-Kumar, 1993; Aggarwal *et al.*, 1993; Praveen-Kumar *et al.*, 1997). Higher status of total N as well as hydrolysable fractions was observed under the canopy of *Prosopis cineraria*. The level and distribution of  $\text{NO}_3\text{-N}$  in the soil profile is subjected to seasonal fluctuations. In the arid soils of Jodhpur the concentration of  $\text{NO}_3$  in the upper layer of soil increased from nearly 3 ppm in winter to more than 5 ppm in summer (CAZRI 1989-90). The fluctuations in the concentration in the lower depths were not marked until rainy season.

Under natural conditions N is added in soil through rainfall and biological N fixation. Rainfall contribute around  $12.5 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  on a world wide basis (West, 1975). Aggarwal *et al.* (1982) reported the N deposition as precipitation ranged from 5.47 to  $10.06 \text{ kg ha}^{-1}$  in the arid regions of India. Nearly the same range was reported by Vlek (1981) for arid regions of USA. Contribution of biological N fixers is estimated to be less. In arid zone to be nearly  $3.6 \text{ Kg N ha}^{-1} \text{ yr}^{-1}$  (West, 1975).

### Phosphorus

Ram Deo and Ruhai (1972) reported that light textured soils of arid zone had 285 ppm of total phosphorus as compared with 327 to 450 ppm in soils of semi-arid zones of Rajasthan. Phosphorus occurs in variety of forms, fixed with varying intensity to the individual soil constitutes. The studies of Ram Deo and Rahul (1972), Pareek and Mathur (1969), Talat *et al.* (1975) showed that 40 to 50 per cent of total phosphorus in arid soils in general and upto 72 per cent Ghaggar alluvium soil is bound to calcium. However, these soils still contained appreciable amounts of aluminium and salloid bond phosphorus.

### Potassium

Soils of arid zone are generally well supplied with potassium. Dhawan *et al.* (1968) and Choudhry and Pareek (1976) have shown that with the exception of a few localities the total potassium is between 825-1890 mg/100 g soil. Water soluble and exchangeable potassium together form 1.5 to 2 per cent of the total potassium and therefore, by far the major proportion is present in a non-exchangeable fixed form or partly as primary mineral lattice.

### Micronutrients

Total zinc content ranged from 5.0 to 95.2 ppm and available zinc from 2.0 to 4.83 ppm in Rajasthan soils (Seth *et al.* 1971; Lal and Biswas, 1973). Dhir (1977) reported the average content of available zinc, 2.07 ppm in arid soils. The total copper content of the soil profile in Jodhpur varied from 10.0 to 11.5 ppm (Dhir, 1977). Seth *et al.* (1971) reported the variation in total copper

content from 19.6 to 228.48 ppm in desert soils, while the available copper varied from 0.21 to 4.28 ppm. Lal and Biswas (1973) reported 0.12 to 0.28 ppm of available copper in the Rajasthan soils. Dhir (1977) reported a decrease in water soluble iron content with the depth from 0.95 ppm in the surface 0.2 cm layer to 0.03 ppm at 170 cm depth. Lal and Biswas (1973) observed available iron to range from 0.3 to 5.6 ppm with an average of 2 ppm in desert soils. Seth *et al.* (1971) found that total manganese content in arid zone soils ranged from 212 to 437 ppm. Of this, on an average 6 ppm was in the available form, which is adequate for plants as per the existing criteria of 5 ppm.

### Response of crops to nutrient addition

Due to low availability of N from soils, application of N is often necessary to achieve high yields. However, response to phosphorus application is often limited (Table 11). The level of fertiliser application is determined by the fertility status of soil (Table 12).

Table 11. Response of different crops to fertiliser application (kg grain kg<sup>-1</sup> nutrient)

Nutrient/crop		Response
Nitrogen	Pearl millet	7.5-18.0
	Sesame	4.0-14.7
Phosphorus	Clusterbean	4.2-5.3
	Greengram	1.4-4.1
	Moth bean	0.0-0.9
	Pearl millet	1.3-17.1
	Sesame	1.0-2.7

Sources: Daulay and Singh (1978), Kathju *et al.* (1987), Singh *et al.* (1978a)

Table 12. Optimum nutrient quantity required for different crops under varying soil fertility conditions

Crop	LMH			LMM			LHH			LLH			LLM		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Bajra (Hybrid)	44.8	33.6	-	44.8	33.6	-	44.8	-	-	44.8	44.8	-	44.8	44.8	-
Jowar (Hybrid)	44.8	33.6	-	44.8	33.6	-	44.8	-	-	44.8	44.8	-	44.8	44.8	-
Gram	11.2	33.6	-	11.2	33.6	-	11.2	22.4	-	11.2	44.8	-	11.2	44.8	-
Cotton	67.2	56.0	-	67.2	56.0	33.6	67.2	33.6	-	67.2	67.2	-	67.2	67.2	-
Groundnut	16.8	28.0	-	16.8	28.0	-	16.8	22.4	-	16.8	33.6	-	16.8	33.6	-
Oilseeds	28.0	11.2	-	28.0	11.2	-	28.0	-	-	28.0	16.8	-	28.0	16.8	-
Clusterbean	11.2	28.0	-	11.2	28.0	-	11.2	22.4	-	11.2	33.6	-	11.2	33.6	-
Wheat	44.8	33.6	-	44.8	33.6	33.6	44.8	22.4	-	44.8	44.8	-	44.8	44.8	33.6
Barley	33.6	22.4	-	33.6	22.4	-	33.6	-	-	33.6	33.6	-	33.6	33.6	-
Fodder	33.6	-	-	33.6	-	-	33.6	-	-	33.6	-	-	33.6	-	-

(Kharif/Rabi)

Source : Mehta *et al.* (1967)

### Response to fertiliser application

Misra (1971) reported higher yields with the combined application of N and P as compared to application of individual nutrients. Mann and Singh (1977) reported yield increase of the order of 35 to 150 per cent with the application of 40 kg N along with 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in good rainfall years. A three year study revealed that maximum grain yield of pearl millet was recorded with combined application of 60 kg N, 30 kg P<sub>2</sub>O<sub>5</sub> and 15 kg K<sub>2</sub>O ha<sup>-1</sup> was made (CAZRI, 1978). However, the response to phosphorus application on grain yield was not observed in some other studies, while it significantly increased the straw yield (Table 13).

Table 13. Effect of fertiliser application on pearl millet yield

Treatments		Yield q ha <sup>-1</sup>	
N	P	Grain	Straw
kg ha <sup>-1</sup>			
0	0	7.37	25.18
45	0	13.12	31.57
90	0	17.44	32.45
45	20	12.19	35.31
90	20	18.21	38.16
45	40	12.58	35.90
90	40	18.60	39.31
Mean		14.29	33.98

Source : AICMIP (1984-85)

Pearl millet varieties differ in their response to N application. Vyas *et al.* (1972) reported N optima of 23.3 kg N ha<sup>-1</sup> for local varieties, while hybrids responded to even higher N levels. Singh *et al.* (1974), Panjab Singh (1977) and Singh *et al.* (1978b) reported 40 kg N ha<sup>-1</sup> as an optimum dose for HB-1 and HB-3. Joshi (1984) reported considerable variation in nitrogen optima between years and among varieties due to variations in quantum and distribution pattern of rainfall. Range of variation in N optima of local was 58.25-65.53 kg ha<sup>-1</sup> and varied from 57.14-62.57 and 69.25-80.93 for BJ 104 and BD 111 respectively. Variations in N optima were also recorded by Joshi and Kalla (1986) in local, BJ 104, BD 111, CM 46 and PHP 12. Results of a study in 1984 with different breeding materials of pearl millet showed that response of RCB-2 and WC-C-75 varied from 5.3 to 6.8 and 8.6-12 kg grain kg<sup>-1</sup> N while ICMS-7703 did not respond to fertiliser application (AICMIP, 1984-85). Similarly response of HHB-67 varied from 7.30 to 8.93 while of Raj-171 varied from 10.3-16.83 kg grain kg<sup>-1</sup> N (AICMIP, 1996).

### Integrated use of fertilisers with manures/crop residues

In view of high cost of chemical fertilisers and uncertain yield crop response in this climate, Aggarwal and Venkateswarlu (1989) suggested the supplementation of chemical fertilisers, with bulky organic manures. Singh *et al.* (1981) observed that under arid conditions of Jodhpur

continuous application of sheep manure in general gave substantially higher yields than the application of urea alone (Table 14). Rao and Singh (1993) showed that substitution of 50 per cent of fertiliser requirement by FYM resulted in yield levels nearly similar to those obtained with complete fertilisation. Aggarwal and Praveen-Kumar (1996) on the basis of a seven year study (1983-89) on arid soils showed not only a beneficial effect of FYM application alone but also a synergistic effect of simultaneous application of FYM and inorganic fertilisers on crop yield. FYM application increases the utilisation efficiency of fertiliser N, however, improvement in soil fertility after FYM application is a very slow process.

Table 14 . Grain yield of pearl millet as affected by FYM and inorganic nitrogen (average 1975-79)

Treatment	Grain yield (q ha <sup>-1</sup> )
Control	8.8
20 kg N/ha(Inorganic) every year	13.9
40 kg N/ha(Inorganic) every year	16.0
40 kg N/ha(Inorganic) once in two years	14.1
10 tons FYM + 10 kg N/ha (Inorganic) every year	15.4
20 tons FYM once in two years	15.4
40 tons FYM once in two years	17.8

Source: Singh *et al.* (1981)

Praveen-Kumar and Aggarwal (1997) did not find any significant change in the yield of succeeding crop of pearl millet after addition of crop residues with wide C:N ratio, whereas incorporation of residues with narrow C:N ratio significantly improved the yield (Table 15).

Table 15. Effect of crop residues, farmyard manure and fertiliser N on grain yield of pearl millet (kg ha<sup>-1</sup>) and utilisation efficiency of fertiliser N (average of two years)

Fertiliser N (kg ha <sup>-1</sup> yr <sup>-1</sup> )	No residue	Residue (t ha <sup>-1</sup> yr <sup>-1</sup> )			FYM (2.00)
		CB (1.66)	PM (1.41)	GG (2.72)	
Grain Yield (kg ha <sup>-1</sup> )					
0	3.35	5.15	4.30	4.35	5.30
20	5.05	6.25	5.40	5.45	6.35
40	5.50	7.15	5.85	6.55	7.70
NUE (% of applied N)					
20	30.10	57.52	38.71	30.71	56.52
40	20.03	35.93	26.26	18.49	39.87

CB - Clusterbean; PM - Pearl millet; GG - Greengram; FYM - Farmyard manure

Incorporation of crop residues into soil has been reported to increase the organic matter content of soil (Aggarwal *et al.*, 1997). Hegde *et al.* (1982) reported higher organic carbon and

available P and K content in soil after 5 years of continuous incorporation of maize residues in soil.

### **Economics of pearl millet production and fertiliser application**

Results of studies conducted during 1977-80, a hectare of pearl millet crop on an average yielded gross income of Rs. 409, which after covering the total cost of cultivation resulted into a net income of Rs. 122 per hectare (Singh, 1982). There were wide variation in income from year to year. The year 1977-78 was favourable to the farmers in respect of income and yields while farmers incurred loss in 1978-79 but could, however, manage to meet the cost in 1979-80 (Table 19). It may be pointed out that in the environment of uncertainty, in spite of incurring loss in unfavourable years, farmers can earn some income over the period. The large income of a single favourable year more than offset the loss of unfavourable years and also leave some surplus to the farmers.

### **Significance of Microbial Inoculants in Crop Production**

Microorganisms play an important role in various biochemical transformations in soil thus influencing the availability of nutrients such as nitrogen, phosphorus, sulphur, etc. to the plants. Low precipitation, high temperatures coupled with intense solar radiation and poor fertility status of arid soils restrict the growth and activities of different microorganisms (Venkateswarlu and Rao, 1981). They further reported the occurrence of very low populations of microorganisms in Indian desert soils as compared to other tropical soils. Because of low generation time and higher probability of selection through spontaneous mutations, microorganisms survive better in these soils compared to the higher forms of life. Microbiological properties of Indian arid soils varied with land use pattern, soil moisture status, soil organic matter content, etc. (Rao and Venkateswarlu, 1983). Stabilisation of sand dunes through the introduction of vegetation significantly improved the populations of different microorganisms and status varied with the degree of stabilisation. Sankaran (1980) reported the occurrence of blue green algae belonging to genera *Aphanotheca*, *Phormidium*, *Microcoleus*, *Nostoc*, *Oscillatoria*, *Chlorococcum*, etc. in Indian desert soils and it was found that these algae help in checking soil erosion through soil aggregation and promoting fertility status (N-content through fixation) of desert soils.

### **Biological Nitrogen Fixation**

Among different free living nitrogen fixing bacteria *Azotobacter* is predominantly present in different Indian desert soils (Rao and Venkateswarlu, 1983).but in low numbers. Nitrogen fixing ability on arid soils varied from each other and is related to the population of *Azotobacter* (Rao and Venkateswarlu, 1983). With cropping or addition of organic matter or improving the soil moisture content, significant increase in its population were observed along with enhancement in soil nitrogen. It was observed that non symbiotic nitrogen fixation could account for only about 2

kg N ha<sup>-1</sup> yr<sup>-1</sup> but may go upto 15 kg depending upon the cropping pattern, organic matter status and soil moisture content (Rao and Venkateswarlu, 1982).

### **N<sub>2</sub>-fixation through *Azospirillum***

The most popularly recognised input of nitrogen in the arid ecosystem is rhizospheric N<sub>2</sub>-fixation associated with non-legumes including succulent xerophytes (Rao and Venkateswarlu, 1982a, b). These bacteria are heterotrophs and depend on an outside carbon source to fix nitrogen forming a loose or para-symbiotic condition on the surface of the roots or growing in the outer layers of the root tissue as ecto-trophic organisms or endo-trophic organisations. The bacteria isolated from the roots of different arid zone plants ranging from grasses to xerophytes were found to be *Azospirillum* and efficiency of these strains varied in their N<sub>2</sub>-fixing potential from one another. Rao and Tarafdar (1990) reported that the strains of *Azospirillum* isolated from arid zone plants were found to be tolerant to chlorides and sulphates but sensitive to carbonates. Being a microaerophilic, a reducing compound, glutathione has been suggested to be included in the liquid medium for the cultivation of *Azospirillum* (Venkateswarlu and Rao, 1983).

Upon seed inoculation of pearl millet, *Azospirillum* was found to be established in both rhizosphere, rhizoplane and within the outer-layers of the root tissue. Root exudates and extracts of pearl millet showed a stimulatory effect on this bacterium (Rao and Venkateswarlu, 1985). N<sub>2</sub>-ase activity of the inoculated pearl millet plants differed among the varieties and was related to the amount of organic carbon released in the root exudates (Rao and Venkateswarlu, 1986). However, the carbon compounds present in the root exudates were found inadequate for the optimum growth in the root zone and, growth and N<sub>2</sub>-ase were directly proportional to the amount of organic carbon exuded. Based on the facts it was further suggested that breeding of pearl millet varieties should be made to select/evolve a variety having higher organic carbon in root exudates for a successful establishment of *Azospirillum* pearl millet association (Rao and Venkateswarlu, 1987). Biomass production and grain yields of pearl millet were enhanced significantly upon seed inoculation with efficient strains of *A. brasilense* (Joshi and Rao, 1989). Inoculation effect was reduced at higher doses of nitrogen fertiliser (Table 16). About 13-20 kg N ha<sup>-1</sup> can be saved in pearl millet. Rao and Venkateswarlu (1988) observed that these cultures can be more useful in enhancing the production of arid zone grasses (*Cenchrus ciliaris* and *Lasiurus indicus*) by 10-15 per cent. Thus the associate symbiotic nitrogen fixing bacteria play a significant role in crop production. Besides nitrogen fixation, enhancement in the crop production was attributed to the production of growth regulators, viz., auxins, gibberellins and cytokinins (Venkateswarlu and Rao, 1983).

### **Legume-*Rhizobium* symbiosis**

Symbiotic nitrogen fixation through Legume-*Rhizobium* association is most popular in any ecosystem. Nodulation of legumes in aridisols is poor and sometimes absent due to lack of suitable conditions of temperature and moisture, the absence of proper endophyte (Anonymous,



1980) and due to limited root system (Venkateswarlu *et al.*, 1981). Clusterbean and moth bean are the two important grain legumes growing in the rainy season. Arid legumes show genetic variability in nodulation and nitrogenase activities among different varieties (Khurana *et al.*, 1978; Rao *et al.*, 1984). FS-277 in cluster bean and Jodhpur local in moth bean were found to be the best among different varieties. No apparent relation was established between nodulation and nitrogen fixing ability with the grain yield in both these legumes.

In general arid legumes tolerate higher intensities of water stress because of their adaptation and growth characteristics (Venkateswarlu *et al.*, 1983). Water stress had not induced any change in the nodule number but caused a significant reduction in nodule fresh weight.  $N_2$ -ase activity was significantly reduced at both vegetative and flowering stages. Upon rewatering, rapid recovery in the activity was noticed. But recovery was faster at vegetative stage compared to that observed at flowering stage. The threshold limits of nitrogenase activity (The plant water potential beyond which no activity could be detected) were found to be -2.4, -2.2 and -1.8 MPa in clusterbean, mung bean and moth bean, respectively (Rao and Venkateswarlu, 1987). The possible approaches for alleviation of moistures stress effects or increasing the stress tolerance could be through the manipulation of micro-symbiont/host plant and the symbiotic system (Lahiri and Rao, 1989). Besides, agrotechniques such as mulching which ensures favourable soil moisture conditions under drought may also help in enhancing  $N_2$ -fixation resulting in higher dry matter production even under drought conditions (Gupta and Rao, 1989).

Table 16. Grain and stover yield of pearl millet as influenced by inoculation with *Azospirillum*

Treatment	Grain(kg ha <sup>-1</sup> )	Stover(kg ha <sup>-1</sup> )
0 N	515	737
0 N+inoculation	718 (39.4)	1387(88.2)
13 kg N	716	1664
13 kg N+inoculation	851 (18.8)	1944 (17.5)
20 kg N	852	1972
20 kg N+inoculation	1008 (16.3)	2279 (15.6)
40 kg N	1084	2448
40 kg N+inoculation	1044 (-3.7)	2430 (-0.7)
LSD(P=0.01)	104	304

(Joshi and Rao, 1989)

Figures in parentheses indicate per cent increase or decrease over control.

Upon seed inoculation with efficient strains of *Rhizobium*, biomass production and grain yields of arid legumes were significantly enhanced over uninoculated control (Table 17). Increase in yields varied from 8-15 per cent over control depending upon intensity and distribution of rainfall. These legumes fix about 30-70 kg N ha<sup>-1</sup> and a residual effect is equivalent to about 15-

20 kg N ha<sup>-1</sup> (Rao and Venkateswarlu, 1983b). On contrary, Chauhan and Bajpai (1979) could not observe any enhancement in biomass production and grain yield of cluster bean upon inoculation. But Singh (1977a) reported that rhizobia inoculation alone obviates the need for fertiliser nitrogen and phosphorus in mung bean under natural conditions. It is a common practice among farmers to adopt crop rotation to improve soil fertility. Rao *et al.* (1995) conducted detailed studies on the effect of legume cultivation for different periods on biological fertility of soil and pearl millet production (Table 18).

Table 17. Effect of rhizobial inoculation on yields of legumes during normal rainfall years

Parameter	Clusterbean		Moth bean	
	Control	Inoculation	Control	Inoculation
Nodule No. Plant <sup>-1</sup>	6.2	20.7	4.5	13.8
N <sub>2</sub> -ase activity*	0.89	3.72	0.62	2.69
Grain yield (kg ha <sup>-1</sup> )	457	523 (14.4)	348	410 (17.8)
Straw yield (kg ha <sup>-1</sup> )	959	1180 (23.2)	689	828 (20.2)

Figures in parentheses indicate per cent increase over control  
( $\mu\text{moles C}_2\text{H}_4 \text{ plant}^{-1} \text{ hr}^{-1}$ )

Table 18. Grain and straw yields of pearl millet after 3 years of crop rotation (Rao *et al.*, 1995)

Rotation	Yield (kg ha <sup>-1</sup> )	
	Grain	Straw
F-PM-F	340	1680
PM-PM-PM	380	1760
MB-PM-MB	440	1900
CB-PM-CB	530	1980
F-MB-MB	560	1940
F-CB-CB	530	1940
MB-MB-MB	630	2200
CB-CB-CB	680	2320
LSD(P=0.05)	80	310

F: Fallow; PM: Pearl millet; MB: Mung bean; CB: Clusterbean

### Microbial Mobilisation of Soil Phosphorus

Arid soils contain a high amount of phosphorus, i.e. 557-729 kg ha<sup>-1</sup> of which only 2.4-3.9 per cent is present as plant available form depending upon the land use pattern while 15-20 per cent (97-110 kg ha<sup>-1</sup>) of the total P is present in organic form as phytin, lecithin, phospholipids and other unidentified compounds (Tarafdar *et al.*, 1989). But response of P-fertilisation in arid soils is variable in arid zone. But in high rainfall years pearl millet responded to an application of 40

kg  $P_2O_5$  ha<sup>-1</sup> and this response was further increased with application of nitrogen (Aggarwal *et al.* 1989).

An extensive survey through arid zones revealed that the population of P-solubilising micro-organisms is relatively low and varied from one place to place (Venkateswarlu *et al.*, 1984). Bacteria were the dominant group in all the soils followed by fungi. But isolation of actinomycetes especially *Streptomyces* sp. which can solubilise inorganic phosphates, from arid soil was reported (Rao *et al.*, 1982). However, P-solubilizers isolated from arid soils could not perform satisfactorily in the field because of lack of competition with the native flora.

Organic P-compounds must be hydrolysed by phosphatases of either plant or microbial origin, into plant available form. Tarafdar *et al.* (1989) reported the presence of phosphatases in different arid soils and varied with landuse pattern. Acid and alkaline phosphatases were observed in the rhizosphere of arid zone crops with maximum activity in legumes (Tarafdar and Rao, 1990). Tarafdar *et al.* (1988) isolated a number of phosphatase producing fungi (PPF) belonging to *Penicillium* and *Aspergillus* from arid soils. After intensive laboratory studies, some efficient PPF have been identified and these PPF were found to significantly enhance the dry matter production and grain yields of clusterbean and mung bean (Tarafdar *et al.*, 1992, 1995). Further there was a significant improvement in the uptake of N, P, K, Ca, Mg, Fe and Zn while there was effect on the uptake of Na, Mn and Cu.

### Role of VAM-fungi

Vesicular-arbuscular mycorrhizal fungi are geographically ubiquitous and are found in association with the roots of various plants. These fungi primarily help in the uptake of phosphorus and water. Arid soils do contain VAMF spores but in low numbers (7-80 100 g<sup>-1</sup> soil). *Glomus*, *Gigaspora* and *Acaulospora* are the common genera found in these soils. Almost all plants growing in desert including xerophytes do carry VAMF infections on their roots (Kiran Bala *et al.*, 1989) and the infection varied from plant to plant. In general the Young plants mostly carry mycelium with a small number of vesicles while vesicles and spores were common on mature roots. Cropping intensity in arid areas is dictated by rainfall. However, population of VAM fungi decline during fallow. Crops sown after long periods of fallow have poorly developed mycorrhizal systems and suffer from P-deficiencies. VAMF infection of neem plants was observed on roots upto 250 cm depth. The intensity of VAMF infections was inversely proportional to the availability of water. It seems that deep-rooted growth habit along with VAMF infections of desert vegetation may be a survival mechanism.

Upon inoculation in the soil at the time of sowing VAM-fungi were found to enhance dry matter production and grain yields of arid legumes significantly (Table 19) besides improving nodulation and N<sub>2</sub>-ase activity (Tarafdar and Rao, 1997). Concentrations of N, P, Zn and Cu in the shoot were found to be significantly higher in inoculated plants. Further, a positive and a significant interaction between *Rhizobium*-VAM fungi was also observed.

Table 19. Dry matter and grain yield of arid legumes upon inoculation with VAM Fungi (Tarafdar and Rao 1997).

Treatment	Clusterbean	Moth bean	Mung bean
Grain yield (kg ha <sup>-1</sup> )			
Control	540	420	480
<i>Glomus mosseae</i>	700***	510***	600***
<i>G. fasciculatum</i>	620**	490***	580***
Dry matter (kg ha <sup>-1</sup> )			
Control	2300	1820	2120
<i>G. mosseae</i>	3170**	2350***	2790***
<i>G. fasciculatum</i>	2990***	2180*	2580**

\*p<5%, \*\*p<1%, \*\*\*p<0.1%

In the light of the above microbial inoculants coupled with organic manures play a significant role in sustainable crop production in arid soils with further improvement of soil biological productivity.

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Of 14.9 billion hectares of land area of the earth, 6.1 billion hectares are drylands. Out of this, one billion hectare is hyper arid. Arid zone in India which covers almost 12 per cent of the geographical area of the country, is characterised with a very high spatial variability and adversity in respect of natural resources and their utilisation. Enhanced production of agricultural commodities in arid zone, therefore, solely depends on safe and sustained exploitation of soil, water and climatological resources. In view of uncontrolled and unpredictable inherited hostilities and adversities in arid areas, the successful cultivation of crops becomes almost a gamble with production precipitating on either extreme.

Crop plants in arid areas have to encounter with a fast changing growing habitats. For instance, germinating seeds face depleted soil moisture and hard soil crust resulting in partial emergence and patchy plant stand. The crops, may vary often, face initial and/or terminal droughts of considerable magnitudes. High wind velocity encountered with high ambient temperature (leading to high ET) may lead to unripe, shrivelled and small sized grain, consequently in poor harvest. Besides, soil and atmospheric droughts, abundance of poor quality underground waters, industrial effluents (mainly from textile, dyeing and printing industries), large natural saline lands and the building up of secondary salinity due to leaching and waterlogging in canal command areas of IGNP pose very serious challenge for crop production. Productivity of arid zone crops is, therefore, dismally low vis-à-vis other climatological zones of the country.

Appreciably, the arid zone crops have very long history of their evolution and the continued process of their natural and deliberate selections, have developed elasticity and plasticity in their genomes hence, providing adaptation to varied ecological constraints at a time and space. For instance, pearl millet, clusterbean and castor bean may exhibit relatively more tolerance to drought, heat and salt adversity. Even though, their mechanisms and the growth tolerance stages may considerably vary. However, tolerance and yield potential having variance with each other and depending on many factors. Mung bean and moth bean being drought tolerant, the former showing escape mechanism due to short growth and the latter showing resistance right from germination to maturity. Moth bean is credited with twin tolerance to heat and moisture deficit. Clusterbean, in spite of, being long duration arid legume, shows quick recovery towards precipitation at any growth stage, thus, depicting drought avoidance phenomenon. During *rabi* season, Indian mustard shows very high adaptation in arid areas (lessening the prospects of diseases, high solar incidence interception for better photosynthetic activities) due to various factors. The same is the case with taramira.

Looking at the adaptation of arid zone crops to agro-ecological nick, in concomitant with poor yield potential, there appears, ample opportunities for genetic fillip of these crops, so as to help bring arid revolution in the country.

For successful cultivation leading to satisfactory production of field crops under varied stress situations, it is prerequisite to sum-up the important breeding objectives and the relevant strategies.

The main aims under deficit soil moisture situations must be to stabilise the production per unit of water and time. The approach must be to evolve genotypes which make the most efficient use of limited available water. In monsoon season, the moisture stress may coincide with the critical stages of crop growth and cause maximum damage. In winter season, the precipitation is rather negligible and the farmers have to make use of the residual soil moisture. Therefore, the breeding objectives should be considered as an integral part of the specific environmental conditions under which the improved varieties will be grown. In general, the objectives would be evolution of physiologically efficient plant types, with:

- high harvest index,
- wide adaptation and giving stable production across, the soil and agroclimatic conditions,
- moderate level of input responsiveness,
- tolerance to important abiotic and biotic constraints, and
- improved quality of the economic product.

## **Pulses**

Following research aspects are important for high pulse productivity through genetic approaches :

- development of high yielding varieties with resistance to important diseases and pests,
- development of varieties with early partitioning and maturity,
- development of relatively photo and thermo-insensitive varieties which can be grown in non-traditional areas and aberrant seasons, and
- development of suitable plant types for inter-cropping and pure cropping systems.

The commodity/cropwise details of the research work carried out on their genetic improvement in arid areas particularly at this Institute is briefed.

### **Moth Bean [*Vigna aconitifolia* (Jacq.) Marechal]**

Moth bean is one of the most important arid legumes, known for its tolerance to high atmospheric temperature and soil moisture deficit situations. It is characterised with trailing and spreading prostrate growth habit, which may help prevent early depletion of soil moisture and its fertility. Besides, as a source of pasture, fodder and green manure, it is also used in a variety of local dishes and snacks. Adaptive and other socio-economic merits attached to it, have led to the

concentration of this arid legume to almost 70 per cent area, principally in the heart of arid regions of the country. The crop, however, suffers from certain inherited bottlenecks which require genetic amelioration as follows :

- development of plant types with erect to semi-erect growth habit having early partitioning (ca 30 d) and maturity (60-70 d);
- inbuilt tolerance potential to diseases like “yellow mosaic virus” and *cercospora* leaf spot diseases; and
- high yield potential in sole, mixed, inter-cropping and other related cropping systems.

Looking to its importance, uses and adaptations to abrupt drying arid areas, genetic improvement work is still at a slow start. Moth bean crop is autogamous in nature, hence pure selection or pedigree methods have been initially used for its genetic upliftment. As a result Baleshwar-12 and Medhi 33 were found that best varieties for Gujarat areas in fifties (Govda, 1950). In arid Rajasthan the strains viz., PLMO-2, PLMO-104 and IC 8833 were found quite suitable. In late seventies, the strains viz., PLMO 39, PLMO 55 and IC 8851 were found high yielding and drought resistant in arid zones of Rajasthan (Chopra and Mittal, 1979). Development of Jadia in 1980 and Jwala a YMV resistant variety in 1985 provided a significant genetic progress in moth bean improvement as these varieties occupied large growing areas of moth bean in Rajasthan.

In continuation to evaluation of local germplasm and development of better strains, other promising varieties like IPCMO-880 and IPCMO-86 (Henry and Daulay, 1987) were added to this list. However, all these strains were spreading types with 80-90 days maturity, the traits, not favouring high yield of this crop in arid areas. Hence, mutation breeding programme with a local variety Jadia was initiated using gamma rays at the Central Arid Zone Research Institute, Jodhpur in eighties, as a result, of which, some promising mutants (JMM-259, JMM-211 and JMM-60) in respect of higher number of pods, higher yield potential and early maturity, were identified by Henry and Daulay (1983a, 1983b). JMM-259 was later on, released for general cultivation by Central variety Release Committee in 1988 in the name of Maru Moth-1 (Henry *et al.*, 1993). Later on, one more variety RMO-40 was developed, particularly for commercial plantation in limited rainfall situations. This variety was also result of gamma-ray treatment in Jwala. RMO-40 was the first variety, and the future source for breeding to erectness and early maturity. This variety due to only 60 d maturity was specifically suited to short growing conditions, however, in the wake long growing season due to extension of rainfall it yielded poorly.

Variability of high and heritable magnitude was reported in moth bean for grain yield, pod number, number of branches and 100-seed weight by Tikka *et al.* (1977, 1980). Similarly, Henry and Krishnan (1986) observed that variability in moth bean germplasm was enough and of exploitable magnitude.

In moth bean, the most desirous attributes required are erect and upright branching behaviour so as to realise higher productivity per day per unit of land. Such types would also suite well in desired cropping systems. Another important character is inbuilt tolerance potential to diseases, with a particular reference to Yellow mosaic virus, damaging crop right from seedling stage to maturity and causing yield reduction upto 90 per cent. Mutation breeding programme which has proved most convenient and efficient tool for genetic upliftment of moth bean, was used for enhanced grain yield through isolation of early (55-60 d) maturing and erect type mutants, viz., CZM-99E and CZM-32E having yield potential of almost 700 kg ha<sup>-1</sup>, 2 fold more to late (80-90 d) and spreading types (316 kg ha<sup>-1</sup>) types, under almost 310 mm rainfall situation. These mutants appreciably required lower quantity of major and micro-nutrients for production of higher grain yield and showing improved uptake potential. These mutants, therefore, appeared nutrient efficient (Kumar, 1996). Moreover, due to early maturity these mutants showed lesser incidence of YMV than the traditional varieties.

Efforts are undertaken to assess the magnitude of variability among the mutants under rainfed situations during two years (1993-1994). Number of pods plant<sup>-1</sup> had the maximum estimates of GCV (49%), broad sense heritability (69%) and genetic gain (78-85%). Results revealed that days taken to 50 per cent flowering and number of pods plant<sup>-1</sup> were the most important traits for yield improvement during dry and wet seasons, respectively (Kumar, 1996).

#### **Exploration of genetic variability**

Efforts to collect genetic variability from moth bean growing belts of Rajasthan were undertaken during 1994 by covering almost 2000 km area. Field evaluation of the collected 270 lines, during 1995 to 1997 has led to isolation of some promising lines, as  
 Exp. 221: Only one line with 55d maturity with erect growth habit was isolated.  
 Exp. 59 and Exp. 61: These lines with semi-spreading growth habit and medium maturity (75-80 d) had appreciably field tolerance to YMV and yielded almost 500-600 kg ha<sup>-1</sup>.  
 Exp. 206: A typical line with fully lobed leaf blade behaviour, looked chillies types. Germplasm collected represented high degree of variability for yield, growth traits and disease reaction.

#### **Clusterbean [*Cyamopsis tetragonoloba* L.]**

Another important arid legume, clusterbean, is reckoned with for export value of the "guar gum" extracted from the endosperm. Being very drought hardy and highly receptive to even limited availability of soil moisture throughout growth period is adapted to long range of planting dates and other growth attributes. Green pods of clusterbean, in the early stage, are used as delicious vegetable. Clusterbean is an important component of inter-cropping in arid and semi-arid regions. The crop is bestowed with branched and unbranched, early and late maturing varieties. Nevertheless it requires genetic improvement in respect of the following traits :

1. Development of varieties resistant to *Alternaria* blight, Bacterial blight and dry root rot diseases.



2. Development of varieties with high grain yield, adapted to poor fertility and marginal and sub-marginal lands with inadequate soil moisture supply.
3. Development of varieties having high galactomanan content in the endosperm of the grain.
4. Development of determinate growth habit.

Evaluation of more than 5000 germplasm lines of clusterbean in phased manner at this Institute from 1970 onwards indicated the existence of enormous genetic variability and diversity for utilisation in hybridisation programme. Looking at the arid environment on the influence of character expression a number of genotype x environmental studies have been made (Jhorar *et al.*, 1980, 1985; Henry and Daulay, 1984; Das *et al.*, 1983). Results revealed that both linear and non-linear components of  $g \times e$  were important for expression of grain yield and other economic traits. Further, stability consideration revealed suitability of Durgapura Safed for Hisar arid situations. In addition to stability, inheritance studies were also carried out wherein, parents FS 277 and HG 182 had highest gum content and were good general combiners for this trait (Jhorar *et al.*, 1985). In another study with 6 parent diallel crosses, three to five dominant genes governed the inheritance of grain yield but the heritability estimates were lower in different rainfed environment in Hisar situation. As far as important yield components are concerned, number of pods and 100-grain weight (Uma Menon *et al.*, 1977), number of seeds and seed weight were the major yield traits under early cessation of rains.

Clusterbean being indeterminate type legume, has obvious defects of unsynchronisation in flowering and podding behaviour. Some useful determinate type mutants following treatment of FS-277 with EMS have been induced which are distinct and improved in yield potential (Henry and Daulay, 1987a). Evaluation of different genotypes of clusterbean at different levels has revealed that HG 75, Durgapura Safed and HG 182 were found ideal for Jodhpur situations (Henry and Daulay, 1983c). Among the single stemmed varieties, PLG-119 and PLG-85 were superior. Among early maturing group the varieties like Naveen and Suvidha proved superior. Evaluation of germplasm in Jodhpur situation, led to the isolation of 2470/12 a promising line. The line following multi-location testing at different levels was released for commercial planting in 1986 and named as Maru-Guar (Henry *et al.*, 1992).

### **Cowpea [*Vigna unguiculata* L.]**

Cowpea has considerable scope in arid areas with limited and uncertain rainfalls due probably to providing food and fodder, early maturity and moderate salt tolerance potential. Research efforts have, however, limited to evaluation of existing germplasm and advanced lines, variability and character associations. Efforts leading to the development of varieties for drought tolerance and high yield potential have still been lacking. In cowpea there is need to evolve varieties which are compact in growth behaviour with relatively erectness, lacking trailing growth habit.

Evaluation of large number of fodder varieties of cowpea under rainfed conditions at Hisar, number of branches/plant and leaves/plant were found most important yield traits (Dangi and

Paroda, 1974). Similarly, evaluation of 40 fodder type cowpea varieties at Hisar, genotypes C4a and Pusa Dofasli were found high yielding under dryland conditions. Divergence studies carried out by Jindal (1985) revealed no geographical origin relations with clustering and the genotypes viz., 123292 and IVU 3427-2 represented rich source of genetic variability. Diallel analysis in cowpea revealed that additive and non-additive type of gene actions were involved in the inheritance of kernel weight. The varieties viz., HFC 20, C 28 and FOS-1 all bold seeded were good general combiners for higher kernel weight (Jatasra, 1980). Not only variability studies but a few studies related to screening varieties for drought tolerance and identification of probable selection traits have also been made. For instance, under rainfed/unirrigated conditions of Jhansi, the varieties HFG 42-1, IGFR-1450 and IGFR-1457 were found drought tolerant (Yadav and Patil, 1984). They also observed chlorophyll stability index as a sensible parameter for drought tolerance.

A large number of varieties evaluated at this Institute revealed better performance of Charodi-1 variety (brownish seed coat colour) under normal and late sown conditions, followed by FS-68 (Henry and Daulay, 1988a). Under late sown conditions variety K-11 also gave promising performance. Efforts through mutation breeding were attempted to induce white seed coat colour in Charodi-1. Consequently certain mutants viz., CAZC-W, CAZC-9 and CAZC-11 were induced which are being evaluated through All India Co-ordinated Trials. Evaluation of different varieties of cowpea in intercropping/mixed cropping systems with pearl millet revealed better suitability of Charodi-1 in such systems compared to other varieties.

### **Green gram (Mung bean) [*Vigna radiata* L.]**

Mung bean, even though, not an arid legume but due to short growth period of 65-70 d, characterised with drought escape mechanism, is coming up as a potential arid pulse. Moreover, its yield potential is generally more than moth bean. The major emphasis is on the development of green gram varieties resistant to YMV and other diseases with stable performance and good cooking quality so that it can be grown in multiple cropping and in rotation with other crops. Efforts on identification of suitable varieties for the region, revealed that variety S-8 gave the most promising performance both under normal and late sown conditions followed by K 851 (Henry and Daulay, 1989). Of late, other varieties which are giving promising performance are RMG-11, RMG-131, RMG 146, P 7093, RMG 268 and PDM-54. Gupta *et al.* (1980) while studying magnitude of heterosis in 20 crosses reported 33.2 to 85.8 per cent heterosis for grain yield in mung bean at Hisar. ML1 x K 851 gave maximum hybrid vigour. Under drought conditions, an ideal plant type should have higher clusters and grain number per pod (Gupta *et al.*, 1982).

### **Horsegram (Kulthi) [*Macrotyloma uniflorum* L.]**

This minor pulse is grown in tribal areas of Pali and Jalore districts and adjoining areas of Sirohi. Varietal improvement in this crop is in incipient stage. Efforts were made to collect the land races from its growing areas. High yielding variant plants were evaluated for various

characteristics. Results revealed that genotypes PL-Selection, SN-selection and SU-Selection were high yielding and stable for various situations (Henry and Daulay, 1988b). Based on high and stable yield, genotype PL-Selection was released and notified for general cultivation in 1989 under the name Maru-Kulthi-1.

### Pigeon pea [*Cajanus cajan* L.]

Pigeon pea is basically the crop of semi-arid region, however, availability of early to extra early genotypes envisaged our interest for its evaluation in arid climate so as to replace low yielding pulses in kharif and/or rabi seasons of arid zone. Pigeon pea varieties along with short duration, resistant to major diseases, viz., wilt, sterility mosaic and *Phytophthora* blight as well as to pests, particularly, pod borer and pod fly are desired.

The evaluation of extra early germplasm during monsoon season revealed existence of genetic variability as well as genetic diversity for the important characters among the genotypes, for utilisation in crossing programmes (Henry and Krishnan, 1992). The performance of different varieties of pigeon pea during winter season revealed the suitability of Basant and Bahar for the post rainy season cultivation under limited moisture supply.

The performance of improved varieties of grain legumes at CAZRI, Jodhpur are presented in Table 1.

Table 1. The performance of improved varieties of grain legumes at CAZRI, Jodhpur

Grain legumes	Varieties	Maturity (days)	Mean productivity (kg ha <sup>-1</sup> ) (long term)	State average (kg ha <sup>-1</sup> ) (long term)	Specified traits
Clusterbean	Maru-Guar, HG-75, G-1	97-105	750-850	216	Branched type
	Suvidha, Naveen	80-85	800-900		Branched type
	FS-277, PLG-119, PLG-85, HFG-314	90-95	600-800		Unbranched type
Moth bean	Maru Moth-1, Jadia, Jwala	80-85	400-600	150	-
	IPCMO-880, T-88	90-95	300-500		-
Green gram	S-8, K 851	60-65	700-900	194	-
	Charodi-1,	60-65	700-900		257
Horse gram	Maru Kulthi-1	100-105	600-700		-

## Oilseeds

Rajasthan is becoming increasingly important state for oilseed production, as it produces country's 18 per cent oilseeds from almost 12 per cent area. The state ranks first in area and production of rapeseed and mustard whereas, ranks first and fifth, respectively as far sesame is concerned. Interestingly, however, 73.4 per cent area of sesame of the state is occupied by 12 arid districts only. Thus, sesame under rainfed conditions and rapeseed mustard under limited irrigation during winter season are considered important oilseeds. Other oilseeds - castor, groundnut, safflower and sunflower are of less significance in arid areas.

### Sesame [*Sesamum indicum* L.]

Locally known as *til*, is an ancient oilseed of dry regions. The crop appears to be susceptible to drought at the initial seedling stage, however, can efficiently utilise stored soil moisture during late growth. Local varieties are leafy with excessive vegetative growth are, therefore, poor in harvest index and may suffer from terminal drought due to long growth period. The crop is also highly susceptible to high degree of flowers and pods shed and towards their shattering at the maturity. The crop is specifically susceptible to phyllody a type of sterility and to pod borer insect.

In view of above bottlenecks and to identify the suitable genotypes for arid situation, a number of strains have been evaluated over the years, confirming the superiority of the varieties viz., T-13, 4-2 and TC-25 (Henry and Daulay, 1987b) and Pb Til-1 and IC-171 (Henry and Kumar, 1991) in respect of high seed yield potential.

In addition to seed yield, the stability of sesame towards varied growing conditions is also of practical significance. A variety with stable performance even with moderate yield level would help bring sustainability. Phenotypic stability of 10 genotypes by growing them in eight environments of growing conditions were therefore studied. Results revealed that TC 171 and C-6 exhibited maximum stability for seed yield in poor environment, whereas top yielder TC-25 with unit regression was found stable towards better environment and so was the case with T-13 also (Kumar, 1988).

### Castor [*Ricinus communis* L.]

Castor oil is non-edible and used for industrial purposes, but due to deep and fast penetrating root systems, characterised with osmoregulation, is known as a drought tolerant crop of dry regions. The traditional castor varieties are tall growing and take very long time (200-250 d) to mature. Therefore, soil moisture recedes by October and the crop suffers from terminal drought.

Castor varieties should be so tailored that flowering upto 3rd order of spikes is completed by the end of September (Ca 90-100 d). In other words, plant type which produces first, second and third spikes by 40, 70 and 85 days of sowing, respectively, would furnish high and assured yields under abrupt rainy seasons. In other words, varieties giving maximum yield through 2-3 picking

by 100 to 120 days would prove quite ideal for arid region. Evaluation of certain varieties and hybrids, revealed better performance of GAUCH-1 and Aruna (Henry and Daulay, 1985a).

Besides, evaluation of castor under rainfed irrigation, the important genotypes were also evaluated for salt tolerance potential in terms of seedling emergence and grain yield. Screening of 46 castor lines revealed that mean seedling emergence at EC16.0 dS m<sup>-1</sup> was observed to the tune of 2.2, 2.6 and 10.4 per cent against the corresponding values of 52.5, 60.0 and 65.2 per cent in control at 8th, 12th and 16th day of sowing, respectively. Height of 30 day old seedlings was decreased by 75-80 per cent at ECe 16 over control. Frequency distribution of mean seedling emergence of the genotypes at 16th day of sowing showed that almost 78 per cent strains in control had emergence from 51 to 70 per cent, whereas 58 per cent strains at ECe 12.5; and 69 per cent strains at ECe 16.0 dS m<sup>-1</sup> had emergence 0 to 20 per cent only (Kumar and Daulay, 1988).

In a related study on screening of 16 strains of castor for salt tolerance potential in micro-plots at ECe 2.4 (Control), 12.5 and 16.0 dS m<sup>-1</sup>, revealed significant adverse effects of salinity on seedling emergence, plant height, cluster length, stem girth, 100-seed weight and seed yield. The strains VI-9, 1379 and a hybrid GCH-4 due to high MSI values were considered tolerant. The tolerant strains were marked with more contents of Na and Cl in leaf tissue and had lesser reduction of NR activity at ECe value of 16 dS m<sup>-1</sup> over control at maturity (Kumar *et al.*, 1989).

### **Sunflower [*Helianthus annus* L.]**

Sunflower due to various merits like high oil content with good quality, its thermo tolerance potential, better adaptation towards dry and saline situations is coming up as an major oil crop of the future.

The performance of newly evolved hybrids and varieties indicated that hybrid BSH-1, MSFH-9 and MSFH-7 and early maturing variety Morden hold the promise for yield potential in the monsoon season (Henry and Kumar, 1991).

Sunflower hybrids and varieties have been evaluated for salt tolerance so as to recommend cultivation on large stretches of saline lands and with poor quality irrigation water. Accordingly, 22 genotypes were screened under soil salinity levels of 16 and 20 dS m<sup>-1</sup> during 1987. Seedling emergence, on 16th day of sowing; and seedling height; leaf, shoot and root dry matter per plant in 30d old seedlings were reduced by 81.9, 65.0, 72.2, 86.0 and 54.4 per cent, respectively, at EC 20 dS m<sup>-1</sup> over control. The hybrids KBSH-13 and NSH-30 with 30.0 and 25.0 per cent emergence at this salinity were salt tolerant. There was a sharp difference between tolerant and susceptible genotypes for phosphatase activity and P nutrition on saline soil (Kumar and Tarafdar, 1989).

### **Safflower [*Carthamus tinctorius* L.]**

It is a drought hardy crop and can also be grown well under salt affected soil conditions and in light to heavy textured soils. It has a strong tap root system which draws water from fairly deep layers of soil profile and, therefore, is best suited to the arid regions.

Compared to other oilseeds, it has low oil content (28.32%), hence, in safflower breeding, high oil content assumes greater importance than any other traits. Another disadvantage associated is that all the native cultivars of safflower are handicapped by very thick pericarp which adversely limits the per hectare yields of oil as well as the quantity and quality of the meal in the crop, thereby making its cultivation low, and less attractive. The incorporation of alleles for low hull or high oil content into the genetic background of locally adapted agronomically superior variety would form an important breeding activity in the immediate future. Like sunflower, poor seed filling is also a problem in case of safflower. It is reported that this may be due to the presence of partial self incomparability coupled with differences in insect pollinators.

A set of 19 promising genotypes of safflower were tested under different environment created by different row spacings following limited irrigations. The crop in general gave better performance when grown in closer row spacings of 30 cm under favourable moisture growing conditions. However, under moisture stress conditions no marked yield response was observed due to different average responses to the changes in environmental conditions. Genotypes like Tara, JL-28-7 and S-4 had high yield potential amongst all the genotypes (Henry and Daulay, 1990a). In another study var. APPR-1 and JLA-900 under adequate moisture supply and var. A-1 and S-4 under limited moisture supply conditions gave better performance (Henry and Kumar, 1991).

More than 80 lines of safflower having wide genetic base were evaluated for salt tolerance with saline water of  $EC_e 8.0 \text{ dS m}^{-1}$  on arid soils. The emergence of these lines ranged from 22.6 (S-144) to as high as 66.6 per cent (HUS-507), whereas, emergence at ESP 30 was as good as that with control conditions. Safflower appears quite tolerant to saline and alkaline situations after seedling emergence. The crop appeared more tolerant to alkali than saline situations. The lines HUS-507 and A-1 appeared better salt tolerant.

### **Rape and Mustard [*Brassica* spp]**

Rape and mustard belong to the group of *Brassica* species. Rape generally refers to the *Brassica campestris* and Mustard or Raya to *B. juncea*. Taramira (*Eruca sativa*) though belongs to a different genus but is considered in the same group. Indian mustard due to high degree of potential for seed yield and tolerance to other biotic and abiotic factors has almost replaced other species. In limited and specific pockets only other species viz., toria, yellow sarson and taramira are grown.

### **Model for increased yield**

Drought resistance appeared to be associated with deep roots, waxy leaves and ability to dropping of the leaves under drought stress after the seeds have been formed in pods. This adaptation to stress appeared to be useful since most of the photosynthate used for the production of seed are produced by the green pods and stems. It is indicated that early maturing cultivars should have adequate sink capacity. The plant should not have more than 12 leaves. The first 3-4

leaves should be fairly large to provide leaf area as quickly as possible and thus, provide nutrients for the production of plant structure, such as roots stems and leaves. The remainder of the leaves should be progressively smaller to provide a pyramidal form which will permit the maximum penetration of sunlight into the plant canopy. The plant should not have more than 3-6 branches near the top and should have very little basal branching. Stem strength should be sufficient to prevent early lodging but slight drooping of branches towards maturity, may be beneficial in reducing wind damage. The variety should also be resistant to aphids and frost damage.

### **Indian Mustard [*Brassica juncea* L. Czern and Coss]**

It was indicated that genotype T-59 (Varuna) was a stable one and was able to take advantage of the favourable growing conditions, as well as yielding reasonably high under less favourable growing conditions compared to rest of the genotypes tried (Henry and Daulay, 1985). Genotype DIR-147 found to perform best over others under poor environments (Henry and Daulay, 1988c). Evaluation of other lines during nineties indicated that genotype Pusa Basant and Pusa Bahar performed better under limited irrigation.

### **Brown Sarson [*B. campestris* var. *brown sarson*]**

Promising genotypes of brown *sarson* were evaluated for 3 winter seasons with 3, 2 and 1 irrigations, respectively of 5 cm each at critical crop growth stages. The highest mean seed yield was obtained with 3 irrigations. Genotype 'Pusa Kalyani' had good response to changing environmental conditions and was also high yielder. However, 'BID-10' gave the highest mean seed yield and was consistent in its performance, besides, being stable. Efforts were also undertaken to study the genetics of the combining ability of yield and important traits of brown *sarson* under normal and alkali soils. Results revealed that gene action was predominately of the non-additive type for all the traits on both soils. Assam Selection and BSH-1 among the females were the best general combiners for seed yield on normal and alkali soils, respectively. The *gca* and *sca* estimates varied considerably with the soil conditions with *sca* being the highest in IB-7 X BSH-1 and IB-5 x Pusa Kalyani for seed yield in normal and alkali soils, respectively. IB-1 x Assam Selection was the only cross with positive *sca* and heterosis for seed yield in both the soils (Kumar and Yadav, 1985).

### **Taramira [*Eruca sativa* L.]**

It could be successfully grown under conserved moisture or with very meagre irrigation resources of the farmers of Rajasthan including desert districts. Five important genotypes evaluated for 3 winter seasons revealed that genotype RTM-1 gave consistent high seed yield during all the 3 seasons and was stable (Henry and Daulay, 1990b).

Similarly, four years of consecutive yield trials (1985-86 to 1988-89) with one pre-sowing irrigation only representing wide sowing dates (10 Oct. to 31 Dec.) gave average yield of 4.5 kg ha<sup>-1</sup>. This yield level obtained following inter- and intra-row spacings of 50 x 10 cm, appears

appreciable. The variety TMH-24 (500 kg ha<sup>-1</sup>) followed by RTM 522 (492 kg ha<sup>-1</sup>) with 31.9 and 30.0 per cent increased yield over T-27 (379.0 kg ha<sup>-1</sup>) were found most adapted to loamy sandy soils of Jodhpur.

Genetical studies pertaining to magnitude of variability, combining ability and stability have been investigated under rainfed conditions at Haryana Agricultural University Regional Research Station, Bawal. Study on variability and character associations in a population of 50 genetically diverse taramira lines revealed that number of secondary branches, siliqua length and 1000-seed weight possessed higher estimates of gca, sca, heritability and genetic advance. Secondary branches per plant and number of siliquae on main shoot had maximum direct positive effects on seed yield (Yadav and Kumar, 1984a). Combining ability analysis following diallel crosses revealed preponderance of non-additive genetic variations for almost all the traits but number of primary branches. Ldh.Comp.1-3, was the best general combiner for seed yield, main shoot length and number of siliquae on main shoot and RTM2 x Ldh.Comp.1-3 was the best specific cross for seed yield (Kumar and Yadav, 1986). Parent ITSA had the maximum estimates for gca for seed yield on both saline and alkali soils. T27 x RTM13 on normal soil and RTM13 x TC35 on alkali soil were the best specific combiners for seed yield (Kumar *et al.*, 1988). Harvest index an important measure of efficient partitioning, was studied for its stability amongst 25 diverse genotypes of taramira under rainfed lands with two fertility levels and dates of sowings. The harvest index increased with delayed sowing (upto 8 Dec.) and the same was more with low fertility. TC-27 and TC-54 with moderate harvest index (25.7 and 23.0%, respectively) and good stability ( $S^2_{di} = -0.06$  and  $-0.13$ , respectively) were adapted to cultivation without N application (Yadav and Kumar, 1984b).

### **Indian Rape [*Brassica campestris* L. var. *toria*]**

Indian rape or *toria* is a short duration oil-seed crop in rape seed-mustard group. It is generally grown in the intervening period of rainy season and winter season as a catch crop. The yield potential of the crop is low. The performance of 11 diverse promising genotypes of toria was evaluated for 3 winter seasons. The genotype 'Sangam' indicated higher yield potential over other (Henry and Dauly, 1990c).

### **Evaluation of Brassicas for salt tolerance**

Brassica species exert distinct response to salinity. *Brassica carinata* and Indian mustard (*B. juncea*) being tolerant whereas, *B. campestris* var. yellow sarson and *toria* being on the other extreme of susceptibility.

### **Seedling emergence**

Evaluation of 50 strains of *B. juncea*, 5 of *B. napus*, 4 of *B. carinata* and 5 of *Eruca sativa* on saline soils of ECe 16 and 20.0 dS m<sup>-1</sup>, revealed that *E. sativa* possessed maximum emergence, while *napus* the least, (Kumar, 1990). In *juncea* CS-38-217 and CS-338 possessed maximum



emergence. Furthermore, relative tolerance of *Brassica* species on normal (ECe 0.2, pH 8.0), saline (ECe 8.8 pH 8.2) and alkali (pH 9.3, ESP 30) soils revealed that seedling emergence was the most seriously affected trait under saline and alkali conditions.

### Seed yield

Evaluation of a number of Indian mustard strains for relative salt tolerance potential in terms of seed yield revealed that DIRA 367, CS-394 and CS-209 were salt tolerant (Kumar, 1989). Besides, other strains viz., CS-52 and NDR 8501 were also obtained salt tolerant which were later on released as commercial salt tolerant varieties (Kumar, 1988). Bold seeded and early maturing juncea RH-30 was also observed tolerant to sodicity in terms of seed yield upto ESP 30 in Bawal conditions (Kumar *et al.*, 1983).

Variability studies in Indian mustard on problem soils was also done in 30 genetic diverse genotypes by growing them in normal (ECe 2.0 dS m<sup>-1</sup>, pH 8.0 and ESP 12.0) and saline (ECe 10.5 dS m<sup>-1</sup>, pH 8.0 and ESP 12.5) soils. The higher estimates of gcv pcv, heritability and genetic advance for seedling emergence, number of siliqua on main shoot, no. of secondary branches plant<sup>-1</sup> and seed yield were obtained on saline soil. Number of siliquae plant<sup>-1</sup>, on normal soil, and seedling emergence and plant height on saline soil had significant positive associations with seed yield. Furthermore, seedling emergence and plant height exhibited maximum direct positive effects on seed yield in saline soil (Kumar, 1993). Thus, selecting genotypes improved in seedling emergence will be helpful for yield increment on arid saline soils.

## Pearl Millet [*Pennisetum typhoides*]

In Rajasthan, work on pearl millet improvement, was initiated in mid fifties. Since pearl millet is an allogamous crop, mass selection was the principal method through which many local types were improved. Using mass selection two pearl millet varieties RSK and RSJ were developed from Jakhra local and Karauli cultivars (Krishnaswamy, 1962). The local populations were selected on the basis of well filled compact, long panicles and high grain weight.

After RSK and RSJ, no serious attempts have been made in Rajasthan to develop varieties suited to arid regions. It was, however, in late 1970s, that attempts were made at SKN College of Agriculture, Jobner, to improve local ecotypes of pearl millet having excellent adaptation and higher yields under harsh agro-climatic conditions of arid and semi-arid regions. Under this programme nine ecotypes LCB 1 to 9 were collected from arid and semi-arid regions of Rajasthan. On evaluation, it was observed that LCB 2, 5, 7 and 8 collected from arid areas were earlier in maturity and less taller and low yielder compared to LCB 1, 3 and 4 collected from semi-arid areas. LCB 2 and LCB 9 though slightly lower in grain yield were comparatively earlier in flowering. Research work on pearl millet improvement was also initiated at Agricultural Research Station, Fatehpur Shekhawati, in 1986 and, leading to improvement of RCB 2 and WCC 75 by recurrent selection for their adaptation to zone IIa.

An All India Co-ordinated Millet Improvement Project was initiated in 1972 at CAZRI, Jodhpur, with the objectives of collection and evaluation of local and improved genetic stocks of millet crops for selection of superior genotypes and breeding for high yield and disease resistance. Since its establishment several studies have been conducted, improved varieties developed and large body of useful data have been generated for guiding future pearl millet research programmes.

### **Germination of Millet Crops under Saline Conditions**

Abhichandani and Bhatt (1965) studied germination of thirty three varieties of pearl millet and Jowar (*Sorghum*) to determine their salt tolerance. It was observed that AF3 from Bombay and X3 from Madras stood upto  $EC_i 20 \text{ dS m}^{-1}$ . Later on salt tolerant studies done on pearl millet, finger millet and proso millet by Manga revealed that pearl millet (BJ 104) was the most salt tolerant of all the three millets as did not show decrease in germination upto  $EC_i 15 \text{ dS m}^{-1}$ .

### **Minor Millets**

Of six minor millet crops viz., *Setaria italica*, *Eleusine coracana*, *Echinochloa frumentacea*, *Panicum miliaceum*, *Panicum miliare* and *Parpalurm scrobicolatum* tried, *Setaria italica* and *Panicum miliaceum* were found suitable for arid tracts. The improvement work was, therefore, taken up on *Setaria italica* (Kanjani) and *Panicum miliaceum* (Chena). Varieties Se 21-1 and SN.9 of Kangani and PM 29 and PM 31 of Chena, developed at CAZRI were recommended as supplementary or substitute to pearl millet. These varieties maturing in 55-60 days and yielding 10-15 q ha<sup>-1</sup> have won recognition in All India Co-ordinated Millet Trials for these traits (Saxena and Verma, 1978).

### **Pearl Millet Germplasm Collection and Evaluation**

Local germplasm of pearl millet collected from western districts of Rajasthan were grouped using  $D^2$  analysis (Saxena *et al.*, 1978). It was observed that accessions from Barmer were early maturing coupled with high yield, those from Jaisalmer were early and but poor yielder, while Jodhpur accessions comprised of early as well as late types with low yield. Studies on germplasm were also conducted with regard to their adaptability, divergence and selective contribution of different components to divergence. Multivariate analysis showed wider adaptability of population collected from Barmer and were characterised with early flowering and maturity, high tillering and yield potential.

### **Breakdown of Male Sterility under Arid Conditions**

Studies on breakdown of male-sterility in eight male sterile lines revealed significant positive correlation with temperature and negative correlation with relative humidity, suggesting rise in percentage of pollen shedders with rise in temperature and lowering of relative humidity. Since, temperature remaining invariability high during flowering time, thus there is always possibility of

the breakdown of this system, consequently it would be risky to take up pearl millet hybrid seed production in arid areas.

### **Correlation and Path Analysis Studies in Pearl Millet under Arid Environment**

Positive association of grain yield plant<sup>-1</sup> with plant height, tillers plant<sup>-1</sup> and ear weight and negative association with days to ear emergence was observed by Manga *et al.* (1985a). Path analysis revealed direct contribution of tillers per plant and ear weight to grain yield and indirect contribution of ear length and girth through ear weight. Path analysis based on ontogeny of pearl millet (Yadav *et al.*, 1994) revealed that grain yield primarily depended upon threshing percentage and panicles m<sup>-2</sup>. More days to flowering adversely affected the threshing percentages.

### **Synchrony of Ear Emergence**

Development of plant types having synchronous flowering of tillers have been advocated for arid areas. A study on synchrony of ear emergence revealed the presence of additive as well as non-additive gene effects with complete dominance for synchrony of ear emergence. Heterosis for this trait ranged from 12.8 to 80.2 per cent over the better parent. Heritability for this trait was moderate (0.51). Significant genotype x environment interactions were observed for this trait, both linear (b) and non-linear (S<sup>2</sup>d) components were significant (Manga *et al.*, 1985b). Out of 30 genotypes, fourteen showed complete absence of G x E interaction. On the basis of synchrony of ear emergence and grain yield per plant genotypes were clustered into six groups.

### **Genetics of Nitrogenase Activity Associated with Roots**

Studies were conducted to study variability and nature of gene effects for this trait in pearl millet. In a diallel cross involving five inbreds, both additive and dominance gene actions with predominance of later were noticed for nitrogenase activity associated with the roots of pearl millet (Manga *et al.*, 1985b). It was observed that both dominant and recessive genes in equal proportion governed high nitrogenase activity. Combining ability and heterosis studies carried out for this trait, revealed that heterosis ranged from 71.76 to 70.26 per cent over the better parent. Parent P 631 had high means value for nitrogenase activity as well as general combining ability for this trait (Manga *et al.* 1987).

### **Root Studies**

A line x tester study revealed the presence of both additive and non-additive gene effects for dry root weight, while non-additive gene effects were predominant for root length, root number, dry root and total dry weight. Significant variability was observed for number of roots, root length, dry root weight, shoot weight and total dry matter both in 15 and 30 days old crop. The number of roots and root length were positively correlated with dry root weight, dry shoot weight

and total dry matter. Dry root weight showed positive association with dry shoot weight and total dry matter and dry shoots weight with total dry matter (Manga and Saxena, 1988).

### **Drought Tolerance Studies**

A set of three hundred genotypes were assessed for three years. Genotypes identified as drought tolerant were combined to form two drought tolerant populations in LDTP (late drought tolerant population) and EDTP (early drought tolerant population). These populations have been used in crossing with other populations for development of drought tolerant high yielding varieties.

A study on the effect of early seedling vigour on yield under both irrigated and rainfed conditions revealed that early seedling vigour was positively associated with grain yield and plant population under rainfed conditions and negatively with per cent yield reduction under rainfed conditions (Manga and Saxena, 1990). No such association was observed under irrigated conditions thereby, emphasising the importance of early seedling vigour in arid environments.

In another experiment, it was observed that bold seeds in general, produced vigorous seedlings, later maturity with greater tillering and higher levels of dry matter. Further plants from bold seeds took longer time to wilting initiation and then permanent wilting, compared with plants from smaller seeds (Manga and Yadav, 1995).

### **Study on Influence of A1 Cytoplasm on Downy Mildew Incidence**

Influence of A1 cytoplasmic substitution on the downy mildew incidence of pearl millet was studied by comparing the disease reaction of 40 pairs of F1 hybrids, each pair carrying respectively A1 male sterile and normal B cytoplasm. The study revealed that in pearl millet A1 cytoplasm is not associated with increased downy mildew incidence. In another study it was observed that downy mildew reaction of hybrids can accurately be predicted on the basis of disease incidence of the pollen parent (Yadav and Manga, 1995).

### **Development of Male Sterile Lines Suited to Arid Conditions**

Presently most of the available male sterile lines do not possess adaptation to harsh arid climate as these have been developed without any genetic contribution from the local material. To fill this gap a number of male sterile lines (CZMS 4 A, 18A, 44A & 47A) were developed at this Institute by transferring male sterility into the genetic back ground of a local landrace using back cross procedure (Manga and Yadav, 1997). A study on the performance of hybrids developed with CZMS 44A and other available male sterile lines, using a set of pollinators revealed that mean grain yield of hybrids on 44A was significantly higher (8-29%) compared to hybrids on other male sterile lines.

### **Top Cross Hybrids**

Bidinger *et al.* (1994) evaluated land races based on top cross hybrids as a quick way for achieving such objectives. Top cross hybrids showed consistent increase in biomass production

across the test environments. Thus, top crossing adopted landraces on high yielding male sterile lines would provide an opportunity to improve disease resistance and grain and/or fodder yield with no apparent loss of adaptation to marginal environments in which the landraces have evolved.

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Agricultural productivity in arid zones faces great risk by the vagaries of weather, particularly uncertainties of monsoon rains, moisture stress and nutrient stress. Besides physiological stresses, crops also have to overcome the biotic stresses posed by pests, *i.e.* the insects, diseases and weed competitors. Substantial research work has been conducted on the pest problems of arable crops through surveys, monitoring and studies on bionomics and management. With the introduction of canal system of irrigation by the Indira Gandhi Nahar Pariyojana (IGNP) in the northern and north-western arid regions of Rajasthan, widespread changes in the agroecosystem have been taking place, with consequent changes in the pest complex and their population structures. Changes in farming systems and cropping intensities lead to new pest records and changes in their status (Vyas, 1996; Verma, 1997a), earmarking the importance of periodic pest surveillance and monitoring for effective pest management strategies. The work done on insects and diseases in Rajasthan was partly reviewed long back (Anon., 1970 a, b). This paper briefly reviews the work done on insect, disease and weed pests inflicting damage to arable crops in arid regions.

### ***Insect Pests***

Kushwaha and Bhardwaj (1977) dealt at length the pests of pearl millet, sorghum, gram, cowpea and clusterbean. Pal (1977) dealt the problem of white grubs and their management. Crop-wise reviews of the pests are available for pearl millet (Verma, 1980a, 1987a) and mung bean (Verma and Saxena, 1987). The incidence of different aphid species in arid regions has been documented by Joshi and Mathur (1967) and Vir *et al.* (1991). Batra *et al.* (1969) and Pal (1971) noted new species of *Myloccerus* weevils in Rajasthan and Pande (1971) reported the bionomics of *M. maculosus*. Verma (1987b) studied relative host preference of leaf weevils. Some of the new records of arable crop pests in Rajasthan are given in Table 1. Srivastava and Kavadia (1977) studied the persistence of soil insecticides in pearl millet and root crops like radish and carrots, and ruled out any hazards for crops grown on soils treated with very high dosages of insecticides.

### **Polyphagous Pests**

Kushwaha and Noor (1976) reviewed the soil inhabiting insects with emphasis on root grubs. Parihar (1981) covered the problem of termites in western Rajasthan. About 14 genera of termites damage crops in desert regions of Rajasthan (Parihar, 1985b). Verma and Joshi (1984) studied effect of intercropping on damage by *Microcerotermes tenuignathus*. Seed dressing with aldrin

Table 1. Some new insect pests reported from arid zones

Family	Name of the insect	Host	*Status
DIPTERA			
Anthomyiidae	<i>Atherigona miliaceae</i>	<i>Panicum miliaceum</i>	s
Anthomyiidae	<i>Atherigona naqvii</i>	Wheat	ms
Anthomyiidae	<i>Atherigona orientalis</i>	Wheat	ms
Chloropidae	<i>Anacamptoneurum obliquum</i> Becker	Pearl millet	m
COLEOPTERA			
Curculionidae	<i>Myllocerus laetivirens</i>	Pearl millet, mung bean	m
	<i>Cyrtozemia cognata</i>		
	<i>Cyrtozemia dispar</i>		
Meloidae	<i>Cyaneolytta coerulea</i> (Leuck.)	Pearl millet	
Melolonthidae	<i>Autoserica nathani</i> Frey.	Sweet potato, pearl millet	ms
Rutelidae	<i>Pachyrhinadoretus</i> sp.	Pearl millet (Adults on ears)	m
	<i>Rhinynptia</i> spp.	Pearl millet (Adults on ears)	
	<i>Schizonycha</i> sp.	Pearl millet (Adults on ears)	m
Cetoniidae	<i>Protaetia terrosa</i> Gory & Perch.	Clusterbean (adults on roots)	ms
Halticidae	<i>Chaetocnema basalis</i> Baly	<i>Panicum miliaceum</i>	
HEMIPTERA			
Pentatomidae	<i>Bagrada cruciferarum</i> (Kirk.)	Pearl millet	
Coreidae	<i>Mirperus jaculus</i> (Thunb.)	Pearl millet	m
Delphacidae	<i>Sogatella longifurcifera</i> (E.& I.)	Pearl millet	m
Aphrophoridae	<i>Clovia puncta</i> Walk.	Pearl millet	m
	<i>Poophilus costalis</i> Walk.	Pearl millet	m
Miridae	<i>Megacoelum stramineum</i> Wlk.	Pearl millet	m
Miridae	<i>Creontiades pallidus</i> Walk.	Pearl millet	m
Aleyrodidae	<i>Caudaleyrodes citrii</i>	Clusterbean	
	<i>Neomaskellia bergii</i> (Sign.)	Pearl millet	m
Lygaeidae	<i>Oxycarenus laetus</i> Kirby	Pearl millet	m
LEPIDOPTERA			
Tortricidae	<i>Cydia ptychora</i> Meyrick	Mung bean	m
THYSANOPTERA			
Phlaeothripidae	<i>Haplothrips</i> nr. <i>eragrostidis</i> Priesner	Pearl millet	m

\*s= Severe, ms= Moderately severe, m= Minor

30% EC @ 10 ml kg<sup>-1</sup> seed, followed by aldrin 5% dust @ 10 g kg<sup>-1</sup> seed was recommended for the control of *Microtermes mycophagus* in castor crop whereas against *Microcerotermes tenuignathus*, 10% BHC dust @ 10 kg a.i. ha<sup>-1</sup> was effective (Parihar, 1978). Interestingly, soil treatment with water extract of *Calotropis procera* leaves ( 1500 L ha<sup>-1</sup> ) or crushed neem seed kernel (50 kg ha<sup>-1</sup> ) protected the clusterbean crop, till harvesting, from termite attack occurring at one month stage of the crop.

A large number of scarabaeid root grubs occur in arid regions but the major species causing economic damage is the melolonthid *Holotrichia consanguinea*. Reports of *H. reynaudi* (= *insularis*) incidence in Rajasthan (Srivastava and Khan, 1963) could not be corroborated. It appears that heavy incidence of 61000 grubs ha<sup>-1</sup> (Pal and Doval, 1970) of *H. insularis* was in fact *H. consanguinea*. Agri-pasture and some silvipasture systems accentuate the problem of root grubs. Adults exhibit varying preferences of hosts in different regions. In arid regions, *Prosopis cineraria* and *Ziziphus* sp. constitute the most preferred hosts of *H. consanguinea*. Studies on the bionomics and control were undertaken by Rai *et al.* (1969). Detailed studies on the insecticidal control of the white grubs were initiated by Kaul *et al.* (1966), Sharma and Shinde (1968, 1970a, b), Yadava and Yadava (1973) and Pal and Doval (1970). Beetle management is the proper strategy for real long term relief from the problems since conventional soil insecticides are not much effective against the grubs, and re-infestation by egg laying of beetles from the wild is a recurrent problem. Campaigns for mechanical destruction of adults have not clicked in Rajasthan and as an alternative approach, defoliation of hosts around arable fields and spraying of select host trees spared with foliage is recommended. The insecticides found effective against adults are monocrotophos, carbaryl, endosulfan, etc.

Important grasshoppers damaging crops are *Pyrgomorpha bispinosa deserti*, *Chrotogonus trachypterus trachypterus*, *Ochrillidia affinis* and *Acrotylus humberianus*. Parihar (1992, 1993) studied the bioecology of grasshoppers and crickets in arid areas.

### **Katra or Red hairy Caterpillar (RHC)**

Host plants in arid zones have been listed by Verma (1983b) and control studied with insecticides (Verma, 1981; Verma, 1980b; Singh and Verma, 1984), chemical antifeedants (Verma 1981, 1990) and plant extracts (Verma and Singh, 1985). Singh and Verma (1984) and Vir and Singh (1985) studied the development of *A. moorei* on different host plants. Parihar (1979, 1985a) reported the ecology of the red hairy caterpillar.

### **Miscellaneous**

Mites constitute a relatively less studied group in arid regions. Mites have been studied by Srivastava and Mathur (1962) on castor mite, Khan *et al.* (1969) on wheat, Jain and Yadava (1989) on coriander and Sharma *et al.* (1991) on cucurbits. Shootflies are usually serious only on millets, although they are also reported on wheat (Joshi and Khan, 1968; Mathur and Mathur, 1968b).

## Crop Studies

### Millets

The insect pest problems in millets are not specifically serious. Reports of new pests in arid zones (Verma, 1979b, 1980a, c) relate only to minor or occasional pests. The damage by root grubs and sometimes termites are of concern. Root bugs (*Stibaropus minor* and *Aethus laticollis*), attacking pearl millet and hybrid napier in some pockets of Rajasthan, are so far absent in the arid regions. Among ear pests, blister beetles are more a nuisance rather than pests. However, adult rutelids are often serious pests causing damage to milky and ripening grains (Yadava *et al.*, 1973; Pal and Sharma, 1973). Rathore and Jain (1991) recommended dusting of BHC 10% or carbaryl 10% (besides endosulfan 0.07%) without regards to residue problem.

Saxena and Verma (1980) proposed cultivation of *Setaria italica* for relief from ergot of pearl millet. Both *Setaria italica* and *Panicum miliaceum* are not preferred hosts for most field pests and are not damaged by storage pests (Verma, 1988b). However, the efforts to introduce small millets had to be abandoned because of the extreme sensitivity of these crops to low soil moisture regime, poor production potential and susceptibility of *P. miliaceum* to shootfly at grain formation stage (Verma, 1988a). Both shootfly and stem borer do not usually damage the pearl millet crop in arid zones of Rajasthan but are serious pests in Gujarat. Raghvani *et al.* (1989) recommended spray of endosulfan 0.07% + dusting with methyl parathion 2% dust @ 20 kg ha<sup>-1</sup> at 14 and 28 days after growing of the crop for protection against shootfly. For stem borer, additionally, a higher seed rate of 5 kg seed ha<sup>-1</sup> and removal of dead hearts was recommended.

Intensive work has been done on pest management and screening of germplasm against major pests of sorghum and pearl millet under the All India Co-ordinated Research Projects. For sorghum shootfly, Subhedar *et al.* (1990) concluded that seed treatment with 5% carbofuran 50 SP was most profitable, followed by soil application of phorate 10G @ 10 kg ha<sup>-1</sup>. Early sowing, preferably in last week of June to first week of July affords sufficient protection to the crop against shootfly.

### Grain legumes

Verma (1987d) reviewed the pest complex of mung bean in India and listed the major, minor and new pest records from arid zones. Important pests include leaf weevils, pod borers and blister beetles. Parihar and Singh (1997) further included *Megalurothrips distalis* infesting flowers of mung bean. Verma and Henry (1988) studied the intensity of insect pests on different cultivars of mung bean. The pod borer *Cydia ptychora* (Verma, 1986) is not recorded on pulses other than mung bean and its perennation in arid regions is not understood properly. The sucking pests like aphids, jassids and whiteflies are important as vectors of virus diseases. The damage caused by these pests has been studied in moth bean and cowpea (Vir, 1984a, 1984c, 1986; Vir and Singh, 1985). Garhwal *et al.* (1994) studied the efficacy of different insecticides against *Aphis*

*craccivora*, the major pest species in cowpea. Foliar damage by leaf weevils and their management has been studied by Singh (1985) and Verma (1988c).

### Oilseed crops

An account of the pests of oilseed crops in Rajasthan has been given by Srivastava *et al.* (1962). In the early sown seedling stage crop of raya mustard, grubs of sawfly (*Athalia proxima*) and the painted bug (*Bagrada cruciferarum*) cause considerable damage. Joshi *et al.* (1989) reported that September - October sown crop escaped aphid attack but suffered 27 to 70 per cent loss in yield due to the painted bug (*Bagrada hilaris*) whereas November - December sown crop suffered 29 to 64 per cent loss in yield due to aphids. Kumawat and Jain (1987) reported the host cross-over of painted bugs in spring. *Lipaphis erysimi* is the major pest of mustard. Joshi and Kaul (1968) tested the efficacy of insecticides to various stages of the painted bug. Vir and Henry (1987) and Vir *et al.* (1990) recorded varietal difference in the susceptibility of different cultivars of raya mustard to the aphid *Lipaphis erysimi*. Vir *et al.* (1984b) gave economic evaluation of insecticides used to control aphids in mustard. Jat *et al.* (1993b) also reported varietal differences in mustard cultivars against the aphid. Varuna and Durgamani were less preferred by the aphid whereas Rohini and Kranti were more preferred. Delayed sowings result in higher infestation by the aphids. Kanwat and Kumawat (1995) found September 30 to October 15 as the best sowing time of mustard for minimum infestation by aphids and maximum seed yield in protected as well as unprotected crops.

Castor is an important oilseed crop of arid and semi-arid regions. Castor semilooper *Achaea janata* is the most important pest and mites constitute another major pest of the crop. Several perennial plants are reported as alternative host of the semiloopers (Kavadia and Verma, 1973; Singh *et al.*, 1991). The moths are important as fruit sucking moths on guavas (Verma and Gupta, 1972). Kapadia (1991) found that triple bloom varieties of castor were more susceptible to leaf miner than double or single bloom varieties.

Sesame is a poor man's crop and suffers much damage by leaf roller, sucking pests and sometimes suffers heavy damage by the death's head moth, *Acherontia styx*. Ahuja (1991) reported 12-68 per cent loss in seed yield due to leaf roller, *Antigastra catalaunalis* in different cultivars. Kumawat and Kanwat (1995) recommended spraying of monocrotophos or phosphamidon for the control of gall fly, *Asphondylia sesami*.

### Spice crops

The insect pests and their management has been studied for cumin by Gupta (1984) and for fennel by Kanwat (1988). *Hydaphis coriandri* is a serious pest on all spice crops like coriander, fennel, cumin and *isabgol*. The avoidable losses caused range from 18 to 49 per cent (Bhargava *et al.*, 1971; Kanwat, 1988). Gupta and Yadava (1986) opined that cumin varieties with high oil content were more susceptible to aphid attack than the varieties with less oil content. Dates of sowing also affect extent of aphid infestation in coriander (Jain and Yadava, 1986) and 55 to 70

aphids per 5 plants during flowering time caused 50 per cent reduction in the yield (Jain and Yadava, 1989). Similar estimates were made for the losses by *Myzus persicae* in cumin by Gupta and Yadava (1989). The pesticides recommended for management of aphids in most crops are phosphamidon, monocrotophos and dimethoate (Jain and Yadav, 1987; Kanwat, 1988).

## Plant Diseases

### Downy Mildew

In this region, pearl millet, mustard and Isabgol crops suffer heavily due to this disease. It appears as downy mildew and green ear stages in pearl millet. As a result of systemic infection, ears are deformed and all floral parts are transformed into twisted leafy structures giving the appearance of green leafy mass. The pathogen *Sclerospora graminicola* is both soil and seed borne in nature. However, Gupta *et al.* (1991) could not detect viable mycelium from the seeds found close to downy mildew affected parts and inferred that chances of transmission of the disease through seed in arid region are negligible. Mathur and Dalela (1971) recorded 18 to 27 per cent disease intensity in a survey conducted in eight arid and semi-arid districts of Rajasthan and estimated a loss of Rs. 20 million at the price level of 1964. Recently, Gupta and Singh (1996b) studied losses due to systemic infection and reported an yield reduction up to 57 per cent compared to protected crop. Among the yield components, plant height and test weight were inversely related to infection. Summer fodder crop has been found to harbour inoculum for the rainy season. Crop stubbles and self sown plants also harbour the pathogen during summer (Mathur and Mathur, 1967a). However, secondary spread of the disease through sporangia takes place at a 'simple interest rate'. Production of sporangia was observed to be nocturnal. The period for sporangial production from infected plants varied from 4 to 21 days. Relative humidity (70-90%), moderate temperature (25-31°C), good sunshine (5 h day<sup>-1</sup>) and mild rainfall favoured rapid secondary spread (Gupta, 1987).

Seeds of resistant variety contained more sugar and less crude protein than the susceptible ones. Gupta and Gupta (1984) reported increase of non-reducing, reducing and total sugars in the roots of resistant variety due to downy mildew infection. High soil moisture has been found to counteract the primary infection (Gupta and Gupta, 1988). Diffusive resistance in infected leaves was significantly higher than in healthy leaves. The lower rate of transpiration and increased diffusive resistance in infected leaves was attributed to altered cell permeability and inhibition in opening of stomata (Gupta, 1995).

Studies conducted on various management aspects revealed that soil application of boron (2.5 ppm), Zn (5 ppm) and Fe (5 ppm) was effective in reduced primary infection (Gupta and Singh, 1995). Incorporation of Jalshakti (20 g 8 kg<sup>-1</sup> soil) also significantly checked primary incidence of downy mildew. Also, flyash, silica gel and bentonite clay could contain the disease up to 30

days after sowing. Similarly, crop sown in NW-SE direction resulted in maximum reduction in disease incidence at 70 days after sowing (Gupta and Singh, 1996a).

Seed treatment with metalaxyl (Apron 35 SD) controlled the downy mildew up to 30 days after sowing. Seed dressing with Metalaxyl (5 g a.i. kg<sup>-1</sup> seed) followed by a spray of Ridomil ZM-280 FW (0.2% a.i.) at 23 days after sowing gave 77 per cent less disease incidence and 100 per cent increase in yield. Harvest time residues of metalaxyl were practically nil (Gupta, 1984; Gupta and Verma, 1991).

Resistance to downy mildew in NHB3 hybrid of pearl millet was studied by Singh and Singh (1987). Studies conducted on the role of A<sub>1</sub> cytoplasm on downy mildew susceptibility in hybrids showed that this source of cytoplasm did not confer additional susceptibility to downy mildew (Yadav *et al.*, 1993). Subsequently, role of other sources of cytoplasm like A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub> were also not found to be linked with downy mildew (Yadav, 1996).

Downy mildew of Isabgol caused by *Perenospora alfa* has become serious threat in recent years. Rathore and Pathak (1996, 1997) made efforts to manage the disease through integration of various strategies like low plant population (1.9 lakh ha<sup>-1</sup>) and by adopting line sowing instead of broadcasting.

## Ergot

Ergot, caused by *Claviceps fusiformis*, poses a major threat to pearl millet cultivation in arid and semi-arid regions (Arya and Kumar 1982; Joshi *et al.*, 1984; Kumar, 1985). Ergot incidence and grain losses up to 62 and 46 per cent, respectively, were recorded in ten cultivars of pearl millet (Kumar, 1978). It appears as small droplets of pinkish or light coloured fluid exuding from the spikelets in different parts of spike. The exudation dries up and in place of honey dew several agglomerated, dark, stocky-patches may be seen on the ear. Severely infected ears rarely produce healthy grains. The occurrence of disease under arid conditions was found to have close relationship with the climatic parameters (Saxena *et al.*, 1978). Subsequently, Gupta *et al.* (1983) reported daily optimum weather conditions for the disease development as 12 mm rainfall, 75 per cent relative humidity 20°C atmospheric temperature and sunshine for 6 hours from protogyny to early anthesis period.

Kumar and Arya (1978a) have studied variation in alkaloid content from different varieties that ranged between 0.182 to 0.364 per cent in honey dew and 0.160 to 0.548 per cent in sclerotia. These studies also revealed that different fertiliser applications to the crop influenced the toxicity of alkaloids independently. Kumar (1980) studied the effect of toxic substances present in sclerotia of the pathogen on germinating grains of pearl millet. A considerable inhibitory effect on root and shoot elongation and on germination was observed.

*C. fusiformis* isolated from ergot sclerotia produced honey dew like secretion on calcium nitrate agar medium (Kumar and Arya, 1978b), conidia from these cultures induced ergot symptoms upon artificially inoculating pearl millet hybrid HB4. Best growth and sporulation of

*C. fusiformis* was also supported by calcium nitrate medium (Kumar and Arya, 1984). Alternate light and darkness, 4.5 to 5.0 pH and 25°C temperature supported luxuriant growth and sporulation. Amongst carbon and nitrogen sources sucrose and ammonium nitrate supported best growth (Kumar and Arya, 1984).

Efforts have been made to select out potentially tolerant lines through tissue culture (Kumar and Arya, 1981). In this attempt, five varieties of pearl millet, B-389, J-88, PIB-228, HB-4 and HB-5 were selected to ascertain nature of tolerance by raising callus. In highly susceptible varieties almost all conidia that came in contact with callus surface germinated and germ tube penetrated the cells directly while in tolerant varieties only a small number of conidia germinated.

### **Powdery Mildew**

The disease is prevalent in most of the arid region on various economically valuable plants like wheat, cumin, mustard, mung bean (*Erysiphe polygoni*) and clusterbean, chilli and sesame (*Oidiopsis taurica*). Warm temperatures (28-35°C), dry weather and moisture stress favour the severe development and rapid spread of disease particularly in the month of February, March and October (Lodha *et al.*, 1986). High water content of the fungal conidia enables them to withstand such conditions.

Powdery mildew of wheat, *E. graminis* f. sp. *tritici* was one of the earliest disease studied from this region (Arya and Ghemawat, 1953). At least five physiologic races are reported. Arya (1962) has reported races 3 and 4 and new race named from Jodhpur. Ascospores germinate best at 16-20°C. High temperature of 30°C has deleterious effect on the disease (Arya, 1962). Ascospores are formed most rapidly at 22-27°C, if the cleistothecial material is exposed to alternate drying and wetting in soil (Arya, 1964). Although, most of the powdery mildews are favoured by dry weather, this is an exception in this respect and thrives well at low as well as high humidity.

According to Arya and Ghemawat (1953), asci and ascospores, even if formed, have practically no chance in nature to germinate and cause infection. Arya (1964) reported that asci remain immature in cleistothecia on fallen leaves but ascospores form in them after 10 minutes if the leaves are subjected to alternating dry and wet soil conditions. Earlier, varieties of wheat like NP 710, NP 718, K 53, E 750, C 591 were considered moderately resistant (Arya, 1962, 1966).

Chilli and cumin, two important cash crops of this region, also suffer heavily from powdery mildew (Lodha *et al.*, 1986; Mathur *et al.*, 1971, 1972; Singh and Lodha, 1985). Most of the varieties of chilli grown in western Rajasthan are highly susceptible to the powdery mildew caused by conidial state of *Leveillula taurica*. Singh and Lodha (1985) screened chilli collections and found 'B 15 R7', Padasali and Tinwari collections as moderately resistant. They also evaluated seven fungicides by slide germination technique and dinocap was found superior with lowest ED<sub>50</sub> and ED<sub>95</sub> values. In field evaluation also, dinocap and tridemorph gave 70 per cent control of powdery mildew. On cumin crop also, best control was obtained with dinocap.



## Leaf Spots and Blights

Seedlings of cowpea, mung and moth bean contract leaf spots caused by *Cercospora canescens* while *Myrothecium roridum* causes leaf spot on clusterbean (Arya, 1956, 1959) but the losses are not serious. On the other hand blights, particularly bacterial, cause serious losses. Bacterial blight on clusterbean caused by *Xanthomonas campestris* pv. *cyamopsidis* has been extensively studied. Lodha and Gupta (1981) and Gandhi and Chand (1985) recorded yield loss of 47-50 per cent at 69-72 per cent blight intensity under Jodhpur and Hisar conditions. Among yield components, number of pods per plant were most severely affected with increasing disease intensity. Jain and Chakarvarti (1988a) studied changes in transpiration rate due to bacterial infection and observed that rate of transpiration increased in blight infected leaves, which continued with increase in diseased leaf area. The bacterium is seed borne in nature. Growing the infected seeds of clusterbean in quartz sand gave maximum infection compared to other methods of detection (Jain and Chakarvarti, 1988b).

Biochemical components of resistant and susceptible clusterbean genotypes against bacterial blight were analysed by Mali *et al.* (1989). With severe infection amount of reducing sugar increased in all the genotypes studied. However, the per cent increase was the highest in resistant genotype HG 75 and lowest in highly susceptible Pusa Navbahar. They also identified glutamine synthetase as an additional parameter for determining relative resistance in clusterbean genotypes. Subsequently, Lodha *et al.* (1993) studied development of bacterial blight and changes in biochemical components in five genotypes of clusterbean. Lesser change in soluble carbohydrate, proteins and chlorophyll coupled with more changes in phenols and peroxidase due to blight infection in resistant HG 75 compared to susceptible genotype Pusa Navbahar partly accounted for the blight resistance in HG 75.

Seed treatment with streptomycin (250 ppm) proved effective in reducing disease incidence and increasing the yield (Lodha, 1984a, b). Foliar sprays with streptomycin (100-250 ppm) and Agrimycin-100 (100-500 ppm) also checked the secondary spread of disease. Under Jodhpur conditions, Lodha and Anantharam (1993) evaluated thirteen spray schedules of streptomycin and found that seed treatment (250 ppm) followed by two sprays (100 ppm) at 5th and 7th week after sowing significantly reduced the blight intensity. This combination provided an additional seed yield of 1.52 kg per rupee of additional investment on the antibiotic.

A large number of genotypes were screened and field resistance was observed in IC 9065, HG 75, G 40-23 and Hagle (Lodha, 1984b). Subsequently HG 75 was used as a resistant parent for evolving strains possessing multiple resistance (Lodha and Solanki, 1993).

A brown web blight of moth bean was reported for the first time. The disease affects all the above ground parts of the plant. Under warm and humid climate this disease spreads vigorously attacking petiole, stem and pods. A new leaf spot of clusterbean caused by *Curvularia lunata* was reported by Chand and Verma (1968). This pathogen also caused blackening of grains in ear heads of pearl millet (Mathur *et al.*, 1960).

Chickpea blight (*Ascochyta rabici*) caused epidemics in Sri Ganganagar district consecutively for three years (Gaur *et al.*, 1983). Studies on epidemiology showed a progressive decrease in above ground infection and increase in under ground infection with increase in depth of sowing (Gaur and Singh, 1993). Further, it was observed that crops sown with rows from north-east to south-west was affected maximum due to blight. Barley intercropping with chickpea yielded maximum followed by wheat-chickpea and mustard-chickpea intercropping (Gaur and Singh, 1994).

### Root Rots and Wilts

Certain agro-climatic factors of arid and semi-arid region are attributed to the development of some specific diseases like root rots and wilts. Low organic matter and microbial population, coupled with poor moisture retention capacity of sandy soils, favour survival and multiplication of soil-borne pathogens (Lodha *et al.*, 1986). In this region, diseases of aerial plant parts are much less common than those involving roots when plants are grown in dry region where humidities are low and rains are infrequent and of short durations. *Macrophomina phaseolina* is one such pathogen which has been extensively investigated. This ubiquitous pathogen has a wide range of hosts in commercially valuable plants like sorghum, sesame, cowpea, clusterbean, jojoba and *Euphorbia* (Bohra *et al.*, 1996; Lodha *et al.*, 1986; Singh and Lodha, 1983).

Studies have been carried out for the past two decades on the biology and pathology of *M. phaseolina* in aridisols. It was established by Lodha *et al.* (1990) that the highest population of *M. phaseolina* (233 sclerotia g<sup>-1</sup> soil) after harvest of clusterbean crop was at 0-5 cm depth followed by that of the 20-30 cm (150 g<sup>-1</sup> soil), 10-20 cm (93 g<sup>-1</sup> soil) and 5-10 cm layer (63 g<sup>-1</sup> soil). A sharp decline in *M. phaseolina* and a sudden upsurge of actinomycetes was observed in subsequent winter months. A significantly high negative correlation ( $r = -0.91$ ) between actinomycetes and *M. phaseolina* was established. It was also revealed that continuous and sequential clusterbean cropping increased the population of *M. phaseolina* but significant variations were recorded with sequences involving fallow or less susceptible crops (Lodha *et al.*, 1990).

Screening procedure to identify sources of resistance was also standardised. It was demonstrated that maximum expression of dry root rot required for screening germplasm can be secured by inoculation of seedlings grown in *M. phaseolina* infested soil at the time of moisture stress (Singh and Lodha, 1986; Lodha 1997). This procedure was used to screen large number of clusterbean lines. In the absence of complete resistance, RGC 471 and Kutch 8 were categorised as moderately resistant (Lodha and Solanki, 1993). These genotypes were used in breeding programme. Inheritance studies showed presence of epistasis in R x R crosses while appropriateness of additive dominance model for R x S cross (Lodha and Solanki, 1993).

It was observed that under similar conditions of soil moisture stress, genotype of a crop or different crops respond differently to *Macrophomina*, when cowpea, clusterbean and moth bean

were grown in grass-legume inter-cropping system, the effect of soil moisture stress was earliest discernible on cowpea which got heavy infection due to *Macrophomina* (Lodha and Singh, 1984). It was followed by clusterbean and moth bean in that order. This indicated that there exists a strong correlation between water stress in host and dry root rot incidence. In subsequent studies, it was observed that susceptibility of cowpea genotypes to *Macrophomina* increased with increasing moisture stress (Burman and Lodha, 1996). Cowpea plants became pre-disposed to fungal infection only after its shoot water potential declined below -14 bars, however, clusterbean and moth bean reached that stage at -18 and -20 bars, respectively.

Singh and Srivastava (1988) studied phenolic changes in moth bean during *M. phaseolina* infection and observed increase in the total phenolic contents with the age in germinating seedlings. Concentrations of the total phenolic contents increased in the pre halo portions surrounding the necrotic lesions of the diseased leaves.

Since the occurrence of *M. phaseolina* is linked to soil moisture stress, effect of varying levels of soil moisture on *M. phaseolina* populations and dry root intensity in clusterbean was studied. Studies revealed that mulching with a layer of pearl millet stover (3.5 tons ha<sup>-1</sup>), farmyard manure (10 ton ha<sup>-1</sup>) and low plant population (1.6 lakh ha<sup>-1</sup>), alone or in combination, effectively conserved available soil moisture during different stages of crop growth (Lodha, 1996). This resulted in increased population of resident bacteria with a corresponding decrease in sclerotial counts of *M. phaseolina*. Enhanced soil moisture and a decrease in *M. phaseolina* population significantly reduced the dry root rot intensity and increased seed yield of clusterbean. In cowpea also mulching resulted in enhanced soil moisture and reduced dry root rot incidence (Gupta and Gupta, 1986).

Effect of polyethylene mulching (soil solarisation) on the survival of *M. phaseolina* was studied. Polyethylene mulching considerably increased the soil temperature during June (Lodha, 1989). The maximum soil temperature at 2 P.M. in mulched plot was 58°C (wet) and 69°C (dry) at 5 cm depth compared to 53°C (wet) and 63°C (dry) in non-mulched soils. Elevated soil temperature and a shift in favour of antagonists reduced the population of *M. phaseolina* considerably (Lodha and Solanki, 1992). This technique was also effective in controlling population of weeds. Clusterbean crop raised in mulched plots remained disease free compared to 12-18 per cent mortality in control plots and resulted in 77 (dry) and 30 per cent (wet) higher grain yield. Soil amendments like FYM and Urea-N extended the efficiency of solarisation by restricting the rebound of *M. phaseolina* and *Fusarium* causing cumin wilt (Lodha, 1995). The treatments proved highly cost effective.

In a laboratory study, significant reduction in the population of *M. phaseolina* occurred in the mustard oil cake and pearl millet residue amended soil within 30 to 45 days. In mustard cake amended soil, total elimination of *Fusarium* population was also achieved (Sharma *et al.*, 1995). Combined effects of cruciferous residues and summer irrigation vis-à-vis soil solarisation were studied. Amendments of cruciferous residues augmented the efficiency of summer irrigation by

reducing 93-96 per cent population of *M. phaseolina*. Combining soil solarisation with amendments and summer irrigation almost completely eradicated viable propagules of *M. phaseolina* irrespective of soil depth (Lodha *et al.*, 1997a, 1997b).

Survival of propagules could be substantially reduced by fortifying the crop residues with 2 per cent to 4 per cent nitrogen during composting process (Lodha *et al.*, 1997c). To further bring down the population, exposing moistened composted material to natural heating (48-53°C) in the month of June was highly successful. Efficacy of composts prepared from different on-farm wastes was studied. A significant increase in micronutrients and microbial population accompanied decrease in the population of *M. phaseolina* and dry root rot incidence in all the compost-amended treatments (Lodha *et al.*, 1997c). Significantly higher grain yield was invariably recorded from compost amended plots compared to the crop-residue amended plots.

Seed treatment with carbendazim, has been found to effectively reduce pre- and post-emergence mortality caused by *M. phaseolina* in cowpea (Lodha, 1986; Singh and Lodha, 1986). Similarly, soil drenching with carbendazim was highly effective in reducing rotting due to *M. phaseolina* in Euphorbia (Singh *et al.*, 1984).

*Fusarium solani* and *F. acuminatum* also causes severe root rots in several arid land plants (Lodha *et al.*, 1986; Lodha and Singh, 1983; Kumar and Vishwanath, 1988). Polyethylene mulching was also found effective in reducing root rot mortality due to *F. solani* (Bohra *et al.*, 1996; Lodha and Vaidya, 1990).

Wilt of cumin, caused by *Fusarium oxysporum* f. sp. *cumini* is, the most serious disease in arid region (Mathur and Prasad, 1964; Lodha *et al.*, 1986). The pathogen from diseased material and the spores of pathogen on seed may be responsible for introduction of disease in new areas (Mathur and Prasad, 1964; Singh *et al.*, 1972). Mustard oil cake was found highly effective in reducing soil population densities of *Fusarium* (Sharma *et al.*, 1995).

*Neocosmospora vasinfecta* has also been found to cause slow wilt in clusterbean and cowpea plants (Lodha *et al.*, 1986). Among other weak soil borne pathogen *Cylindrocarpon lichenicola* has also been isolated from arid soils (Bohra *et al.*, 1996).

In arid region, *Ganoderma lucidum* was found to cause root rot diseases in several trees and other plantations (Lodha *et al.*, 1986). Twigs of *Ganoderma* affected jojoba plants started drying from top of the branch; leaves turned yellowish brown and finally abscised. Plants dried up within 3 months. Pathogenicity of the fungus was established by keeping the infected root segments in direct contact with roots of healthy jojoba plants which were subjected to moisture stress (Lodha *et al.*, 1994).

## Smuts

This group of diseases occurs less except in pearl millet and sorghum. Smut, caused by *Tolyposporium penicillariae*, may cause 40 per cent crop losses under favourable conditions. The disease is favoured by high humidity and high temperatures during flowering. Studies revealed

that three sprays of Calixin (0.1%) or Dithane M-45 (0.25%) were effective in controlling this disease (Gupta, 1984). Varieties CM 46, CJ 104 and MBH 110 of pearl millet have also shown better resistance to smut as compared to other varieties developed from 5141 A line (Joshi *et al.*, 1984). No association between CMS and smut incidence was observed while comparing the disease severity of 35 pairs of F1 crosses, each pair carrying male sterile or normal cytoplasm (Yadav, 1994 a, b; Yadav *et al.*, 1992).

Sorghum long smut, caused by *Tolyposporium ehrenbergii*, is generally important in low rainfall regions (Kumar, 1995). Kumar and Vishwanath (1991b) developed an illustrated rating scale for rating the severity of infection. The number of sori on infected panicle formed the basis of rating the severity. Seed treatment with thiram (2 g kg<sup>-1</sup> seed) proved more effective than carbendazim.

### Viral Diseases

Legumes, such as cowpea, mung bean, clusterbean and moth bean, are highly susceptible to number of viral diseases under rainfed conditions. The heavy incidence of yellow mosaic disease together with attack of white fly *Bemisia tabaci* and jassids *Empoasca kerri* is the major problem affecting the production of moth bean in arid region (Vir, 1980; Lodha *et al.*, 1986). The disease is not reported to be transmitted by sap, soil or seed. The vector *B. tabaci* acquires the virus within 15 minutes of acquisition feeding.

Rathore and Agnihotri (1995a) analysed biochemical components and found that per cent reduction in chlorophyll and carotenoid pigments in YMV infected plants was more in highly susceptible varieties compared to healthy ones. Other metabolites like phenols, nitrogen and crude proteins were also higher in diseased leaves of susceptible moth bean genotypes compared to healthy ones.

Yellow polyethylene mulching was found most effective in reducing YMV incidence, vector population and increasing the yield of moth bean (Rathore and Agnihotri, 1995b). Six genotypes IPCMO-943, IPCMO-1035, T-16, T-2, Jadia, PLMO-240 and PLMO-216 were found least susceptible to YMV under Jodhpur conditions (Vir *et al.*, 1984). At Fatehpur-Shekhawati conditions, IPCMO-131 was found free from YMV (Shekhawat and Bhardwaj, 1987).

### Phanerogamic parasites

Among phanerogamic parasites, *Striga lutea* var. *albiflora* is a common root parasite attacking pearl millet in Rajasthan, particularly in Sikar, Jhunjhunu, Alwar and Nagaur districts. This parasite causes losses up to 70-80 per cent. The affected plants remain stunted in growth and are pale looking in appearance. In the badly affected plants there is no grain formation (Mathur and Mathur, 1966). The minute seeds which remain viable for 20 years, are easily disseminated by wind within one field or to other fields (Anon., 1970b). The best control measure recommended was pre-emergence spraying of 2,4-D sodium salt followed by post-emergence application of the same chemical at the rate of 1 lb active ingredient acre<sup>-1</sup> dissolved in 80 to 100

gallons of water (Mathur and Mathur, 1966). Application of 20 kg nitrogen ha<sup>-1</sup> resulted in substantial decrease in striga plants and significantly increased yield of pearl millet (Mathur and Mathur, 1967b).

## Nematodes

Most of the nematode problems in arid lands relate to crops grown under assured irrigation. Surveys of rainfed crops have revealed the presence of *Tylenchorhynchus* sp. and *Pratylenchus* sp. on pearl millet, *Hoplolaimus* sp., *Pratylenchus* sp. and *Helicotylenchus* sp. on *Cenchrus ciliaris*, *Heterodera cajani* and *Meloidogyne javanica* and *M. incognita* on guar and *M. javanica* and *M. incognita* on mungbean ( Dutta *et.al.*, 1987; Jain, 1980; Gupta and Verma, 1990). On irrigated crops especially vegetables, fruits, pulses and spices, species of *Meloidogyne*, *Pratylenchus* *Hoplolaimus* *Tylenchorhynchus*, *Helicotylenchus*, have been reported (Yadav *et. al.*, 1970 ; Singh and Khera, 1978, Anon., 1985). The root-knot nematodes cause 91, 46 and 27 per cent yield losses in okra, tomato and brinjal (Bhatti and Jain, 1977).

On chillies soil application of carbofuran @ 2-4 kg a.i. ha<sup>-1</sup>, foliar spray application of carbosulfan or triazophos at 500 ppm, soil ammendment with mustard oil cake @ 2% w/w have been found effective in reducing number of root galls and soil and root population of *M. incognita* (Anon., 1991, 1992). More reliable, less cumbersome and simple methods for the screening of germplasm, using *in-vitro* techniques, have been developed (Kaul, 1994, 1997). In Haryana, *M. javanica* is considered as most important nematode pest of horticultural crops. Amendment of soil with chopped leaves of *Tagetes patula* or su-babool or castor @ 40 g kg<sup>-1</sup> soil has been reported to cause significant reduction in number of egg masses and total population of this nematode on tomato, brinjal and okra (Pruthi *et al.*, 1987; Zaki and Bhatti, 1989; Walia and Gupta, 1997). Application of neem leaf extract @ 40 g kg<sup>-1</sup> soil has also been found to reduce *M. javanica* population on chickpea (Kali Ram and Gupta, 1979). Similarly, intercropping of *Tagetes patula* with brinjal has been reported to suppress soil population of *M. javanica* (Jain *et al.*, 1990). Sensitiveness of plant nematodes to heat and drying has also been exploited variously for bringing down their populations below threshold levels. Ploughing of fields during summer months has been found to reduce nematode population drastically. Three summer ploughings (10-15 cm deep) at an interval of 10 days during the months of May and June in combination with bare root dips in phosphamidon at 1000 ppm for 8 h has been reported to decrease *M. javanica* population by 92.3 per cent in tomato (Jain and Bhatti, 1989). Similarly, in okra normal ploughing (10 cm) or deep ploughing (20 cm) followed by a fallow period of two months and application of aldicarb seed treatment and soil application of aldicarb @ 1 kg a.i. ha<sup>-1</sup> has been found to cause 79.2 and 76.3 per cent reduction in *M. javanica* population (Jain and Gupta, 1990).

Rodents in Indian arid zone are represented by one species each of porcupine and squirrel, 4 species of gerbils, 7 species of rats and 5 species of mouse. Beside these, other species inhabiting the arid regions are of minor importance in agriculture. However, species like *Gerbillus gleadowi*

and *Hystrix indica* may also acquire pest status occasionally. Like insect pests, there is no clear specificity of rodents for any particular crop. Generally speaking, *T. indica*, *M. hurrianae* and *R. meltada* may be considered as an important pest complex of arable crops of arid regions (Tripathi *et al.*, 1992). A brief account of each is given hereinbelow.

#### **Indian gerbil (*Tatera indica*)**

This gerbil is distributed throughout India. It is nocturnal and inhabits simple burrows. It breeds throughout the year and litter size varies from 1-9 (av. 4.78) with a gestation period of 28-30 days (Jain, 1970 and Prakash and Rana, 1970). Stomach content analysis revealed grasses, standing crops and insects as its food (Prakash, 1959; Parveen, 1992). It is found in association with *Meriones hurrianae* and *Gerbillus gleadowi* in eastern part of the desert and with *G. nanus* and *Rattus gleadowi* in western desert tract. In Haryana, Punjab and Gujarat this gerbil is found in association with *Bandicota bengalensis*, *R. meltada* and *Mus* spp. in crop fields.

#### **Indian desert gerbil (*Meriones hurrianae*)**

It is one of the most studied mammal, which inhabits exclusively the xeric regions of the country. Prakash (1981) has reviewed the CAZRI's findings on its taxonomy, distribution, population ecology, behavioural patterns, food, reproduction, adaptation for desert survival and the ventral scent marking gland of *M. hurrianae*.

#### **Soft furred field rat (*Rattus meltada pallidior*)**

This rat usually occurs in irrigated fields and is regarded as submesic in nature. It is nocturnal and lives in simple burrows. In Rajasthan desert, it breeds during spring and monsoon with a litter size of 3-9 (Rana and Prakash, 1984). It is a serious pest of wheat, mustard, groundnut, sugarcane, cotton, pulses and other vegetations.

#### **Mouse (*Mus* spp.)**

This group includes house mouse, *Mus musculus*, brown spiny mouse, *M. platythrix*, field mouse, *M. booduga* and fawn coloured mouse, *M. cervicolor*. Among these *M. musculus*, which is regarded as a commensal species have also been recorded from crop fields. Other three species are exclusively field mouse and *M. booduga* is recognised as a pest of arable crops. *M. musculus* breeds round the year with a litter size of 3-6 in laboratory and 1-8 in the fields. *M. booduga* litters during October (Prakash, 1975) in Rajasthan and during September, October, February and June in other parts. Rana *et al.* (1992) trapped house mouse from cotton, sugarcane and wheat fields in Sriganganagar district of Rajasthan.

#### **Mole rats (*Bandicota bengalensis* and *Nesokia indica*)**

*B. bengalensis*, the lesser bandicoot rat is considered a prime rodent pest of the country, however, this species is true mesic in the nature and was not found in western Rajasthan desert. With changes in landuse pattern and increase in irrigated agriculture due to incoming of Indira

Gandhi Canal, the bandicoots have invaded the northern Rajasthan. They are found in the areas which are under canal irrigation since last 60 years or more. *Nesokia indica*, the short tailed mole rat was first reported from Sriganganagar by Prakash *et al.* (1971). It is also a mesic rodent. It has now further spread up to Nagaur district (Jain and Tripathi, 1988a). The bandicoot is known to hoard upto 450 kg of food ha<sup>-1</sup> in their burrows. It breeds all the year round with a litter size of 4-12. Both the species are nocturnal and make mole hills at burrow openings.

### Losses due to rodents

Estimates of rodent damage to arable crops have been variously reported by several workers (Table 2), but for want of a common methodology these figures are not comparable. However, these reports spread over three decades span, clearly reveal very high degree of damage to the standing crops.

Table 2. Extent of rodent damage to arable crops in arid regions

Crops	Study Area	Stage	Extent of damage (%)	References
Wheat	Jodhpur	-	16.29-21.28	Advani and Mathur, 1982
	Jaipur	Seedling	0-1.90	Singh and Saxena, 1989
		Tillering	0.18-1.7	
		Jointing	0.68-2.42	
	Hisar	Seedling	2.2	Singhal and Pasahan, 1993
		Growth	4.1	
		Maturity	10.5	
Barley	Rajasthan	Overall	5.8	Prakash, 1978
Pearlmillet	Jodhpur	Seeding	100.0	Prakash and Mathur, 1987
	Punjab	-	107.7 kg/ha	Bindra and Sagar, 1968
	Gujarat	-	9.93	Anonymous, 1990
Sorghum	Rajasthan	-	5.8-6.3	Prakash, 1978
	Haryana	-	3.6	Chandana and Garg, 1987
Gram	Jaipur	-	2.14	Singh and Saxena, 1987
	Gujarat	-	7.27	Anonymous, 1990
Mustard	Jodhpur	Vegetative	33.2-45.2	Jain and Tripathi, 1992
Chillies	Jodhpur	Just sown	18.5-12.5	Advani and Prakash, 1984
		Vegetative	10.3-12.5	
		Maturity	26.5-29.5	

Rana *et al.* (1993) reported that squirrels and gerbils eat even the sown seeds before germination. In western Rajasthan, *G. gleadowi* proved most destructive during 1970 at sowing stage, when farmers of 4 districts had to resow pearl millet 3-4 times (Prakash, 1976). At harvest,



the bajra cobs from the field are heaped in the threshing yards near the huts. The gerbils mainly *M. hurrianae* and *G. gleadowi* follow the cobs, dig tunnels under the heaps and feed on bajra grains. In one such village, Prakash (1976) counted some 40 gerbils in a 15x40 m<sup>2</sup> area - a very high density of gerbil population. An upsurge in population of *T. indica* was noticed in 1989 during kharif in Rajasthan, which resulted in serious losses to bajra, mung and moth. Similarly, in chillies, *T. indica*, *M. hurrianae* and *R.m.pallidior* complex damaged 15-20 kg of fruits per ha per day at a very high population density of 142 burrows/ha resulting in about 40per cent damage to chilli fruits. In the rabi season, mustard is infested by rodents at vegetative growth stage when 33.2-45.2per cent plants are eaten away by rodents in the peripheral zones of the crops fields at a burrow density of 73.1ha<sup>-1</sup> (Jain and Tripathi, 1992). Three commonly grown wheat varieties, Kalyan sona, Kharchia and desi suffered an average damage to the tune of 16.29, 21.28 and 18.66 per cent, respectively (Advani *et al.*, 1982, 1988). Advani and Mathur (1982) observed the highest damage to radish and tomato and minimum (less than 5per cent ) to bottle gourd, sweet potato, okra and spinach. *Tatera indica* showed maximum preference for musk melon and kachra seeds, however seeds of ridge gourd and carpet beans were not preferred (Jain *et al.*, 1995).

### Management Strategies

The work on rodent control techniques have been exhaustively reviewed by Prakash and Mathur (1987), Jain *et al.*, (1993) and Rana *et al.* (1993). These techniques may be grouped as (i) non-chemical, and (ii) chemical measures.

#### Non-chemical measures

Trapping can be effective on its own on a limited scale (Jain *et al.*, 1992). Among cultural practices, reduction in bund size, light ploughing, flooding and removal of weeds have been reported to create stress for rodents leading to their migration from cropped areas (Prakash and Mathur, 1987; Pasahan and Sablok, 1987; Jain and Tripathi, 1994). Prakash and Mathur (1987) reported that *Opuntia* plantings on the bunds may also reduce the pest population. Similarly 20-30 m strip of unpalatable crop like guar or unpalatable grasses sown around the main crop would keep the immigrating rodents involved with the unpalatable crops and the main crop could be saved from rodent pests.

#### Chemical measures

A large number of acute rodenticides viz., scilliroside, RH-787, strychnine sulphate, sodium monofluoroacetate, barium carbonate and zinc phosphide have been evaluated in laboratory and fields against desert rodents (Prakash and Mathur, 1987). Among these, zinc phosphide is the most widely used rodent poison in India. It is highly toxic to a variety of desert rodents. Its LD<sub>50</sub> is 35 mg kg<sup>-1</sup> for *T. indica* and *M. hurrianae* and 250.0 mg kg<sup>-1</sup> for *M. musculus* (Prakash *et al.*, 1969; Rao and Prakash, 1981). It should be used at a concentration of 2.0% (W/W) in freshly prepared baits. Higher or lower concentration in baits results in induction of bait shyness among

rodents due to sublethal consumption. This behavioural manifestation among rodents persists for 10-104 days in different species (Rana *et al.*, 1993). Aluminium phosphide fumigation of rodent burrows also yielded significantly higher control success in irrigated crops of arid zone (Soni *et al.*, 1995). National Programme on Rodent Pest Management launched by Government of India and ICAR during 1975 also recommended aluminium phosphide fumigation as a follow-up measure after zinc phosphide baiting. CAZRI has evolved a new technique of bait preparation which is easy, simple and more economic than earlier techniques (Jain, 1986a). With the advancement in knowledge of anticoagulants several rodenticides have been evaluated against desert rodents. Warfarin, fumarin, chlorophacinone and coumatetralyl were found effective against a variety of rodent pests, however, these chemicals required multi feeding for 7-14 days for causing effective mortality of rodents (Mathur and Prakash, 1980, 1982, 1983). In eighties, single dose anticoagulants, referred to as second generation anticoagulant rodenticides, were introduced. Bromadiolone and brodifacoum, both proved highly effective against arid rodents at 0.005% conc. (Jain, 1986b; Jain and Tripathi, 1988c). Later, in the same series, flocoumafion was also introduced as a potent rodenticide (Jain *et al.*, 1992).

### Pearl Millet

The weeds normally found in millet crops are: *Cyperus rotundus*, *Cenchrus biflorus*, *Tribulus terrestris*, *Tephrosia purpurea*, *Pulicaria wightiana*, *Euphorbia hirta*, *Phyllanthus niruri*, *Crotalaria burhia*, *Avena tomentosa*, *Heliotropium arbulatum*, *Echinochloa colonum*, *Trianthema portulacastrum*, *Digera muricata*, *Amaranthus viridis*, *Physalis minima*, etc.

Under rainfed conditions, weeding considerably improves yields. The effect of weed control on grain yield is more marked in low rainfall years. Soil moisture content is higher in weeded than in unweeded plots. There is 25 to 50 per cent reduction in grain yield of pearl millet, if weeding is not done prior to 30-45 DAS. Primary tillage has profound influence on the control of persistent and perennial weeds (Singh, 1985).

Hand weeding causes minimal soil disturbance and helps in effective control of weeds. In situation where chemical control is economically feasible, herbicides are the best answer for weed problems in millet crops. However, very few chemicals are selective in millets (Rao, 1983). Propazine (0.5 to 1 kg ha<sup>-1</sup>) shows good selectivity and atrazine shows selectivity when applied at 0.5 to 0.75 kg ha<sup>-1</sup>.

Pre-emergence application of herbicides can help in reducing the rate of nitrogen application. Tomar *et al.* (1977) found it better to control weeds with atrazine at 0.5 kg ha<sup>-1</sup> and apply 60 kg N ha<sup>-1</sup>, instead of weed control by mechanical means and using 120 kg N ha<sup>-1</sup>. Uptake of N and phosphorus by different weeds increased progressively with an increase in time of weed removal and was maximum at 60 DAS in *Echinochloa colonum* and 50 DAS *Trianthema portulacastrum* and *Digera muricata* (Singh and Yadav, 1994a). They further observed that weed removal at 20 DAS resulted in significantly higher nutrient uptake by grain as compared to other stages of weed removal.

Singh and Yadav (1994b) found that two hand weedings + application of 0.5 kg atrazine ha<sup>-1</sup> and 0.75 kg terbutryn ha<sup>-1</sup> significantly decreased the N and P uptake by weeds, compared to one hand hoeing + one hand wheel hoeing, application of 0.25 kg atrazine ha<sup>-1</sup> and 0.5 kg terbutryn ha<sup>-1</sup>. Maximum N and P uptake by grains and stover was recorded in clean weeded treatment and minimum in unweeded control.

Carpet weed and barnyard grass reduce the pearl millet yield to an extent of 16 to 94 per cent (Umrani *et al.*, 1980). Carpet weed (*Trianthema portulacastrum*) and barnyard grass (*Echinochloa colonum*) constituted 97 and 94.2 per cent of the total weed population in pearl millet in unweeded check (Balyan *et al.*, 1993). They observed that application of atrazine 0.25 or 0.50 kg ha<sup>-1</sup> at 7 or 14 DAS proved highly effective against most competitive and aggressive weeds like carpet weed and barnyard grass. The effect of atrazine at 7 or 14 DAS was better than its pre-emergence application and its application at 21 DAS failed to control these weeds. Pre-emergence application of atrazine has been reported quite effective against weeds in pearl millet (Malik *et al.*, 1980).

Singh and Prasad (1991) found atrazine applied at 1 kg ha<sup>-1</sup> as pre-emergence best amongst the other herbicidal treatments (alachlor 2 kg ha<sup>-1</sup> as pre-emergence, Methabenzthiazuron 2 kg ha<sup>-1</sup> as pre-emergence and dicamba 0.9 kg ha<sup>-1</sup> at 20 DAS). Hand weeding at 30 DAS and atrazine 1 kg ha<sup>-1</sup> gave green fodder and dry matter yield at par to that of weed free check.

One post-emergence cultivation of 5 cm depth done 20 days after emergence substantially reduced weed population, lowered bulk density and increased root growth of pearl millet (Gupta and Gupta, 1982). Average grain yield of pearl millet increased from 3.4 to 11.8 q ha<sup>-1</sup> with post-emergence cultivation. Deep tillage prior to planting pearl millet was effective in reducing infestations of *Cyperus rotundus* and *Cenchrus biflorus*. At Jodhpur, weed control through pre-emergence application of atrazine (1 kg a.i. ha<sup>-1</sup>) increased the grain yield by over two-fold (Singh, 1985).

A combination of herbicides and mechanical methods is more economical and effective than either used alone. Tomar and Singh (1973) observed that repeated ploughings have no advantage over zero or minimal cultivation in pearl millet.

## Clusterbean

Kumar *et al.* (1996) found no adverse effect on plant height and yield attributes (no. of grains pod<sup>-1</sup>, test weight) of clusterbean when it was in competition with weeds. Grain yield increased significantly when plots were kept weed free up to 15 DAS and beyond.

Solarisation reduced the weed population and growth (dry weight) by 75 and 60 per cent respectively, compared to non solarised control (Lodha, 1995). The common weed species reduced were: *Cenchrus biflorus*, *Boerhavia diffusa*, *Gisekia pharnaciodes*, *Crotolaria burhia* and *Portulaca* sp. Polyethylene mulching was also effective in controlling the weed population in standing crop; reduction being greater in the wet mulched plots (Lodha and Solanki, 1992). They

further observed that reduction in weed population increased the yield in wet mulched plots which was 77.4 and 30.2 per cent higher than that in the dry and wet non-mulched plots, respectively. Gupta and Gupta (1983) observed reduced weed growth and population in legumes with grass mulching.

Pre-plant incorporation of fluchloralin at 1.0 kg ha<sup>-1</sup> provided 84 per cent weed control and grain yield of clusterbean was at par with that from one or two hand weeding or weed free treatments and it was superior to all pendimethalin treatments (Kumar *et al.*, 1994). Pendimethalin application 0.5 to 1.5 kg ha<sup>-1</sup> resulted in decreased density and dry weight of *Chenopodium album* after 230 days of herbicide application. Pendimethalin residues remain in soil after 230 days of its application caused a reduction of 46 per cent in population, 63 per cent in shoot dry weight and 40 per cent in root dry weight of *C. album*.

Zero tillage was very effective in controlling *Cyperus rotundus* as the rhizomes do not become free to sprout. Dicot and grasses showed less presence (Jalaja Kumari *et al.*, 1987). There was no difference among ploughing the land once or twice or leaving fallow.

### **Moth Bean**

Seed yield of moth bean is reduced by weed competition. One to two hoeings, starting 20 DAS may be done to check weeds. Basalin or treflan 1.5 kg ha<sup>-1</sup> pre-plant incorporation controls the weeds effectively (Henry and Singh, 1985).

### **Cumin**

Pre-emergence application of pendimethalin 1.0 kg ha<sup>-1</sup> with one hand weeding at 30 DAS gave effective weed control on sandy loam soil and recorded 56.8 per cent higher seed yield (892 kg ha<sup>-1</sup>) and higher B:C ratio (22.4:1) than conventional two hand weeding (569 kg ha<sup>-1</sup>) in cumin (Parihar and Singh, 1994).

### **Pesticide Use and IPM**

Residue hazards of commonly used insecticides have been studied in mung bean (Verma and Saxena, 1988a, b; Singh, 1991, 1994). In view of the poor resource base of arid zone farmers in general, and with environmental concern in particular, strategies for IPM are receiving attention, especially in the canal command areas growing irrigated crops under diverse pesticide umbrella. Already problems of pest management have grown out of control in crops like cotton and cruciferous vegetables. Verma (1994) stressed on non-pesticidal approach for polyphagous pests such as red hairy caterpillar and white grub. Reports of natural biocontrol agents are there (Mathur and Mathur, 1968a; Mathur *et al.*, 1970; Mathur, 1971; Verma, 1983a; Verma and Gupta, 1988) but their field application is a far cry. Vir and Verma (1997) dealt at length the prospects of non-hazardous neem based pesticides for agroforestry, silvipasture and agricultural applications.

## **Transfer of Technology**

Farm bulletins to create awareness of Integrated Pest Management (IPM) among the farmers were published by Verma and Kavadia (1968) for sorghum and maize, for pearl millet by Verma (1988c) and by Vir *et al.* (1987) for general plant protection. The technology of IPM has been spelt out for hairy caterpillars (Verma, 1982) and white grubs (Yadava *et al.*, 1975; Anon., 1991). Verma and Kavadia (1969) and Joshi *et al.* (1984) listed the technologies of weed, insect pests and disease management in millets.

Rodent management technology evolved by CAZRI is easy to operate, quick result oriented and cost-effective. These can easily be translated into practice in the farmers' fields. Transfer of rodent management technology has been one of the most important mandates of institute. AICRP on Rodent Control operates a unique programme of social engineering activity on rodent control, wherein the scientists conduct various field experiments at farmers fields in the process of technology assessment and refinement. CAZRI, Jodhpur is also the main centre of Apex Level Training on Rodent Control, which organises trainings for senior officials of key departments of North-western states and union territories. So far, twelve such trainings have been organised. Besides this the Institute provides trainings to all the strata of Govt. and non-governmental organisations. Trainings to the farmers under on and off-campus programmes are regular features of the Institute.

## **Future Strategies and Approach**

Verma (1997b) discussed the research priorities of plant protection in arid zones. Accentuating problems of pests, considerations of environment and consumer safety, growing cost of inputs and desirability of greater reliance on non-monetary inputs in peasant agriculture (Verma, 1997c), all indicate toward need of resistant or tolerant cultivars, proper monitoring and if possible, forecasting of pest incidence, use of non-hazardous narrow spectrum pesticides or judicious use of broad spectrum pesticides. Concomitant farmers training in IPM technologies and institutional support for biocontrol measures are all the same necessary.

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## FORESTRY RESEARCH IN ARID TRACT OF INDIA

J.C. Tewari and L.N. Harsh

Forests are Nature's most beautiful and versatile renewable resource, providing a wide range of economic, social, environmental and cultural benefits. India is the seventh largest country in the world with land area of 328.8 million ha with a human population over 900 millions. In terms of cattle population, it is at the top of the list of countries. The forest area as per estimate of 1993, stands at 640.10 thousand sq km, which accounts for 19.47 *per cent* of country's geographical area (Anon., 1995).

The national forest policy of 1988 aims at restoring ecological balance and conservation of country's natural heritage by evolving socially acceptable, technically viable and ecologically sustainable management practices. The policy lays emphasis on scientific research to achieve these objectives. Likewise, Agenda 21 in Rio Conference recognised the world wide importance of conservation and management of forests through involvement of common people. According to conservative estimates, arid zones and their advance effect around 400 million people directly or indirectly (Duhart, 1985). Desertification processes represent a struggle in which man and land are engaged. It must be admitted that man himself, or the increase of his population and of his livestock, contributes to the expansion of desertification processes. And, yet, he suffers the worst consequences of such processes, by having to be satisfied with left over of the land. Currently, between 36 *per cent* and 43 *per cent* of the Earth's area is rated as deserts including parts of Indian sub-continent especially, north-west part of India and south-east to south-west part of Pakistan.

The arid regions of Australia, the USA, Arabian peninsula, Israel and some other petroleum rich countries meet out most of their domestic energy demands through kerosene oil, natural gas or other petroleum products, and contrary to this, in arid zones of India, the natural vegetation forms the chief source of fuel, besides, contributing to the requirement of small timber and fencing material (Kaul, 1963). Baumer and Ben Salem (1985) while discussing the role of forestry in the control of desertification emphasised that forest trees and perennial vegetation have a definite and positive role to play in such development. The importance of this role lies in the fact that this vegetation cover :

- acts as a soil stabiliser, and prevents water and wind erosion thus leading to increased food production;

- is an important source of forage for livestock and wildlife, particularly during critical period when green fodder is not available;
- serves as a source of firewood, charcoal, poles, timber and other minor forest products; and
- contributes to environmental amelioration under critical arid conditions.

Though the functional allocation of land for agriculture and forestry exists in almost all the parts of the world, it is rarely practised. This is primarily because of greed and political interventions. Systems for enhancing productivity under different landuses are available but, its full benefit is not achieved mostly due to short sighted policies for quick gains (Tewari *et al.*, 1989a). In arid regions of India the land which is not suitable for agriculture is continuously being brought under plough which in turn damaging the fragile ecosystems in the region. Forestry has both protective and productive roles in arid land development but, it can not be considered as the "user of residual land". The need of hour is the integration of forestry in rural landscape through various eco-friendly and economically viable approaches. .

Though over all situation of forest cover in arid region of western Rajasthan is very gloomy, but it is heartening to note that forest cover in this part, according to 1993-94 survey registered as increase of 16 *per cent* over the forest cover estimated in 1984-85 (Anon., 1987, 1994a, b). This clearly reflected increasing awareness among masses regarding vital role of trees and forests for sustenance of vital life support systems.

Beginning of R&D activities in the field of arid zone forestry dates back to establishment of Desert Afforestation Centre at Jodhpur in 1952. The very first task taken into hand was establishment of forest nurseries at many places in arid western Rajasthan for large scale plantation forestry programmes on sand dunes and sandy plains (Bhimaya and Kaul, 1960). Following discussion essentially deals with various important aspects of arid zone forestry research and development in western Rajasthan.

## **Nursery Development**

Afforestation through direct seeding in arid regions often fails due too harsh climatic conditions (erratic rainfall, long moisture stress, high temperature, poor water holding capacity of soil, etc.) and also due to hard seed coat dormancy of majority of tree species (Sen, 1977; Bohra *et al.*, 1995). Thus nursery raised seedlings of various tree species are only alternative for plantation activities in arid land forms (Kaul, 1963).

The techniques evolved during the successive years are: Selection of sites, size of beds and depth, standardisation of container size and type, nursery media, time of seed sowing, depth of seed sowing, irrigation frequency in nursery during different stages of seedling growth, fertiliser requirement of growing seedlings, etc. (Kaul 1964 a, b; Mann and Muthana, 1984; Tewari *et al.*, 1990; Mutha *et al.*, 1995). In the recent past, advanced nursery techniques have been standardised

to develop quality seedlings. Vegetative propagation techniques to get true to type individuals have also been given greater emphasis (Anon., 1996).

The significant achievements of nursery research are:

- Nursery should be established at two site i.e., central nursery, where all facilities like, necessary inputs and sufficient equipments are available, and field nurseries, which should be closer to plantation sites. In both the nurseries optimal conditions for raising of nursery should be available (like good quality of water, fertile soil, etc.).
- Nursery beds side should be 5 x 1 m in size. The one meter width of the nursery bed is optimal for weeding and irrigating the stock.
- *Pucca* (cemented or polyethylene lined) beds are more effective than the *Kutchra* beds as they prevent the seedling root penetration in the soil.
- Polypots of size 10" x 4" are most suitable for optimum seedling growth. Black polyethylene tubes are better than white ones to prevent the algal growth.

Though polypots are good for raising of tree seedlings but, in these seedling roots often get coiled, and many times penetrate in bed soil. Due to root coiling, growth of seedlings often gets suppressed on the field. Similarly, due to root penetration in the soil, at the time of outplanting, seedlings generally suffer from root shock and in turn per cent survival is badly affected. Therefore, now emphasis is on root trainers as alternative to polyethylene bags. In root trainers, as soon as roots come out from the containers, they come up in contact with air and get dried up as they are kept on elevated platforms. Due to this very fact, more fibrous root system is developed in seedling and more root volume is achieved. The seedlings developed in root trainers are more handy as far as transportation and plantation activities are concerned and such root trainer raised seedlings perform better than the seedlings raised in polyethylene bags.

- Soil media for polypots and root trainers have been standardised. In polypots 2:1:1 ratio of sand : clay : FYM is most suitable, where as in root trainers soil media should be more porous. For that, Peat, weed compost, perlite (gravel) and pure sand have been found most suitable.
- Sowing depth for different tree species have been standardised. The sowing depth of seeds depends on the size of seed. The seeds of *Eucalyptus*, Chenopods are very light and small, therefore, such seeds are placed on the media surface of the container with slight covering of soil or the media used specifically, whereas for most of the seeds of other species sowing depth is almost one cm. In case of Jojoba, 1/4th part of seed should be kept out (i.e., in air) from micropilar end and rest in side the soil mix or other media used in containers.
- Irrigation schedule in the nursery have also been standardised. During early period i.e., upto first 30 days of seedling growth very light irrigation twice a day is to be given. Thereafter seedlings should be irrigated daily @ 25 ml water/seedling upto 120 days of seedling growth. After this period alternate day irrigation at the rate of 25 ml water/seedling should be applied upto field out-planting. Most of the arid zone tree seeds have hard coat dormancy and

therefore they require specific pretreatments to break the seed coat dormancy (Tewari and Harsh, 1997).

## **Evaluation of Tree Species from Isoclimatic Regions**

The temporal and spatial variations in physical conditions of arid region of Rajasthan resulted in diversified phyto-geographic stock. But, in general, the vegetation consists of scrubs with dominance of thorny xerophytic plant types. The plant communities in this region are found in several stages of degradation (Kaul and Ganguli, 1964). Therefore, it is rare to find optimal proportions of different components of natural plant communities on different land forms; there is great scope for plantations as certain land forms are more favourable for afforestation. The most common native woody species in this region are:

Trees: *Acacia nilotica*, *A. leucophloea*, *A. senegal*, *Anogeissus rotundifolia*, *Prosopis cineraria*, *Salvadora oleoides*, *S. persica* and *Tecomella undulata*.

Small Trees and Shrubs: *Acacia jacquemonti*, *Balanites aegyptica*, *Calligonum polygonoides*, *Calotropis procera*, *Flacourtica indica*, *Gymnosporia spinosa*, *Leptadenia pyrotecnica*, *Lycium barberum*, *Mimosa hamata* and *Ziziphus nummularia*.

All these species are extremely slow growing and moreover, general environmental conditions of this part do not support their much required regeneration. Therefore, it becomes necessary to introduce the species of relatively higher growth rates and at the same time tolerant to draught and frost. Efforts in this direction were initiated in early sixties (Bhimaya *et al.*, 1964; Kaushik *et al.*, 1969; Mann and Muthana, 1984; Tewari *et al.*, 1989b; Harsh *et al.*, 1993). These involved introduction of both exotic and indigenous (from other arid part of the country) tree/shrubs species from isoclimatic regions. Till date over 500 accessions of about 300 species have been evaluated through long term screening trial for their adaptability and growth performance in arid western Rajasthan. The exotic species introduced owe their origin to Israel, Australia, USA, Russia (former USSR), Chile, Peru, Sudan, Kenya, Argentina, Zimbabwe, etc., and tried at Jodhpur (deep sandy soil; mean annual rainfall = 366 mm) and Pali (shallow soils ranging from 15 to 23 cm in depth with overlying hard calcareous pan; mean annual rainfall = 411 mm). Adaptability and growth performance of these species have been documented by Tewari *et al.* (1993a, b), Harsh *et al.* (1993), Hocking (1993) and Tewari *et al.* (1997).

In general, performance of *Eucalyptus camadulensis* and *E. terminalis* was found to be better than any other *Eucalyptus* species in both the locations. Excepting *Acacia cyclopsis* and *A. ligulata*, others have flowered and produced viable seeds. *A. tortilis* has proved to be most promising introduction having a mean annual increment (MAI) rate in height and dbh around 78 cm and 1.1 cm, respectively at Jodhpur and 77.2 and 0.7 cm, respectively at Pali. The performance of this species has been particularly good on shifting dunes and skeletally soils (Mann and Muthana, 1984). However, the farmers are not able to accept this tree as its undergrowth of arable

crops had not been comparable with that under *Prosopis cineraria*, a climatic climax species of arid region.

### **Choice of Species and Afforestation in Arid Land Forms**

About 58 per cent area of arid western Rajasthan is covered by drifting and semi-stabilised sand dunes which at some places are as high as 100 m (Raheja and Sen, 1964; Harsh *et al.*, 1989). In fact, in low rainfall areas (150 mm to 400 mm), human and animal interference with native vegetation has given rise to shifting sand dunes. Due to high wind velocity the sand drifts from the dunes and creates lot of problems for near by agricultural fields, canals, wells, buildings and communication channels. Techniques for afforesting shifting sand dunes were standardised after experimentation of a decade (Kaul and Ganguli, 1964) and modified time to time to get better tree establishment rate and obtain higher production (Kaul, 1985; Harsh and Tewari, 1993; Kavia and Harsh, 1993; Harsh *et al.*, 1995; Harsh and Tewari, 1997). In addition to sand dunes, there are other degraded habitats in western Rajasthan viz., sandy plains, shallow soils, rocky areas and saline patches. Planting technique and choice of species vary from situation to situation.

There is a lack of data on the subject of productivity (either biological or economic) of sand dunes from India. Shifting sand dunes, when afforested as per the techniques developed by CAZRI, Jodhpur, have at the end of 5 years produced a wood yield of 15 to 20 t per ha in 200-360 mm rainfall tract (Kaul, 1985). *Acacia tortilis* has proved to be very promising on sand dune. In Barmer region (rainfall zone = 280 mm), seven years old trees attained an average height of 7 m and average fuel yield per ha was in the order of 25 t at the rotation of ten years.

In order to assess the optimum age of exploitation of *P. juliflora* trees for fuel yield, a study carried out in five habitats of sandy areas representing different mean total annual rainfall zones, indicated that the average fuel wood yield vary considerably with age of trees and location.

Experience in dune afforestation has shown that despite the apparent similarity of sites in sand country, they are not homogenous. Different tree growth responses occur, apparently affected by measurable or observable factors. The most important factors governing tree establishment and growth on sand dunes are climatological, edaphic and hydrological. An overall economic analysis of sand dune stabilisation programme by vegetative methods in arid western Rajasthan revealed that the return from per rupee investment ranged between Rs. 1.83 and 3.58 depending upon the localities (Kalla, 1974).

### **Species Selection for Tree Products**

Trees can always be used. In arid tract of India, there is continuous deforestation and degradation of wood lands with ever increasing human and livestock population, essentially for meeting fuel wood and fodder needs. But local population, especially rural folk with their ingenuity have selected various drought hardy and multiple use species of trees and shrubs for sustainable production according to climatic and edaphic features of landscape (Saxena, 1997).

As population grew, more land came under cultivation and more pressure was applied to the remaining forested land to provide the range of products needed for domestic and industrial purposes. As long as there was sufficient tree rich landscapes these needs were easily met. But rather suddenly, the era of "sufficient" woodlands ended. In such situation species selection for tree products on the basis of demand and supply conditions are of prime importance. Besides native woody species, a number of exotics which have potential to adapt in environmental conditions of arid zone are identified for many tree products through long term trials (Tewari *et al.*, 1993a, b; Mann and Muthana, 1984; Hocking, 1993; Tewari, 1997). Table 1 summarises a list of useful tree species recommended for small and as well as large scale plantation forestry activities on the basis of tree products.

Table 1. Species selection for tree production (Ratings of trees for various uses)\*

Tree species	Rating of tree quality for				
	Fodder	Fuel	Timber	Erosion protector	other products
<i>Acacia albida</i>	8	7	7	5	-
<i>Acacia aneura</i>	3	5	3	6	-
<i>Acacia auriculiformis</i>	2	6	2	8	-
<i>Acacia leucophaloea</i>	6	5	5	4	-
<i>Acacia nilotica</i>	7	10	8	5	-
<i>Acacia salicina</i>	2	3	4	7	-
<i>Acacia senegal</i>	5	7	6	4	8(G)
<i>Acacia seyal</i>	7	5	4	6	-
<i>Acacia tortilis</i>	5	7	8	6	-
<i>Ailanthus excelsa</i>	6	3	3	4	-
<i>Albizia amara</i>	7	7	4	5	-
<i>Albizia lebbek</i>	4	6	5	4	-
<i>Anogeissus latifolia</i>	5	7	3	6	9(G)
<i>Anogeissus rotundifolia</i>	5	7	3	7	5(G)
<i>Azadirachta indica</i>	6	5	6	4	-
<i>Balanities aegyptica</i>	6	4	3	6	-
<i>Bauhinia variegata</i>	8	5	3	5	-
<i>Boswellia serrata</i>	5	7	6	5	5(OR)
<i>Capparis decidua</i>	2	3	3	8	-
<i>Casia siamea</i>	4	7	6	5	-
<i>Colophospermum mopane</i>	8	6	4	7	-
<i>Commiphora wightii</i>	7	6	2	7	7(OR)
<i>Cordia rothii</i>	5	5	3	6	-



<i>Dalbergia sisso</i>	3	5	10	2	-
<i>Dichrostachys cineraria</i>	6	4	3	10	-
<i>Emblica officinalis</i>	4	4	3	4	-
<i>Eucalyptus camaldulensis</i>	1	6	8	5	3(G)
<i>Eucalyptus tereticornis</i>	1	5	7	4	3(G)
<i>Ficus religiosa</i>	7	4	4	6	-
<i>Grewia tenax</i>	8	5	4	3	-
<i>Hardwickia binata</i>	9	8	8	5	-
<i>Holoptelia integrifolia</i>	3	3	3	6	-
<i>Parkinsonia aculeata</i>	1	5	3	9	-
<i>Phoenix dactylifera</i>	1	4	8	2	-
<i>Pithecelobium dulce</i>	8	5	5	6	-
<i>Pongmia pinnata</i>	6	7	4	5	-
<i>Prosopis cineraria</i>	10	8	8	4	-
<i>Prosopis juliflora</i>	5	9	8	8	4(G)
<i>Salvadora oleoides</i>	4	5	5	7	-
<i>Tamarix aphylla</i>	2	5	4	8	-
<i>Tecomella undulata</i>	3	5	10	5	-
<i>Zizyphus mauritiana</i>	6	8	7	5	-
<i>Zizyphus nummularia</i>	8	3	3	7	-

\* Rating are, the higher the numbers (range 1 to 10), the better it is and the higher the quality for that use, relative to other trees, G = Gum; OR = oleo-rasins

Source : Hocking (1993)

### Shelterbelts and Their Usefulness

Shelterbelts have been widely recommended and adopted in a number of countries such as Australia, Canada, China, USA., USSR and India (Mann, 1985). The use of shelterbelts has been found to be very effective where trees easily grow, but in arid areas there is limited choice of trees to be grown as windbreaks. The establishment of shelterbelts depends on the proper choice of tree species.

The shelterbelts have been found to be extremely useful in increasing productivity of agricultural lands in arid and semi-arid regions by providing protection against sand drifting and modifying the microclimate (FAO, 1974).

Shelterbelts are generally planted across and on the margins of agricultural fields (Ganguli and Kaul, 1969). Successful shelterbelts of *Acacia nilotica* var. *indica* and *Dalbergia sisso* over a 102 km length were established at the Central Mechanised Farm, Suratgarh in Bikaner district. According to Bhimaya *et al.* (1958), Bhimaya and Choudhari (1961) and Kaul (1969, 1970), the soil working consisted of digging ditches of triangular cross-section, i.e., 45 cm wide and 45 cm

depth along the planting line with a mechanical ditcher. Seeding of *A. nilotica* var. *indica* was carried out on either side of the ditch such as that the sown lines remained just above the irrigation water level, whereas the pre-sprouted stumps of *D. sisso* were planted in the pits.

For successful plantation of tree species in shelterbelts, planting pits of 60 x 60 x 60 cm should be dug out and half filled with the loose weathered soil before planting with the onset of rains in the month of July. Sturdy seedlings of 9 to 10 months should be planted in the pits provided with saucer-like depressions around the plants in plains. Crescent shaped ridges of 15 cm high are formed across the local slope if planting is to be done on slopes so as to arrest the run-off water during monsoons. Plantation of tree shelterbelts in saline areas is only possible by ripping open the pan to a depth of a metre by a tractor (D.C. 8 crawler type) followed by cross harrowing. Once the pan is broken, the area should be cross harrowed to break the crust formation. After this operation, ridges of 1 metre wide at the base and 1 metre high are constructed with the help of dosers. The inter-ridge space is about 1.5 to 2.0 cm. Planting is carried out on the crest of ridges to lower depth providing better soil condition and rooting depth for increased transplant establishment and growth.

Kaul (1969) suggested five row shelterbelts with a pyramidal shape for arid conditions of western Rajasthan. Shelterbelts consisting of a row of tall trees viz., *Acacia tortilis*, *Tamarix articulata* or *Azadirachta indica* flanked by two rows of smaller trees like, *Acacia senegal*, *Prosopis juliflora*, or *Parkinsonia aculeata* with two rows of shrubs like *Aerva tomentosa*, *Ziziphus spina-christi*, *Calligonum polygonoides* (duny habitats) found to be suitable under western Rajasthan conditions. Such a shelterbelt would be effective up to a distance of 15-20 times the tree height depending upon the particular conditions (Harsh *et al.*, 1991).

The overall economics of the shelterbelts can be evaluated on the basis of the costs involved in their establishment and management, as well as by considering the loss of agricultural land and other disadvantages against the improvement of the productive capacity of the land. Often shelterbelts themselves can prove as a source of income providing firewood and meeting the energy requirements to a certain extent.

## **Silvicultural Investigations**

Silvicultural studies on some promising arid zone tree species viz., *Acacia tortilis*, *Albizia lebbek*, *Prosopis cineraria*, *Acacia senegal*, *Tecomella undulata*, *Hardwickia binata*, *Acacia bivenosa*, *Eucalyptus*, *Calligonum* sp. etc. have been conducted (Kaul, 1962; Puri *et al.*, 1973; Muthana and Arora, 1976; Muthana *et al.*, 1983; Anon., 1992; Tewari, 1997). The important finding of these studies are as follows :

It was found that 6-9 month old seedlings showed better establishment than 18 to 24 month old seedlings.

- The best time of transplanting of seedling on the field is first fortnight of July as compared to other periods.
- Transplanting of seedlings showed better results than the direct sowing. The soil working of 60 cm<sup>3</sup> half filled pits with a créscent shaped ridge along the local slope gave a high rate of establishment. The four type of soil working viz., (a) pick axing the soil to a depth of 22.4 cm strips, (b) trench cum ridge with 30x30 cm cross section, (c) pits of 30 cm<sup>3</sup> were dug out and then refilled with entire weathered soil prior to planting, and (d) pits of 60 cm<sup>3</sup> were dug out and half of the pit was refilled with weathered soil and with remaining soil in the lower slope of pit a crescent shape ridge of 15 cm height was constructed.
- When planted at spacing of 1.6 m x 1.6 m the crowns of planted trees touched each other within a period of seven years and thus it requires thinning after this period.
- Studies on water and fertiliser requirements of seedlings of all the four species under nursery condition showed that alternate day watering @ 20 ml per container with fertiliser application of 1 g urea or 1 g DAP (per 50 seedlings) was found to be ideal for promoting the growth of seedlings. Weeding on field conditions significantly promoted the growth of different tree species, however, different levels of watering did not significantly affect the height growth.
- Felling cycles of *Eucalyptus* species in arid tract was found to be slightly over 10 years, while *A. lebbek* and *H. binata* should be felled after 15 years. *A. senegal* had a rotation age of 20 years. *A. bivenosa* had the shortest rotation age (6 to 7 years).

## Agroforestry

Since the cultivation of crops is very risky and uneconomical in arid lands, most desert farmers raise livestock as a subsidiary occupation, and allow trees and shrubs to grow on cultivated tracts in order to cover risk and uncertainty of crop production. In fact, agroforestry although integrated with agriculture, is an age old, well defined land use system of western Rajasthan. Though a large number of trees and shrubs are grown on agricultural fields, khejri (*Prosopis cineraria*) and bordi (*Ziziphus nummularia*) are the most important multipurpose woody components of traditional agroforestry systems (Mann and Saxena, 1980, 1981).

Arid land management by practising various agroforestry systems is meant not only for the production of fuel, fodder, fertiliser, fibre and fruits but also for the conservation and rehabilitation of land resources in the region. Efforts to improve various agroforestry systems for higher productivity and better economic returns in arid tract of Rajasthan are on way (Muthana *et al.*, 1985; Shankarnarayan *et al.*, 1987; Tewari and Harsh, 1987; Tewari *et al.*, 1989a; Harsh *et al.*, 1992; Saxena, 1997).

## Agri-silvicultural System

*Acacia albida*, a tree introduced into the arid region of Rajasthan from East Africa, had attained a mean annual height increase of 108.2 cm when planted with clusterbean and mung bean

at a spacing of 5 m x 5 m, 10 m x 5 m and 10 m x 10 m. *Prosopis cineraria* did not interfere with grain production at any stage of 3 consecutive years. Clusterbean yield was adversely affected during the third year when grown in association of *A. albida*.

If unlopped, *Holoptelia integrifolia* trees reduced the yields of mung bean and clusterbean because of the shade. Lopping not only provided fodder but also resulted in higher crop production. In traditional land-use system it is a common practice to frequently harvest the foliage of khejri and bordi for getting fodder and higher grain yield.

*Acacia nilotica* var. *cupressiformis*, whose branches grow upwards and not sideways, do not cast much shadow, may be grown in association with mung bean, clusterbean and sorghum. But since the tree roots develop slowly in the system, the crops, particularly sorghum, affect the growth of the tree.

Studies have shown that the grain yields of mung bean and clusterbean and forage yield of sorghum can be increased when they are grown in association with established trees of *Acacia tortilis* if the surface feeder roots of the tree are cut by digging trenches to avoid nutrient and moisture competition with the crops (Chopra *et al.*, 1993).

### Silvi-pastoral System

The principal merit of the presence of trees and shrubs in pastures is that animals can feed on their leaves, fruits and flowers at the time of scarcity of grass fodder. The silvi-pastoral systems in arid and semi-arid ecosystems have been precisely documented by Yadav *et al.* (1997).

A study of silvi-pastoral system showed no significant difference in grass production under different species. The average dry grass yield was 28 q ha<sup>-1</sup> from *Dichanthium annulatum*, 25.1 q ha<sup>-1</sup> from *Cenchrus ciliaris*, 25 q ha<sup>-1</sup> from *Cenchrus setigerus* and 21.6 q ha<sup>-1</sup> from *Panicum antidotale*. When grown in association with grasses, the growth of *Azadirachta indica* was less affected than that of *Albizia lebbek*.

The average carrying capacity of pure pasture after 9 years of initial establishment was 3.9 sheep per hectare. In silvi-pastoral system it was 8.5 sheep per hectare 7 years after the initial establishment (Table 2). Besides this increase in carrying capacity, a substantial amount of fuelwood can also be harvested from such tree and grass combinations.

### Agri-horticultural system

When mung bean was grown in inter-row spaces of 3-year-old ber (*Ziziphus mauritiana*) plants, the economic returns were Rs. 7,680 ha<sup>-1</sup> fetching a net profit of Rs. 2,800 ha<sup>-1</sup>. In between the spaces of ber plant rows, a legume crop can be sown, which gives grain yield of about 5 q ha<sup>-1</sup>. With expansion of ber plant canopies over time, the available cropping areas gradually decreases, but this reduction in grain yield is compensated by more and more fruit production from ber plants.

### Silvi-Horti-pastoral and Silvi-agri-horticultural Systems

When fodder grasses were sown in combination with ber plant as well as *Acacia tortilis* tree, the fodder yield and seed production were higher than the yields obtained when grass alone was grown. Similarly, when *A. tortilis* and ber; and pearl millet and clusterbean were grown in same unit of land, the fodder and grain production under the canopy of woody component were not much affected. In fact, in arid regions, the introduction of fuel, fodder and fruit trees in pastures or in agricultural fields acts as an insurance against frequent crop failures.

### Tree/Crop Interactions

In monoculture practices, whether of crops or forest or fruit trees, competition for moisture, light and nutrients is less critical than in two- or three-tier systems. Harsh and Tewari (1993) hypothesised that tree/crop interactions in agroforestry silvi-pasture and agri-horticulture systems in arid regions of India follow a systematic progression.

Table 2. Fodder production and carrying capacity in different systems

Years initial planting	Pure pasture		Silvipastoral system			
	Grass fodder yield (q ha <sup>-1</sup> )	Carrying capacity (sheep ha <sup>-1</sup> yr <sup>-1</sup> )	Grass fodder yield (q ha <sup>-1</sup> )	Leaf fodder yield (q ha <sup>-1</sup> )	Total fodder production (q ha <sup>-1</sup> )	Carrying capacity (sheep ha <sup>-1</sup> yr <sup>-1</sup> )
1	10	2.4	8.2	-	8.2	1.9
2	15	3.6	12.3	-	12.3	2.9
3	20	4.8	16.4	-	16.4	3.9
4	25	6.0	20.5	-	20.5	4.9
5	20	4.8	16.4	-	16.4	3.9
6	20	4.8	16.4	-	16.4	3.9
7	15	3.6	12.4	23.1	35.5	8.5
8	10	2.4	8.4	6.6	15.0	3.6
9	10	2.4	8.4	6.6	15.0	3.6
Average of 9 years	16.1	3.9	13.3	4.0	17.3	4.1
Average fuel production (q/ha)	-	-	-	2.64	-	-

Source : Harsh *et al.* (1992)

### Tree seedlings suppressed by grasses or crops

When tree seedlings planted simultaneously with crops, seedling growth is dramatically reduced. Crops and grasses grow very rapidly in the early stages and absorb moisture nutrients

from the top layer of the soil profile. In the initial stage, the roots of the tree seedlings also remain in the top 50-100 cm of the soil, side by side with the roots of crops and grasses. The result is fierce competition for moisture and nutrients. Such interactions continue for roughly the first three years of the intercrop system when the seedlings grow very slowly. The interactions of this period do vary depending on how the root system of the introduced trees develops (Muthana *et al.*, 1985).

#### **Mutual share of resources by tree with crops or grass**

In the next phase trees and crops do not have any negative effects on other because the tree roots by this time have penetrated deeper, leaving the upper soil layer free for crop or grass roots. Furthermore, the trees do not yet have a fully developed canopy, thus there is no chance of shade adversely affecting the growth of plants under the trees. Both components may grow independently of one another.

#### **Negative effect of trees on growth of crops or grasses**

The third phase is the result of the maturation of the trees. The well-developed root systems of tree compete with crop and grass roots for moisture and nutrients at the same time fully developed canopies shade the crops and grasses underneath. This interaction generally begins in the eighth or ninth year after initial planting of the tree/crop combinations.

Various management practices, such as the following, can minimise the negative interactions between trees and crops (Harsh and Tewari, 1992; Chopra *et al.*, 1993):

- When the tree seedlings are small, leguminous rather than cereal crops should be sown among them to avoid shading by tall cereal crops.
- When trees are fully matured both the canopy and roots can be pruned. The canopy should be lopped, pollarded or thinned, and the roots may be pruned by digging trenches (50-70 cm deep) near the trees to cut the trees' subsurface roots.
- Tree rows should be oriented east to west to minimise the effect of shade.

### **Towards Sustainable Forestry**

Most of the land in arid regions has been under constant cultivation since last three decades regardless of its marginality. In many cases the farmer can hardly get back his seed from the field he cultivates. In fact, in arid regions of India continuous cultivation and irrational utilisation of resources under unbalanced man/resource ratio on the one hand and their inherently fragile nature on the other, have given rise to a critical deterioration of environment. With more destruction, more pressure is exerted on the resources in order to obtain continuous yield and services, since horizontal expansion is the only way, rather than the vertical improvement. In many places, the depletion has already reached an irreversible stage and in many other places getting worse.

Young (1989) stated that sustainable landuse is that which achieves production combined with conservation of the resources on which production depends, thereby permitting the maintenance of productivity. Forests supply a considerable amount of subsidy for the operation of agro-

ecosystems in form of fodder and fuel wood. Pandey and Singh (1984) while studying the energy-flow relationship between agro- and forest-ecosystems in central Himalaya found that for each unit of energy employed in agronomic (plus milk) production, 7 units of energy are expended from the forest ecosystems in form of fodder and fuel wood. In arid region of Rajasthan 80 per cent of cooking energy needs are met in form of fuel wood from locally available woody vegetation. Similarly, trees also provide substantial part of fodder need of livestock. The land which has been covered into agricultural landuse (howsoever marginal it was), now can not be bring back in its original landuse category. Therefore, in arid tract combined protective-productivity system and indirectly integrated system will be most suitable for enhancing tree cover in the landscape. Sand dune stabilisation around cultivated sandy plains and silvipastoral systems in village community lands, with proper management practices are the best examples of combined protective-productivity systems. In fact, combined protective-productive systems become much more important in critical areas, where they act as buffer strips to protect fringes of good lands for encroachment of desartic conditions (Eren, 1995). Increasing tree cover through farm boundary plantations of MPTs, plantation along roads, railway lines and canals, home gardens are some of the examples of indirectly integrated system. The above discussion clearly indicated that only integrated landuse system could be remedy to reverse the ruthless exploitation of woody biomass in one hand and will be helpful to restore the much required tree cover on the other.

As also mentioned in the beginning that forestry can not be considered as the user of "residual land" and this is particularly true for arid land situation of western Rajasthan where even more than 70 per cent of sand dunes are farmers' owned. Faroda (1997) rightly pointed out that land tenure giving security to land owners would encourage long term investment by the farmers. For sustainable growth of forestry sector the national and provincial rules of tree tenure and their relationship with land tenure is critical. In any kind of plantation forestry programme, component of tree tenure (i.e., right to own or inherit the trees, the right to use trees and tree products and right to dispose tree) if included and followed in true spirit for larger interest of rural masses substantially sustainable growth and production could be achieved even in inhospitable environmental conditions of arid zone.

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Horticulture has special significance in arid zone especially in drought prone areas because fruit crops once established, become permanent source of income and impart stability to uncertain agriculture.

Horticulture crops constitute a significant component of the total agricultural production in the country. These crops cover nearly 11.6 million hectares area with a total production of over 91 million tonnes. The estimated production of fruits and vegetables is much below the annual requirement of population if the recommended level of per capita consumption of 85g of fruit and 280g of vegetables is taken as base (Chadha, 1993). To meet this gap in production, the emphasis now is given to utilise the arid and semi-arid lands, which have so far remained as "land reserves".

At present most of the arid zones of India has animal husbandry based economy which is not sufficient to provide the required stability in the income of people and therefore, people at large in this region are nomadic in habits. Provision of sustained and stable income to these people shall be sufficient incentive for them to grow fruits. We are now aware that there are a number of fruit crops which have great capacity to stand drought and salinity and still provide good income to the growers. For example, the ber which was considered to be a wild fruit a decade back has gained commercial importance in the states of Rajasthan, Gujarat, Haryana and Punjab. Like wise, pomegranate, aonla and bael can also provide considerable income to the growers.

The sick saline and alkaline soils, which can not be put under cereal crops owing to greater sensitivity, can be successfully used for fruit crops like ber, datepalm, pomegranate and aonla and even their tolerance can be raised by using resistant rootstocks.

Post harvest losses are estimated to be in the order 20-40 per cent. In terms of value it exceeds Rs. 2000/- crores annually, which are caused due to inadequate knowledge of processing, preservation, storage, handling, etc. thus leading to seasonal glut, fluctuation in the market and high percentage of losses. More over, the preservation of fruits under arid condition is all the more important due to non availability of fresh produce through out the year as well as more chance of spoilage due to extreme weather condition

### ***Present Research Set Up***

Fruits have always been considered as luxury in our country and therefore, researchers gave priority to high value fruits like mango, banana, grapes, citrus and apple. Arid fruits remained neglected during 50s and 60s and were given low priority by both planners and researchers. A

beginning was probably made by Central Arid Zone Research Institute (CAZRI), Jodhpur in seventies by working on water harvesting and moisture conservation, fruitfly resistance and rootstock studies in ber, improvement in pomegranate for quality attributes (aril colour, sweetness and seed content); evaluation of germplasm, processing techniques in ber, pomegranate, aonla, bael, date palm. Some work on nutritional studies and irrigation scheduling in pomegranate, ber and date palm; propagation studies in aonla, bael, *Capparis decidua*; germplasm collection in aonla, bael, annona and karonda has now been initiated. Institute has its sub-station at Pali, Bikaner and Jaisalmer (Rajasthan) and Bhuj in Gujarat.

Indian Institute of Horticultural Research, Bangalore, has done some work on chemotaxonomy of annonaceous fruits and pomegranate evaluation. Its experimental station at Godhra has started works on silvi-hortipastoral system for arid regions. The National Bureau of Plant Genetic Resources, Regional Station, Jodhpur conducts some work on germplasm survey and conservation for arid zone fruit crops. Punjab Agricultural University, Ludhiana; Haryana Agricultural University, Hisar; Rajasthan Agricultural University, Bikaner and Gujarat Agricultural University, S.K. Nagar, Gujarat also work on fruits like ber, datepalm, pomegranate etc.

Arid zone fruits research got impetus with the start of Cess Fund Scheme entitled, "Research on some selected fruits in the arid semi-arid areas in India" at 10 centres (during the period 1.7.76 to 30.7.81) spread over the states of Punjab, Haryana, Himachal Pradesh, Rajasthan, Gujarat, Maharastra, Karnataka and Tamil Nadu on fruits like datepalm, ber, pomegranate, fig, custard apple, walnut and apricot. This scheme was merged to create cell III of the All India Coordinated Fruit Improvement Project (AICFIP). During the Seventh Five Year Plan, the cell III of AICFIP was restructured and strengthened to form an independent All India Coordinated Research Project for Arid Zone Fruits (AICRFAZF) with 13 centres. Realising the potential of horticultural productivity of arid zone, as evidenced by the research efforts made at CAZRI, Jodhpur and AICRP on arid zone fruits, ICAR approved the establishment of National Research Centre for Arid Horticulture (NRCAH) at Bikaner with the objectives "to conduct mission oriented research for improvement of productivity of horticultural crops and development of horticulture based cropping system under arid environment; and to act as a repository of information related to arid horticulture."

## **Germplasm Collection, Conservation and Evaluation**

### **Ber (*Ziziphus mauritiana* L.)**

A wide variability of germplasm consisting of 74 cultivars was collected and evaluated for economic trial. Early fruit ripening cultivars viz. Gola - Seb and Mundia were recommended for cultivation under unirrigated areas having less than 500 mm rainfall (Pareek and Vashishtha, 1983; 1986 and Vashishtha and Pareek, 1989). As water is a limiting factor in arid region, late fruit ripening cultivars have not been found successful. The cultivars were also evaluated for

biotic and abiotic stresses. Studies conducted for the tolerance of saline water irrigation revealed that cultivars Seb, Gola and Mundia could tolerate salinity in irrigation water upto 6, 4.5 and 2.5 dS m<sup>-1</sup>, respectively.

### **Pomegranate (*Punica granatum* L.)**

Thirty five cultivars of pomegranate have been introduced at CAZRI, Jodhpur for evaluation. Selection from locally grown plants in Jalore district of Rajasthan was made and named as cv. Jalore Seedless. The cultivar is evergreen, soft seeded, high yielding, pink to red colour of fruit, sweet and pleasant flavour. The arils are deep pink to deep red colour. The average yield per plant is 20 to 25 kg under basin irrigation system and 30 to 35 kg per plant under drip irrigation. The cultivar is best suited to arid conditions and recommended to growers (Bankar and Prasad, 1992).

### **Datepalm (*Phoenix dactylifera* L.)**

A germplasm of 20 cultivars and five different males was collected from Abohar as well as imported from USA, Iraq, Afghanistan, Saudi Arabia etc. under UNDP funded programme. These cultivars have been evaluated for their performance (Vashishtha, 1985). Cultivar Halawy has been found to be ideal for arid conditions of West Rajasthan due to early fruit maturity (Vashishtha, 1981; Mertia and Vashishtha, 1985).

### **Sitaphal (*Annona squamosa* L.)**

The programme on survey, evaluation and propagation was started in 1985. The survey of *Annona* as growing region in Rajasthan revealed that there is a great genetic variability in fruiting. Rajasthan is having annonas in wild state at Chittorgarh, Kumbhalgarh, Aravalli hill ranges. The collection of thirteen types including wild and important cultivars have been made. The evaluation of germplasm revealed that cv. Balanagar and Chittorgarh local are performing better and give 50 to 100 fruits per plant depending on the rainfall (Bankar and Verma, 1987; Bankar and Prasad, 1993).

### **Gonda (*Cordia myxa* L.)**

Exhaustive survey of potential *Cordia myxa* growing areas was done and 20 different collections were made and evaluated. The promising types have been identified. Floral biology has been studied and anthesis was recorded after 2 A.M. (Vashishtha *et al.*, 1985).

### **Karonda (*Carissa carandus* L.)**

Twenty seven collections were made from hilly areas of karonda growing areas in Maharashtra and Rajasthan. The genetic variability was observed in growth of plant, fruit size, shape and colour of fruit. Karonda seedlings started fruiting in third year. The fruits of whitish pink, red, dark red and pink colour were observed. The shape of fruit was round, oblong and oval types. The size of fruit was small to big (Bankar and Prasad, 1992; Bankar *et al.*, 1993).

### **Aonla (*Emblica officinalis* Gaertn.)**

Aonla is a very promising fruit crop for arid region after Ber and Pomegranate. Introduction of cultivars Krishna, Kanchan, NA-7, Banarasi, Francis, Chakaiya have been made (Prasad and Rathore, 1989). The varietal evaluation in cvs. Krishna, Kanchan and Chakaiya revealed that cv. Kanchan gives about 40 - 50 kg fruits in 7th year and 80 - 100 kg fruit in 9th year. cultivar Krishna is having bigger size fruit and give 20 to 30 kg yield per plant (CAZRI, 1994). The maturity standards have been worked out and it is observed that the fruits of cv. Krishna and Kanchan mature from 26th December onward (Prasad and Bankar, 1993).

### **Bael (*Aegle marmelos* L.)**

Cultivars Laljeet Sambhipuri, Dhara Road, CAZRI selection K.B.-10, Ayodhya and Faizabadi local have been introduced in 1983-84. The evaluation of germplasm revealed that cvs. Laljeet Sambhipuri, CAZRI selection and Faizabadi local are performing well in arid conditions. The fruit weight ranges from 1.5 to 2.0 kg and yield from 50 to 60 kg per plant (Bankar and Prasad, 1989).

### **Ker (*Capparis decidua* L.)**

After surveying western Rajasthan, 25 different collections were made and raised. They are being evaluated for their growth, yield and quality attributes in arid regions (CAZRI, 1995).

### **Recommended cultivars**

Recommended cultivars of ber are Gola (Early), Seb (mid-season), Mundia and Umran (Late); of pomegranate are Jalore seedless, Ganesh and G-137; of datepalm are Halawy, Khadrawy, Shamram and Medjool; of aonla are Kanchan, Krishna and NA-7; and of bael are Laljeet Shambhipuri, Faizabadi local and CAZRI Selection.

## **Propagation**

### **Ber**

#### **Standardisation of rootstock**

Cultivars Seb and Gola budded on four different rootstocks i.e. *Ziziphus rotundifolia* *Z. nummularia*, *Z. spina-christi* and Tikadi revealed that *Z. rotundifolia* has performed well whereas *Z. nummularia* produces inverted bottle shape incompatibility at the bud union (CAZRI, 1989; Bankar and Prasad, 1992).

#### **Propagation techniques**

Propagation techniques standardised at this Institute has revolutionised ber expansion programme. In this techniques, the seedlings are ready for budding in 90 days and buddlings are ready for out planting in 120 days. The seedlings are raised in polythene tubes (open at both ends)

and budded in the nursery. Based on this technology about 30 ber nurseries are operating in and around Jodhpur which have supplied about 4 million ber seedlings during past decade (Vashishtha, 1993). A poly-pack method of bare root budding in sphagnum mass soaked in nutrient solution has also been developed which reduces the weight of plant (70 g as against 1.5 kg in polythene tube with soil), found to be useful for export of buddings (Pareek and Vashishtha, 1980).

**Pomegranate** : Pomegranate is propagated by stem cutting (semi-hard wood). Research conducted at CAZRI revealed that treatment of cutting with 1000 ppm IBA, for 30 seconds gave 60-80 per cent success in rooting (Bankar and Prasad, 1992). The third week of February to first week of March is the optimum time for planting. The cuttings failed to root from April to June. After six months the rooted cuttings are ready for transplanting in the field. The pomegranate is also propagated through air layering but survival after removing air layers is poor in arid region and moreover, the method is also cumbersome (Prasad, *et al.*, 1997).

**Datepalm** : Datepalm is propagated through suckers. Treating datepalm suckers with 2000 ppm IBA and with any copper fungicide before planting increased the establishment percentage. Work on micropropagation (tissue culture) is also in progress (CAZRI, 1989). Use of bentonite as sub soil barrier was also found to be useful in the establishment of suckers.

**Sitaphal** : The rooting of cutting was obtained about 26 per cent with 2500 ppm IBA. The vinear grafting gave about 78 per cent success. The 'T' budding resulted in about 70 to 75 per cent success. The best time of budding is in the month of March (Bankar, 1989).

**Gonda** : T budding has been found to be successful. The seedlings are grown in the nursery and can be budded after 100 days.

**Karonda** : The cuttings are difficult to root. The budding (T) in the month of November and March gives about 60 to 80 per cent success. The one year old rootstock raised from wild seedlings is suitable for budding (Bankar and Prasad, 1994).

**Aonla** : 'T' budding was found most successful in arid region. 5 - 6 month old seedlings are suitable for rootstock and the best time of budding is July - August. Propagation by 'T' budding in the month of July - August gives 80 per cent success.

**Bael**: In case of Bael, 'T' budding was also found best. Bael seedlings also take about 6-7 months to be ready as rootstock. July - August is the optimum time for budding. Research conducted at this Institute revealed that 'T' budding gives 60 - 70 per cent success.

**Ker** : Ker is difficult to root. The seedling population is quite variable. Therefore, hard wood and semi-hardwood cuttings were treated with Indol butyric acid (1000 to 5000 ppm) and planted every month except December and January. The best results (30 to 40% success) were obtained by treating with 1000 ppm IBA and planting in July and August when the atmospheric humidity was high (Vashishtha, 1987).

## Agrotechniques

### Ber

- Planting Distance : For rainfed conditions, a distance of 6m x 6m in square system has been found to be appropriate (Pareek and Vashishtha, 1979).
- Pruning : Under arid conditions, the best time of pruning is second fortnight of May. Pruning of current year growth to 75 per cent has been found to increase growth as well as yield (Vashishtha, 1989; Prasad and Rathore, 1989).
- Nutrition : Application of fertiliser by perforation technique through hole combined with slope (5%) increased the leaf nitrogen and yield of ber cultivar Kaithali in good rainfall year. Foliar application of urea (2%) and zinc sulphate (0.5%) applied at fruit set stage increased the yield to 18 kg tree<sup>-1</sup> as compared to control (13.5 kg tree<sup>-1</sup>) in cultivar Banarasi Kadaka (Singh and Vashishtha, 1994). Inoculation with S-51 and S-54 strains of *Azospirillum* enhanced the height, shoot, root growth and nitrogen uptake in ber cultivars, Gola and Seb, respectively.
- Growth Regulators : Of the three growth regulators studied, minimum fruit drop was observed with G-A 50 ppm with maximum fruit setting in cultivar Jogia and Gola (Vashishtha, *et al.*, 1981; Bankar and Prasad, 1990).
- Plant Protection Measures : The major insect attacking ber is fruitfly (*Carpomyia vesuviana*). Two spray of any systemic insecticide (0.03% a.i.) can manage the insect. The first spray should be given when the fruits are in 'pea' stage and the second spray three weeks after the first. To control powdery mildew spray of Karathane (0.1%) should be done in the month of September and November.

### Pomegranate

Standardisation of agro-techniques was initiated in 1986. Propagation, nutrition, planting density, water requirement have been worked out for pomegranate cv. Jalore seedless.

#### Nutritional trial

Sandy soils are deficient in nitrogen (Jain *et al.*, 1990). Hence the doses of nitrogen 0, 250, 500 and 750 g per plant were given for 5 year old trees. The dose of 500 N per plant found to be optimum for pomegranate under arid conditions (Bankar *et al.*, 1990).

#### Spacing trial

The trial with 4 spacing (5 x 2, 5 x 3, 5 x 4 and 5 x 5 m) were tried. The row to row spacing of 5 meter is better as it gives scope to grow inter crops. The yield after three years was recorded and found that 5 x 2 m spacing resulted in 12 tonnes fruit ha<sup>-1</sup> and 5 x 5 m spacing gave approx. 5 tonnes fruit ha<sup>-1</sup> (CAZRI, 1991). The quality of fruit was not affected by close spacing initially but in the fifth year the 5 x 2 m spacing resulted in crowding and the fruit size decreased. The optimum spacing for arid conditions, therefore, observed to be 5 x 4 or 5 x 5 m depending on soil



and irrigation system. The drip irrigation system results in continuous growth of plant and therefore, the spacing of 5 x 5 m observed to be optimum under drip conditions (Prasad *et al.*, 1990).

### Water requirement

The irrigation was applied to pomegranate at 0.6, 0.8 and 1.00 IW/CPE ratio water regime with 7.5 and 10 cm of depth of irrigation. The application of water at 1.0 IW/CPE ratio of 10 cm depth of irrigation was found to be the best for irrigating pomegranate. The water was applied in basin on the basis of pan evaporation. The number of irrigations from flowering to fruiting in the month of June to February was 11 to 12 (CAZRI, 1990). Drip irrigation increases the yield in pomegranate to the tune of 146 per cent over basin irrigation system (CAZRI, 1994).

### Plant Protection Measures

Anar butterfly, red mites, aphids, thrips and nematodes are pests affecting the fruit crop. The spraying of monocrotophos or other systemic insecticides (0.1%) in September and October saves the fruit from their menace.

Bacterial blight, black spot and anthracnose are main diseases. The spraying of streptomycin (200 ppm) in September control the bacterial blight. The black spot can be controlled by spraying of Indophyl M-45 at the time of flowering and fruit growth in the month of September-October.

### Datepalm

- Pollination studies : The techniques of pollination has been standardised. Each spathe should be pollinated three times on alternate days for effective fruit set (Vashishtha, *et al.*, 1985).
- Metaxenia : Five male palms were evaluated to see metaxenia effect and better one has been identified (Vashishtha, 1981).
- Strand thinning : Removal of one third strand from the centre has increased the berry quality as against other treatments. It has been a recommendation for datepalm growers (Vashishtha, 1981).
- Pre-harvest technology : Treating doka berries with 1500 ppm ethrel at colour break stage initiated early dang stage in cultivar Halawy (Vashishtha and Pareek, 1978).
- Plant Protection : Graphiola was observed to be major disease, though not affecting the yield. Epidemiological studies on Graphiola revealed that increase in temperature favours the incidence and intensity of disease. Two types of Graphiola infection were observed. Both strains were different in their size of sterile filament, spores and cultural characteristics. Fytolon (0.2%) gave maximum control of this disease. New diseases like *Botryodiplodia theobromae* and *Diplodia phoenicum* were also recorded. To control Praetoria scales, spray of systemic insecticide combined with brushing of more affected leaves was found to control the insect.

## Gonda

- **Planting :** For wind break, it should be planted at 5m distance in staggered two to three rows. For orchard, 6 x 6m distance was found to be ideal (Vashishtha, 1988).
- **Defoliation :** The flowers appears after natural defoliation in March - April. To produce an early crop, the trees should be defoliated in the second fortnight of January to get marketable crop by end of March when the prices are quite high (CAZRI, 1991).

## Water Conservation Practices

Moisture conservation is of utmost importance in arid region. For the establishment of plant, use of bentonite as a sub soil barrier has been found to be very useful. It is a natural mineral available in West Rajasthan. A hollow cylindrical drum having 2 - 3 cm less diameter than that of pit is placed in the pit. About 2 - 3 cm thick layer of soil and bentonite mixture is spread at the bottom and the interspace of drum and pit is also filled with the same. The drum is taken out. The water can neither seep through the bottom nor from sides (Vashishtha, 1985).

A double walled pot, known as Jaltripti is also used for establishment of plants. The plant is planted in this pot, having inner part hollow and outer part sealed with inner one of the bottom. It is placed in the pit. The water in between two walls of pot is used by the plant .

*In situ* water harvesting has a great potential in arid region. Effect of run off water on the production of ber under dryland condition was studied with five catchment sizes having varying slopes of 0.5, 5 and 10.0 per cent. A catchment area of 54 m<sup>2</sup> with 5 per cent slope has given significantly higher per plant yield (based on 6 years data). The average per plant yield in control (no catchment) was 18.31 kg as compared to 25.90 kg in 54 m<sup>2</sup> catchment area with 5 per cent slope. The moisture storage was monitored upto 3 meter soil depth and was found higher in this treatment (Vashishtha, 1984).

Irrigation trial through drip system in pomegranate revealed that the application of irrigation @ 8 litre per hour for 3 hours daily during flowering and fruiting increased the yield to the tune of 146 per cent over basin irrigation system with considerable reduction in fruit cracking. The quality of fruits in terms of weight, size and juice content was better under drip irrigated plants as compared to basin irrigation(CAZRI, 1994).

## Breeding

### Ber

#### Breeding for fruitfly (*Carpomyia vesuviana*) resistance in Ber (*Ziziphus mauritiana*)

Fruitfly is a major pest of ber. In order to breed a resistant variety to fruitfly, the germplasm was screened to isolate source of resistance. A local cultivar Tikadi was found to be resistant but with inferior quality fruits (Singh and Vashishtha, 1984). Therefore, hybridisation was attempted

with success in producing F1 hybrid of cultivars Seb x Tikadi. The F1 hybrid was resistant to fruitfly but did not have fruits of acceptable quality because of dominance of characters of Tikadi. Back cross of Seb x F1 hybrid was attempted to incorporate good qualitative characters of Seb, retaining the resistance to fruitfly. The back cross generation has 87 - 90 per cent resistance to fruitfly along with desired fruit characters. Fruit weight of BC<sub>1</sub> was 16g as compared to F<sub>1</sub> (4.5 g) and Tikadi (4.7 g). On the basis of oviposition marks, a mean of 13 per cent fruitfly infestation was observed in BC1 fruit. An average of 17.2 per cent of the oviposition resulted in maggot hatching indicating a high degree of antibiosis inherent in BC1 fruits. However, in Seb the fruitfly infestation was 47.3 per cent with 63 per cent hatching (Vashishtha *et al.*, 1997).

### Biosystematics

Studies on the biosystematics of 59 ber cultivars was done with the help of morphological characters and chemotaxonomy to find out the relationship among these cultivars (Vashishtha, 1985, 1989, 1995, 1997). The cultivars were divided into three groups viz. erect, semi-erect and spreading types based on morphological characters. Relationship/differences among the cultivars were ascertained on the basis of leaf flavonoid spot pattern by thin layer chromatography. Cultivars Umran, Ajmeri and Katha was found to be isogenic and have been named differently at various locations. All Gola types had independent identity.

### Breeding for early cultivars with long shelf life

Seb and Gola, though early fruit ripening cultivars, have very short shelf life ranging from 24 to 48 hours. Umran has long shelf life with late fruit maturity. F1 hybrid of Seb x Umran has shelf life of 3 days in addition to other economic traits (Vashishtha and Pareek, 1995).

### Pomegranate

Under breeding programme, 13 crosses were made between important cultivars of pomegranate viz., Jalore seedless, Ganesh, Muscat, Khog, Bedana-I, Bedana-II, Bedana Bosc, Sirin Anar, Gulsa Red, etc. The promising types of seedlings have been identified. Crosses between Ganesh x Jalore seedless and Bedana-I x Ganesh, Bedana-II x Jalore seedless, Jalore seedless x Ganesh and Ganesh x Bedana Bosc are promising and are in stage of release (CAZRI, 1995).

## Farming System

### Horti-pastoral System

Establishment, growth and top seed production of two jujube species viz., *Ziziphus nummularia* and *Z. rotundifolia* were studied in an established pasture of buffel grass, *Cenchrus ciliaris* at Samdari. In the first year of establishment, maximum mortality (80.5%) was recorded in *Z. rotundifolia*. Growth of jujube species was severely affected in buffel grass pasture. After 5 years of establishment, growth of both the jujube species was more than two times and *Pala* (dry

leaves) and bushwood production more than six times in control (no pasture) plots as compared to established pasture of buffel grass. Different plant density of jujube species in pasture plots did not affect the forage production. Hence planting of jujube in pasture is recommended at 6 x 6 m spacing (Sharma and Vashishtha, 1985).

### **Ber Based Farming System**

Studies on standardisation of ber based farming system revealed that 5m x 8m spacing for cultivating ber cultivar Gola along with grain legume was ideal. Cultivation of guar in such a farming system gave additional yield of 7.82 q ha<sup>-1</sup>. Guar grain yield was highest as compared to mung bean and cowpea.

In another experiment of Jodhpur, *Cenchrus ciliaris* was introduced in 18 year olds ber orchard. The results revealed that there was no adverse effect on ber yield, an average addition of grain of 25 q ha<sup>-1</sup> dry forage and 25 - 30 kg ha<sup>-1</sup> grass seed yield could be achieved. The average yield of ber fruit was 7.5 t ha<sup>-1</sup> under varying rainfall situation for three years (Vashishtha and Prasad, 1997).

### **Post Harvest Technology**

#### **Ber**

Among the arid zone fruits, ber is an important drought hardy fruit being grown commercially under hostile agroclimatic conditions. With the introduction of improved and high yielding cultivars, the area and production is increasing many folds in the states of Rajasthan, Haryana and Gujarat. As a result seasonal has started in the local market and growers are not able to get the remunerative prices of their produce (Prasad and Vashishtha, 1997). Moreover, the shelf life of fruit is very short. After harvesting, if not handled properly, it becomes over mature within a day or two at ambient temperature. Also due to short shelf life its fruit can not be transported to the distant places even in the country. Therefore, developing and standardisation of processing techniques will help to stabilise the price level and utilise the surplus produce (Prasad *et al.*, 1990; 1995). Keeping this in view, products like ber squash, ber jam, ber preserves, ber pickle, and dehydrated ber have been prepared at this institute.

#### **Pomegranate**

Pomegranate is another important fruit crop being grown successfully in arid region. The main problem the main problem in this fruit is cracking at maturity stage. About 20-40 per cent cracking is reported (Vashishtha, 1982 ; Bankar *et al.*, 1995). These cracked fruits neither looks attractive nor fetch good price to the growers. Moreover, these cracked fruits can not be transported to the distant places also. Preparation of processed products is, therefore, most judicious and best way to utilise the cracked and under sized fruits (Prasad *et al.*, 1997). At

CAZRI, Jodhpur methods and recipes of Pomegranate squash, Pomegranate jelly and Anardana have been standardised.

### **Aonla and Bael**

Aonla is the third important fruit crop after ber and pomegranate being grown commercially under arid conditions. Its cultivation is becoming more popular because besides being hardy in nature, it is salt tolerance and can be grown successfully in saline soil and irrigation conditions (Prasad and Rathore, 1989). It has a medicinal properties and contain maximum (600-700 mg per 100 g pulp) vitamin C which can be easily preserved by preparing murabba, jam, squash, shreds, etc. Similarly bael is also an important medicinal plant and can be successfully grown under arid conditions. A very tasty and delicious squash, nectar, RTS, Jam, Preserves, etc. can be prepared from this fruit (Prasad *et al.*, 1997; Prasad and Vashishtha, 1997). The recipes have been standardised for the preparation of squash, jam murabba, shreds and pickle of aonla; and squash, jam murabba and powder of bael.

### **Ker and Gonda**

Through generations the farmers/house wives have developed the traditional ways for preservation of indigenous fruits like Ber, Ker, Gunda and Sangri, etc. Dried bordi fruits are sold in a large quantity in the states of Rajasthan and Gujarat. The ripe fruits are sun dried and packed in a polythene bags. Similarly pickles of Gunda, Ker and Sangri have been made by rural women folk since ages. The improvement over traditional method would improve the quality of the products which will compete in the urban market and ultimately the socio-economic conditions of the farmers will be improved by using developed technology (Prasad and Vashishtha, 1997). Keeping this in view, work has been initiated for the preparation of pickles from these fruits at CAZRI, Jodhpur.

### **Irradiation Studies on Pomegranate**

This study was conducted in collaboration with Defence Laboratory, Jodhpur to prolong the shelf life of fruits. The mature fruits of uniform colour and size treated with 10 different doses of Gama rays from 8.33 to 88.3 KGr with control. A dose of 25 KGr was found best to prolong the shelf life of fruit upto 24 days with least (15.7%) loss in weight. The colour of fruits also remained attractive upto 24 days of storage with least shrinkage of rind at this dose (Anonymous, 1990).

### **Impact of Technology**

- The technology developed for ber budding has become very much popular and based on this technology about 30 nurseries are operating in and around Jodhpur.
- The early fruit ripening cultivars of ber and pomegranate with long shelf life will check the post harvest losses to the farmers, thus generating more income per unit area.

- Recommended cultivars of aonla and bael will give an opportunity to diversify the crop for sustainable production and will improve the health of the region.
- Standardisation of propagation methods will increase the area of fruit crops by making plant available to the farmers.
- Farming system with ber + grass will provide additional income to the farmers in dry land farming.
- The resistant to fruitfly cultivar will not only save the cost of insecticide spray and labour but also check pollution in the environment.

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## GRASSES AND GRASSLAND MANAGEMENT

M.S. Yadav and S.K. Sharma

Arid zone is marked by hostile agroclimatic conditions and frequently recurring famines due to scanty and erratic rainfall. The local people obtain sustenance from livestock to ameliorate their sad plight. West of the Aravallis is an arid tract poorly represented in vegetation on account of adverse climatic, soil and biotic conditions. The livestock population is relatively high as compared to the available resources. This results in heavy pressure on the natural vegetation, including pastures. Since about 62 per cent of the total area in western Rajasthan is grazed by the animals, it has large potentialities of improvement as good pasture lands. The existing areas, earmarked for grazing in the villages are not properly managed and there is always a heavy pressure of cattle on the land. The existing grasses lose their regenerating power. This results constant deterioration in the nutritive and palatable grass species from these areas. Such areas, if properly managed, can be developed into pastures rich in nutritive and palatable species.

Preliminary survey of Indian grasslands (Whyte *et al.*, 1954) established eight types in the Country. *Dichanthium-Cenchrus-Eleusine* is the major type occurring in arid Rajasthan with a rainfall below 300 mm (Dabadghao, 1957). Later studies by Shankarnarayan and Satyanarayana (1964) established 5 distinct types of grass associations from the alluvial plains of Central Luni basin.

There has been unnecessary heavy expenditure on preparatory tillage and sowing operations during the years of failure of rains which are frequent. Hence in this region grassland management and forage production needs emphasis. Due to present heavy pressure of human population and its higher increase (2.5% per year, as against 2.0% for the country), man will try to put marginal and submarginal lands under crops inspite of adverse and hostile agroclimatic conditions.

Agrostology and Range Management sections are engaged in research on selection and improvement of important fodder grasses and legume varieties, their performance in different landforms and agroclimatic conditions, pasture establishment techniques, protection of range lands and their reseeding, grazing management and studies on different silvi- and horti-pastoral systems. It has been shown that fodder production can be substantially stepped up through proper management, reseeding of pasture lands, fertiliser use, soil and water management, etc.

## **Rangeland Protection, Its Recovery and Rehabilitation**

Ahuja and Mann (1975) reviewed the progress of rangeland and pasture development. The rangeland improvement involves selection of site, protection from biotic factors, grubbing out unwanted bushes, propagation of top feed cum shade trees, adoption of soil conservation measures, stabilisation of sand dunes, forage production, reseeding with appropriate grass species, fertilisation, development of water resources, rodent control and controlled animal husbandry to help to establish productive ranges for their long term utilisation.

The first step of rangeland improvement is their protection from biotic factors. Amongst various types of fencing tried and studied for protection of rangelands, angle iron posts with barbed wire fencing was found most effective and economical in the long run (Bhimaya *et al.*, 1967). If properly maintained, such fencing last for more than 20 years. As iron and steel materials are becoming scarce, trench and corewall fencing, corewall thorn fencing or live hedge fencing may be raised on cooperative basis by villagers, during forced idle periods or lean periods. Such types of fencing need regular care and repairs.

With adequate protection and controlled grazing in native rangelands could be practically doubled in about three years time. By grazing these lands with controlled number of animals the production from poor, fair and good condition rangelands increased from 337 to 688 kg, 552 to 869 kg and 703 to 1523 kg ha<sup>-1</sup>, respectively in 3 years (Ahuja, 1975). Studies on effect of long term enclosures on changes in dune vegetation have shown that protection led to improvement in the species diversity and richness. Marked improvement in the botanical composition, relative frequency and relative cover of the herbs and shrubs was also noticed on the top, the slope and at the base of protected dune (Shankar and Dadhich, 1977). Phytosociological variations on the old alluvial flats at Jodhpur were recorded for a period of 5 years. Perennial grasses were the prominent contributor to the basal cover in all the seasons. Ephemeral and therophytes contribute relatively less after the post monsoon season due to heavy loss of moisture by evaporation and downwards penetration to subsqil layers. A decrease in total percentage basal cover was recorded under enclosures without any utilisation after a five year period (Gupta and Sharma, 1973). Vegetation surveys and ecological studies were carried out in 52 range paddocks located in 10 districts of western Rajasthan. Based on dominant grass species cover, high forage production potential, high protein content and ultimately following the climax vegetation criteria, the rangelands were classified into excellent, good, fair, poor and very poor condition classes (Bhimaya and Ahuja, 1969). During normal years of rainfall, the carrying capacity of different condition classes of such rangelands on year long basis per 100 ha of land has been worked out for excellent, good, fair, poor and very poor category of rangelands as 25-30, 20, 17, 13 and 0-6 A.C.U (Adult Cattle Unit), respectively.

Gupta and Sharma (1971) enumerated the list of 106 grasses based on collections made during the surveys in the arid Rajasthan for over a number of years. Their uses particularly with regard to palatability and contribution to the fodder resources in the region have been included for

individual grass species. Long term seasonal grazing studies (1970-77) in a desert rangeland (*Lasiurus-Eleusine-Aristida* cover) revealed overall improvement in the basal cover of ground vegetation. In the first year of grazing, highest basal cover was 2.88 per cent from all seasonal grazed plots and it increased remarkably upto 23.6 per cent in the final year of study. Remarkable change in percentage frequency of *Lasiurus indicus* was noticed and its luxuriant growth scaled down the dominance of less palatable species (Sharma *et al.*, 1980).

## Grazing Management

Community grazing lands and rangelands in arid and semi arid parts of the country usually succumb to heavy grazing pressure of village grazing herds of cattle, sheep and goats. Over grazing in grasslands results in slow but inexorable deleterious change in botanical composition which however varies with the type of grass cover, its palatability, forage productivity and the way in which it is utilised and the sequence of climatic events. It triggers off succession and invariably the degenerated stage consists of inferior less palatable perennials and annuals such as *Oropetium thomaeum*, *Aristida adscensionis* and *Eragrostis unioloides* accompanied by reduction in the per cent cover of the desirable species.

The physiognomy and growth of the desirable species are also affected from basket to saucer shape which are strongly influenced by grazing and soil moisture relations. The impact of browsing, is nowhere more pronounced than in top feed trees such as *Ziziphus nummularia*, *Salvadora oleoides* which assume bush form, whereas *Prosopis cineraria* and *Anogeissus pendula* became "Pillow cushion" form (Shankarnarayan, 1977a).

The dynamics of herbage production is influenced by the severity of grazing which is attributed to the destruction of shoot apex resulting in lowered growth rate as evidenced in *Iseilema laxum*, *C. ciliaris*, *C. setigerus* and *Sehima nervosum* grasslands. Concurrently the root biomass and root number also get decreased with overgrazing. Heavy intensity of grazing on *Lasiurus-Aristida* rangeland showed lowest weight gain in Tharparker yearling heifers both in low and medium rainfall regime.

The trampling by hooves of stock appear more damaging leading to disintegration of humus and organic matter and altering the mechanical composition of the soils. The hydrology is drastically impaired with high bulk density, lower infiltration and increased runoff. Overgrazing in grassland gave maximum runoff (27%) and maximum soil loss (2100 lb acre<sup>-1</sup>). Likewise in landuse having overgrazed fallow the runoff was 22 per cent but soil loss was as high as 2029 lb acre<sup>-1</sup> (Shankarnarayan, 1977a).

Effect of grazing adult ewes in four different pasture paddocks, viz., (i) *Cenchrus ciliaris* and *Lasiurus indicus*, (ii) *C. ciliaris* and *C. setigerus*, (iii) *C. ciliaris*, *C. setigerus* and *L. indicus*, and (iv) Natural and protected, revealed that the perennial grasses withstood the grazing stress well and there was an over all increase in their basal cover, ranging from 0.5 to 3 per transact in different pasture paddocks. *C. setigerus* was found to be most palatable among the perennial

grasses, whereas *Brachiaria ramosa*, *Convolvulus microphyllus*, *Indigofera cordifolia* and *I. linifolia* were found to be more palatable among the annual species. Crude protein of the perennial grasses varied from 9.2 to 2.8 per cent in different seasons of the year and it gradually decreased from September onwards. Among the annual species *Boerhavia diffusa*, *Convolvulus microphyllus*, *I. cordifolia* and *I. linifolia* recorded comparatively higher crude protein, viz., 17.3, 17.5, 11.7 and 12.4 per cent, respectively (Chakravarty *et al.*, 1970).

In another sheep grazing study, a considerable seasonal variation was found in the chemical composition and dry matter yield of *Heteropogon* grasslands. The crude protein, calcium and phosphorus which was maximum in July decreased steadily in subsequent months, showing inverse relationship. The body weight gain in sheep was maximum (88 gm day<sup>-1</sup> animal<sup>-1</sup>) in October and decreased thereafter recording the lowest gains in May. This also coincided with the decrease in nutrient content of herbage.

The *in vitro* digestibility values were found to be maximum in *Sehima* + 60 kg N ha<sup>-1</sup> treatment, however, the *Cenchrus* + *Siratro* group showed not only high level of IVD and maximum crude protein retention capacity but also resulted in the highest weight gains 27 gm day<sup>-1</sup> animal<sup>-1</sup> in Mandya sheep. The low weight gains in sheep in the *Sehima* control is attributed to the high neutral detergent fibre and low protein level (Shankarnarayan, 1977b).

Amongst the various systems of grazing, e.g., deferred and deferment cum-rotational grazing, the highest livestock returns were given by year long continuous controlled grazing. The gain in body weight of yearling heifers on poor and fair ranges have been recorded as 64.5 and 67.9 kg year<sup>-1</sup>, respectively (Ahuja, 1964). Irrespective of the type of pastoral treatment, the highest level of livestock production was attained during the period of July to October when the forage on the ranges remains mostly green, succulent and highly nutritious. During this period, the rate of increase of body weight of Kankrej and Tharparker heifers has been found to be 10.5 and 12.5 kg month<sup>-1</sup> animal<sup>-1</sup>, respectively (Ahuja *et al.*, 1968).

### Grazing Studies on Improved Strains of Different Grasses

Forage utilisation by cattle ranged from 67.2 to 79.2 per cent in different paddocks of grass varieties. Cattle showed maximum preference towards *Lasiurus indicus* (79.2% utilisation) followed by *C. ciliaris* var. Marwar Anjan (Chakravarty *et al.*, 1970).

### Germination, Growth of Pasture Grasses

Majority of pasture grasses exhibit polymorphism and their germination depends on healthy and vigorous seed, appropriate soil and land forms and suitable agroclimatic conditions. *C. ciliaris* and *C. setigerus* have wider adaptability in the arid and semi-arid conditions. Population studies indicated that the percentage of black headed plants of *C. ciliaris* are comparatively lower on the sand dunes than it was on the level land at the foot of the dune. On the other hand, percentage of plants with coloured stigma is higher on the dune than on the plains. The association of colour

head plants with the habitat factor is very perceptible here and this information may be useful in selection of types for different habitats (Chakravarty and Das, 1965).

Larger and heavier seeds of a given genotype, having a higher protein content have also been found to have a higher germination percentage as compared to smaller and lighter seeds. Higher food reserve in larger seeds of *C. ciliaris* contributed towards greater forage production as compared to that of small seeds only during the first year of establishment (Kathju *et al.*, 1978). In germination studies media also play important role. Ahuja and Bhimaya (1967) found that for successful germination trials of desert grass seeds, petridishes with moist filter paper are not suitable and give unreliable results of the variability as compared to sand culture. Germination percentage of *Panicum antidotale*, *Lasiurus indicus*, *C. ciliaris*, *C. setigerus* and *Dichanthium annulatum* averaged to 73.1, 65.1, 61.4, 54.7 and 28.2 percent, respectively in sand culture.

Comparative studies of *C. ciliaris* and *C. setigerus* for their germinability, growth and crude protein content have shown that *C. ciliaris* is a better species than *C. setigerus* on account of its higher germination percentage, better salt resistance and fodder production under similar conditions. Both the grasses thrive better on alluvial soils as compared to other soil types studied. The best time for utilisation of these species is the boot leaf stage as the crude protein content is maximum at this stage (Gupta *et al.*, 1970).

Germination studies of eight grass species in five salt concentrations under laboratory conditions have shown that germination of *Dactyloctenium aegyptium*, *Dichanthium annulatum* and *Chloris virgata* in maximum salt concentration (13.6 g litre<sup>-1</sup>) was 50, 14 and 22 per cent, respectively. *Dactyloctenium indicum* and *C. setigerus* were highly sensitive to saline media (Sharma and Gupta, 1971).

## **Pasture Establishment Technique**

In Rajasthan about 80 per cent of grazing lands are poor whose estimated average production of forage is less than 300 kg ha<sup>-1</sup> on air dry basis. Improvement of the denuded pastures and establishment of sown pastures by reseeding is one of the major problems related to the overall improvement of the economy of the arid zone. Several studies in the past on the subject have shown that seed rate has great influence on pasture establishment and subsequent pasture production. Methods of sowing and seed treatments also affect the establishment of pastures. Chakravarty *et al.* (1966) found that seed rate treatment was significant in *C. ciliaris* in the year of normal rainfall and in *Lasiurus indicus* it has not been found significant. Establishment of *C. ciliaris* pasture was about 43 per cent in low rainfall year as compared to 100 per cent in normal rainfall year (on the basis of average seed rate). Similarly, it was 56 per cent in normal rainfall year and 34 per cent in low rainfall year in case of *L. indicus*. Hulled seeds gave very poor germination as compared to unhulled (normal) ones in both the grasses. This may be due to the mechanical pressure exerted by the surrounding soil forming a crust after the rains.

Dry matter production from the pasture established by different seed rates was correlated to the number of seedlings in the pasture and not with the seed rates. *L. indicus* pasture was found to yield about 60 per cent more dry matter than the *C. ciliaris* pasture in the second year of its establishment even with 70 per cent less number of seedlings. Chakravarty and Verma (1970) in their study on the effect of reseeding of natural pastures with *C. ciliaris* by different soil working methods and fertiliser treatments on pasture production observed comparatively higher germination of seeds in the plots where complete soil working and seeding was done. Herbage production from the pasture increased by 50, 18 and 37 per cent, respectively in the three successive years from the year of soil working and seeding. In all the three years nitrogen (22.4 kg ha<sup>-1</sup>) either singly or in combination with P, or P and K indicated increase in height and tillering of plants as compared to those receiving no fertilisers. But yield of herbage indicated increase in the first year only in similar set of treatments.

The effect of different spacings and weeding on establishment and forage production of *C. ciliaris*, *L. indicus* and *Panicum antidotale* indicated increase in forage yield by 86, 120 and 248 per cent, respectively from these grasses due to one weeding in the first year of their establishment. The weeding indicated better growth in height, tillering and basal diameter of all the grasses, whereas closer spacing (30 cm apart) indicated better growth in *L. indicus* and wider spacing (90 cm apart) in *P. antidotale*. Gupta *et al.* (1971) recorded 53.5 per cent more dry matter production from *C. ciliaris* plants growing without competition from the surrounding herbage than in plants under competition with the surrounding herbage.

Sharma (1987) summarised the results of different pasture establishment techniques on different locations. In case of *C. ciliaris* direct sowing of seed was found better than seed pelleting. Seeds of pasture grasses could be sown few days before rains (pre-monsoon) or after first good rainfall. Pre-monsoon sowing is in favour of farmers as they have enough time before crop sowing operations. In pre-monsoon or monsoon sowing success of pasture establishment is determined by the incidence of rains following sowing. Better establishment of pasture in the pre-monsoon plots was observed in the first year of sowing. It was also observed that pelleting of *C. ciliaris* seeds and formation of bunds in sandy to sandy loam soil are not required for establishment of pasture. Moreover, seed pelleting is helpful for covering large sandy, undulating tract under reseeding programme in a limited favourable period during monsoon. Pelleted seeds are ideal for aerial seeding programme, as pellets prevent loss of buoyant grass seed on windy days and also from birds and ants. A simple rotatory pellet making device has been developed at CAZRI, Jodhpur. Seed pellets of desired diameter (0.5 cm) may be prepared with the help of this machine in a very short time by putting a mixture of 100-125 gm grass seed + 3 to 3.5 kg clay powder (Tank silt) + 250 g FYM powder + 250 g sand in a rotating tyre and slowly spraying water through spray pump nozzle. Pellets are sun dried and stored (Yadav, 1997).

## Use of Fertilisers

Since majority of grasslands are spread over on sandy, degraded lands having poor soil fertility status. Several workers have emphasised the need of application of fertilisers in such soils for better establishment of pasture and increased forage yield in first and subsequent years of pasture establishment. Dabadhao *et al.* (1965) observed favourable and significant response of nitrogen either singly or in combination with phosphorus or phosphorus and potash at the rate of 22.4 kg ha<sup>-1</sup> for *L. indicus*, *C. ciliaris*, *C. setigerus* and *Panicum antidotale*. Das and Gupta (1964) noted 58, 26, 82 and 108 per cent increase in the yield of crude protein after suitable fertiliser application in case of *C. ciliaris*, *Panicum antidotale*, *L. indicus* and *C. setigerus*, respectively. In case of legume forage species, phosphate fertiliser boost up the fodder yield and seed production. In different inter row spacing and three doses of P<sub>2</sub>O<sub>5</sub> viz., 20, 40, and 80 kg ha<sup>-1</sup> the seed yield increased in the order of 2.0, 23.3 and 39.8 per cent, respectively. Inter row spacing of 25 cm resulted in maximum forage yield but the effect of spacing treatments was not well marked (Verma, 1975). Faroda and Amar Singh (1969) emphasised the need to ascertain the requirement of fertility elements in the soil before application of any fertiliser. They also worked out N and P doses at the rate of 20 kg ha<sup>-1</sup> for Dhaman, Anjan, Gramna, Sewan, Karad, etc. Though soils of arid regions are not deficient in Potash, but in case of its requirement for some habitats, 20 kg K ha<sup>-1</sup> may be applied.

## Use of Fertilisers for Increasing Seed Production

Variations in seed yield have been reported in different arid and semi-arid environments using different doses of N and P fertilisers. Application of nitrogen up to 40 kg ha<sup>-1</sup> was found economic. Highest seed yield (162.8 kg ha<sup>-1</sup>) was recorded with 40 kg nitrogen and 50 kg phosphorus ha<sup>-1</sup>. Fertiliser application resulted in 83.1 per cent increase in dry matter yield and 112.6 per cent increase in seed yield over control. On varietal comparison in *C. ciliaris*, CAZRI-358 and Bundel Anjan gave consistently higher yield over other strains in arid and semi-arid zone, respectively (Singh and Yadav, 1986). The highest seed yield was obtained on one cutting over two or three cuts. Application of 20 kg N ha<sup>-1</sup> to *C. ciliaris* resulted in 83 per cent increase in dry forage yield and 112.6 per cent increase in seed yield (Faroda, 1974).

## Development of Improved Varieties

Four varieties of pasture grasses and one of pasture legume have been developed at CAZRI, Jodhpur. The important characteristics of each are described here.

### Marwar Anjan (CAZRI-75) of *Cenchrus ciliaris*

It, is a tall (90-125 cm), erect, thick stemmed, leafy, drought hardy, with green yield potential of 70 q ha<sup>-1</sup> year<sup>-1</sup> yielding 53 per cent higher over the check variety Molopo. It has high crude

protein (8.3%) which is 32 per cent higher over the check. The variety was released by Central Sub-Committee on Crop Standard, Notification and Release of Variety in 1985.

### **Marwar Dhaman (CAZRI-76) of *Cenchrus setigerus***

It is a clonal selection from exotic material EC 17655. It is a medium tall (50-60 cm), thin stemmed, leafy (leaf-stem ratio, 2.3), foliage remains green upto December. It is drought hardy, high tillering ability (29 tillers plant<sup>-1</sup>), fast regeneration (2-3 cuts in a year), average green fodder yield (40 q ha<sup>-1</sup>) and 15 q dry matter yield which is 38 per cent higher over the check var. Pusa Yellow Anjan. It is also nutritious, having 9.6 per cent crude protein at 50 per cent flowering stage. The variety was released by Central Sub-Committee on Crop Standard, Notification and Release of Variety in 1985.

### **CAZRI-30-5 of *Lasiurus indicus***

The variety was developed through mutation breeding by Yadav (1988). It yields 97 q green fodder and 33 q dry matter yield per hectare which is 38 per cent higher over the check var. Jaisalmer Local. It attains a height of 1 m. It is drought hardy, remains productive even in the regions receiving an annual rainfall of less than 100 mm, leafy (leaf-stem ratio 1.9 which is 46% higher over check). Its crude protein yield is 3.75 q ha<sup>-1</sup> which is 63 per cent higher over check. Its pasture remains productive up to 15 years in the arid zone.

### **Bundel Anjan of *C. ciliaris***

It is a clonal selection from indigenous material. It was identified as promising cultivar for semi-arid regions, giving 40-110 q ha<sup>-1</sup> dry matter yield and 0.80 to 1.0 q ha<sup>-1</sup> seed yield. It is a drought hardy, persistent, aggressive and highly nutritious and palatable. The variety was released by Central Sub-Committee on Crop Standard, Notification and Release of Variety in 1989.

### **CAZRI-1461 of *Lablab purpureus***

It yields 181q ha<sup>-1</sup> green fodder (15% higher over the check) and 44 q ha<sup>-1</sup> dry matter yield (20.5% higher over the check) and provides nutritious fodder during lean period from November to January. It attains a plant height of 132 cm, leaf-stem ratio of 0.56 and has profuse branches (3.2) and the crude protein yield is 7.6 q ha<sup>-1</sup>.

## **Genetic Studies**

### **Development of Selection Criteria**

Selection criteria for fodder yield and quality components in forage crops through biometrical approaches and other classificatory procedure, i.e. D<sup>2</sup> statistic, factor analysis, canonical roots, metroglyph analysis, heritability, genetic advance, correlation coefficients, path analysis and stability analysis were developed and employed in arid zone grasses for genetic improvement programme (Yadav *et al.*, 1974; Yadav *et al.*, 1976; Yadav *et al.*, 1980; Bhagmal *et al.*, 1981).



Fodder yield, tiller number and branch number were influenced by productivity factor. Growth factor affected culm thickness, leaf breadth and leaf length. Leaf-stem ratio and leaf breadth were affected by quality factor (Yadav and Krishna, 1987).

### **Germplasm Grouping Based on Intra-specific Chromosomal Races**

The cytomorphological studies indicated the polymorphic nature of *Pennisetum pedicellatum* and *C. ciliaris* and occurrence of intra-specific chromosomal races (Darlington and Wylie, 1955; Bashaw, 1962). The two chromosomal races (4x and 6x) formed distinct groups in metroglyph diagram where aneuploid races fitted in hexaploid group. Varieties with low index values of *P. pedicellatum* belonged to tetraploid, whereas the varieties with high index value were from hexaploid group (Yadav *et al.*, 1981).

### **Genotype x Environment Interaction**

Promising strains of *C. ciliaris*, *C. setigerus*, *Pennisetum pedicellatum*, *Lasiurus indicus*, *Dichanthium annulatum*, and *Lablab purpureus* were studied under different locations, years, soil types, fertility, defoliation stress, photo-periods and grazing (Yadav, 1981; Roy *et al.*, 1995).

### **Biodiversity in Pasture Grasses**

Rajasthan desert is known as the primary centre of genetic diversity of pasture grasses. About 106 species of grasses are found in western Rajasthan. At Central Arid Zone Research Institute, Jodhpur a sizable genetic stock is being maintained, and has been studied for various morphological and genetical aspects of variation. Wide range of genetic variation was observed in the characters contributing to forage yield, forage quality and underground biomass for *C. ciliaris*, *C. setigerus*, *Lasiurus indicus*, *Dichanthium annulatum* and *Pennisetum pedicellatum*, using various biometrical approaches (Singh and Yadav, 1971; Yadav *et al.*, 1980; Yadav and Krishna, 1985; Yadav and Krishna, 1987). A wide range of variation was observed for growth habit, plant pubescence, spike colour, stigma colour and root rhizome production in *C. setigerus* (Yadav, 1981). High coefficient of variation, moderate to high heritability and high genetic advance were observed in *C. ciliaris*, *L. indicus* and *D. annulatum* for tiller number, stem thickness and fodder yield. A wide range of variation was observed in *L. indicus* for quality traits, viz., dry matter, silica, lignin and crude protein content. These characters showed high heritability and high genetic advance (Gupta and Yadav, 1985).

### **Screening of Germplasm for Forage Quality**

Germplasm collection including promising strains of pasture grasses and legumes were analysed for crude protein, *in-vitro* dry matter digestibility (IVDMD), cellulose, hemicellulose, lignin, silica, acid detergent fibre (ADF), neutral detergent fibre (NDF) and bulk density at different stages of growth over years (Gupta and Yadav, 1985 and Yadav, 1981).

## **Technology Development on Pasture Grasses and Legumes**

### **Additional Yield of Grass Hay and Grass Seed from Horti-Pastoral System**

Five rows of grass (spaced at 70 cm apart) were introduced between two rows of 15 year old ber plants. Three years results indicated that there was no significant difference in the yield of ber with or without grass. An additional average yield of grass fodder 16.2 q ha<sup>-1</sup> and grass seed 22 kg ha<sup>-1</sup> were obtained in grass + ber horti-pastoral system.

### **Pasture Evaluation for Persistency and Aggressiveness**

Ten superior strain of *C. ciliaris* and eight of *C. setigerus* were studied for forage yield, root weight, rhizome weight and associated weed species composition and, yield during 5th year regrowth. Significant variations for dry matter yield (23 to 35 g h<sup>-1</sup>), weed infestation proportion in per cent (23.2 to 91.1%) and root-rhizome weight (11.2 to 34.0 q h<sup>-1</sup>) were observed. Strain No. 358 and CAZRI 75 of *C. ciliaris* were found persistent on the basis of higher forage yield, less weed infestation and moderate to higher yield of root-rhizome at 5th year regrowth. Similarly, in *C. setigerus* var. 569, 758, 1, 175 produced higher dry forage yield (14 to 19 q h<sup>-1</sup>) with less weed infestation proportion (15-46%) and higher root-rhizome weight (18.4 to 35.6 q h<sup>-1</sup>).

### **Storability of Seed**

Storage studies revealed that 3 year old seeds of *C. ciliaris* maintain desirable germination standard (30%) and after that germination percent declines (Yadav, 1994). *Lasiurus indicus* seed could be stored up to six years as the seed remains viable for eight years.

### **Effect of Pasture Ageing on Seed Production**

Seed yield potential of *C. ciliaris* varieties were studied for five years. Maximum seed production 74 kg ha<sup>-1</sup> was recorded in second year followed by 3rd year (56.7 kg ha<sup>-1</sup>) and in 4th year (52 kg ha<sup>-1</sup>). Variety CAZRI-358 was found superior and gave maximum yield (56.3 kg ha<sup>-1</sup>).

### **Effect of Spacing and Time of Harvest on Seed Yield**

Narrow spacing 25x25 cm gave maximum seed yield (159.2 kg ha<sup>-1</sup>) followed by 50x25 cm (157.6 kg ha<sup>-1</sup>). Spacing of 75x25 (143.4 kg ha<sup>-1</sup>) was found optimum for *C. ciliaris* seed production and easy for interculture operations. Seed yield of *C. ciliaris* and *C. setigerus* differed significantly for different times of harvesting. Maximum seed yield of 151 kg ha<sup>-1</sup> in *C. ciliaris* and 108 kg ha<sup>-1</sup> in *C. setigerus* were obtained when seed was collected during 12 to 16 days after anthesis (Singh and Yadav, 1986).

### **Breeder Seed Production**

Breeder seed production and seed multiplication programme of improved varieties of *C. ciliaris*, *C. setigerus*, *L. indicus*, *P. antidotale*, *D. annulatum* grasses is the main activity of the

Institute under National Seed Project since 1986. Besides grasses, the seed of *Clitoria ternatea*, *Lablab purpureus* and *Alyosia scarabaeoides* is also produced under seed multiplication programme. The average seed production from 1986 to 1996 was 27 quintal ha<sup>-1</sup> (Yadav and Singh, 1997) and 14.3 tonnes seed has been supplied to 608 Institutes/ agencies/ scientists/ farmers during this period.

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## GENETIC IMPROVEMENT OF TREES AND SHRUBS

Manjit Singh, S.K. Jindal, N.L. Kackar and Anjly Pancholy

Trees and shrubs are extremely important in arid ecosystems as both human and livestock depend on these, especially in drought years. In Indian arid zone there is a sharp decrease in forest cover and reduction in the number of trees and shrubs on cultivated fields in the last few decades because of farm mechanisation and over-exploitation of vegetation resources for meeting the ever increasing needs of fuel, food and fodder. Since mid-1950s, tree breeders have demonstrated that simple selection-type breeding operations can substantially increase yield and modify many traits and adaptabilities (Namkoong *et al.*, 1988). Forest genetics and breeding has not made the desired impact on less productive lands. The importance of trees was realised very early in Indian arid zone and research and development in the fifties was concentrated on afforestation as is evident from the proceedings of the Symposium on the Rajputana Desert organised by National Institute of Sciences of India in 1952 and the mandate of Desert Afforestation Centre established at Jodhpur in the same year (Anon., 1952). That overall productivity can be increased by using genetically improved stocks of trees and planting of trees is a long term investment was emphasised by the First Achievement Audit Committee for Central Arid Zone Research Institute (Anon., 1967), and the committee recommended the initiation of work on tree genetics. The actual programme was initiated in late seventies. Since then work on arid zone forestry has also been initiated in other institutes of the region which include Haryana Agricultural University, Hisar; Gujarat Agricultural University, Ahmedabad; and Punjab Agricultural University, Ludhiana.

In tree improvement programmes, agricultural breeding systems cannot be adopted as paradigm because long life span of trees does not permit iterative breeding, there are very few morphological markers available in trees for genetic studies, and the objectives of tree improvement programmes are invariably different and multifold. Genetic improvement of tree species involves survey of the region, identification of plus material, collection of seed from single trees, procurement of germplasm from other sources, standardisation of nursery techniques, evaluation of germplasm in nursery and in field, establishment of progeny/provenance trials and seed orchards. Vegetative propagation and micropropagation for rapid clonal propagation, monitoring of genetic diversity in natural populations and estimation of outcrossing rates in arid zone trees by the use of biochemical markers and isolation and improvement of nitrogen fixing rhizobia are some other important areas. In the last few decades work has been undertaken on all

these aspects in the Indian arid zone. Though major emphasis has been given on indigenous trees, work has also been undertaken on some promising exotics.

## **Tree Improvement**

### **Morphological Variation *in situ* and Germplasm Collection**

Over a century ago, Darwin (1859) noted the universality of natural variation and this formed the inspiration for his great work on the evolution of species by natural selection. Genetic diversity found in tree species is a part of nature's strategy for defence and survival against all types of risks encountered in the long life span of forest trees (Heybrock, 1978). The use of diversity of wild species for genetic gain is the basis of tree improvement work.

#### ***Prosopis cineraria***

Till end of seventies, no planned explorations were undertaken for collection of germplasm of arid zone trees in Indian arid zone and its use for genetic improvement. *Prosopis cineraria* is the most important tree of Indian arid zone. The importance of this tree in western Rajasthan was recognized long ago by the natives of Thar desert. This multipurpose tree has played an important role in the rural economy of western Rajasthan as it provides fodder, fuel, vegetable, fruits, etc. Farmers through generations of experience have realized that *P. cineraria* improves grain yield and forage biomass production of the field crops (Mann and Saxena, 1980). Because of its economic value and positive effect on growth of field crops, this tree is spared in arable lands. Possibly because of its key role in daily lives of the people of Thar desert, this tree attained a religious value and was held in high esteem and treated as an object of veneration in the scriptures. This tree has been described as 'Kalp-Taru' i.e., wishful-filler (Purohit and Khan, 1980). Among indigenous arid zone tree species of Thar desert, no other species excels *Prosopis cineraria*. This multipurpose tree, however, suffers from relatively slow growth. The required expanse of its stands in the afforestation programmes is felt by all but this lacuna is brought on the fore while deliberating for the choice of species.

Although wide distribution of *Prosopis cineraria* suggests that it is likely to be a variable species, the variation within *P. cineraria* was not investigated scientifically till 1981 (Leakey and Last, 1980). Jatasa and Paroda (1981) further added that though no published report is available on genetic diversity in this species, travelling through the vast Thar desert, one could easily conclude that wide range of variability is available particularly for growth habit, canopy area, fodder yield, spiny habit and so on. They were of the opinion that large genetic variability available in this species offers a vast scope for selection of fast growing, spineless and high yielding genotypes.

Jatasa (1982) collected two hundred fifty strains of *P. cineraria* by the 'random biased' sampling from Thar desert during May-June 1981. The quantitative data recorded on 223 trees indicated a wide range of genetic variability for tree height, d.b.h., stem height, canopy height and



canopy diameter. Ranking for leaf fodder and seed yield revealed vast exploitable variations. He further selected 15 best trees for various quantitative traits. Maximum number of plus trees were selected from Sikar, Salasar and Laxmangarh areas. He emphasised the necessity of recurrent germplasm collection along with various precautions and suggestions for undertaking such surveys.

Continuing this study, Jatasa and Paroda (1983) reported that in natural stands tree height varied from 4 to 22 m with mean value of 9.19 m, stem height and canopy height ranged from 1 to 8 m and 1 to 20 m respectively. Mean stem/canopy ratio value (0.56) indicated that canopy grew almost double the height of stem. Branches per tree ranged from 4 to 43. Very high range for canopy volume indicated the presence of wide variability for fodder yield in *P. cineraria*. Maximum variation was observed for canopy volume and least variation was observed for stem height. The strains from Sikar, Salasar and Laxmangarh areas were comparatively less spiny. It was observed that high forage yielding tree was not necessarily high seed producer; rather there appeared to be negative association between these two attributes. The comparison of mean of selected strains and the population mean revealed that number of branches, canopy height and canopy diameter of the selected genotypes were almost double in magnitude. The canopy volume of the selected tree was more than thrice that of the base population. Hence these four traits appeared to be most important contributing traits of leaf fodder yield in *P. cineraria*. The stem height of the two populations was almost same and so stem height appeared to have exerted little influence on forage yield in *P. cineraria*. They concluded that there existed a vast exploitable genetic variability for leaf fodder and its component traits.

A regular programme on genetic improvement of *P. cineraria* was initiated at Central Arid zone Research Institute, Jodhpur in 1983. An exploratory survey was undertaken in 1984 and germplasm collection from 140 trees was made from various places of Indian Thar desert viz., Ajmer, Barmer, Bikaner, Churu, Jaipur, Jaisalmer, Jalor, Jhunjhunu, Jodhpur, Nagaur, Sikar and Tonk districts. Analysis of three characters i.e., seed weight, pod length and number of seeds per pod revealed enough variability. Maximum range of variability for pod length was observed in Jodhpur provenance (8.6-26.0 cm with mean  $13.46 \pm 1.12$ ), whereas for the number of seeds per pod, range was maximum (2.0-17.0 with mean  $9.60 \pm 1.48$ ) in Nagaur provenance and for seed weight maximum range was observed in Churu provenance (4.0-7.4 g with mean  $5.34 \pm 0.25$  g). Coefficient of variation was highest for number of seeds per pod and lowest for seed weight. Barmer region represented more than 30 per cent C.V. for all the three characters studied (Kackar *et al.*, 1986a). Kackar *et al.* (1986b) reported variation for other morphological characters of *P. cineraria* in natural stands from various adaphic sites and rainfall zones of western Rajasthan. The height of the trees was found to be variable in all the eleven provenances. The maximum and minimum mean height of 16.3 and 8.8 m were observed in Barmer provenance and Tonk provenance, respectively. The mean values of forking height varied from 2.04 to 4.28 m in Tonk and Barmer provenances (over all mean,  $2.79 \pm 0.28$  m). Average forking height was lower than

three metre in all the provenances except Barmer and Nagaur. Subsequently, detailed surveys and germplasm collection from arid parts of Rajasthan and Gujarat were undertaken during 1986 and 1991 during which seed from 70 and 79 plus trees was collected and utilised for nursery studies and establishing progeny trials and germplasm (Kackar, 1988; Singh *et al.*, 1993). Provenance variation in seed and pod characteristics has also been studied by Arya *et al.* (1992).

### *Tecomella undulata*

*Tecomella undulata* (Rohida) belongs to family Bignoniaceae. The seeds are very light and papery and easily get wind dispersed. In Indian arid zone it is locally called as "Marwar Teak" or Desert Teak because of its wood quality. Presently it is one of the most important desert timber tree species. Last three decades have witnessed large scale export of its carved furniture. This factor has caused a heavy demand for quality wood. Thus indiscriminate felling continued and at present the desert tract has almost exhausted large bold and healthy plants. Consequently the population of this species decreased drastically and it is now listed as threatened species (Saxena, 1993).

In western Rajasthan, rohida (*T. undulata*) is generally recorded on sandy plains, undulating hummocky plains and undulating interdunal plains with deep to very deep sandy soils. There are two distinct concentration zones of high density of rohida: (i) district Barmer and (ii) Sikar. In Barmer district, tehsil Chohtan, Barmer and north Bhakasar show high density of rohida (20-60 plants ha<sup>-1</sup>) on flat and hummocky interdunal areas. This is a low rainfall tract (150-250 mm) but the soil moisture in lower depth is always present round the year and perhaps this factor helps in providing high tree density of rohida and khejri. Rohida is always a common associate of khejri (*P. cineraria*) community in these areas. Low dunes and longitudinal ridges of these three tehsils of Barmer district are also occupied by *P. cineraria* with 10-20 plants ha<sup>-1</sup>.

Phenotypic variability in morphological traits and flower colour of *T. undulata* was initially documented by Chakravarty and Chand (1975). Jindal *et al.* (1985a, 1987b) reported wide variation for tree height, basal diameter and d.b.h. Maximum frequency of this species was observed in interdunal areas of Barmer district. Coefficient of variability for tree height, d.b.h., basal diameter and canopy diameter was also maximum in this district. Tree height ranged from 2.0 m to 12.8 m with mean value 5.78 m and forking height 0 to 4.2 m with 1.63 m mean. Branches per tree ranged between 1 to 15. Basal diameter and d.b.h. ranged from 7.1 to 136.8 cm and 3.8 cm to 130.4 cm, respectively. Maximum coefficient of variability was observed for basal diameter (61.3%) followed by d.b.h. (59.2%) and minimum for leaf size (30.6%).

### *Acacia* spp.

There are reports available on natural variability in other important arid zone trees. Solanki *et al.* (1985a) reported phenotypic variations in pod and seed size in natural stand of *A. senegal* in western Rajasthan. From their studies of 52 individual trees they reported enough variability for various pod characters like pod length, pod breadth, seeds per pod and 100-seed weight. In an

earlier study, Solanki *et al.* (1984b) compared tree height, basal diameter, d.b.h., canopy diameter and estimated volume per tree of 22 year old *Acacia senegal* and *P. cineraria* grown in Jodhpur, Rajasthan. Coefficient of variation was more in *P. cineraria* for all the characters except volume.

*A. senegal* is an important fuel and gum yielding tree on rocky habitats. An exploratory survey was undertaken during 1984. Maximum variability was found in Barmer district. In 52 trees enough variability could be observed in various pod characters like pod length (4.2-10.3 cm), seeds per pod (2.8-7.0) and 100 seed weight (7.40-18.88 g). Variation in different traits has also been observed in progenies of 13 plus trees established in 1985 at Jodhpur, Bhopalgarh and Jaisalmer. At present there are about 700 trees in field representing 18 single plant progenies. Gum production has been observed in these plants. The gum yield was, however, more in some of the exotic plants (200 g tree<sup>-1</sup>) in a provenance trial representing African provenances.

Large variability for tree morphological traits, seed yield and oil content in neem has been reported by Jindal *et al.* (1997).

### Variation in Nodulation

Variation in 70 single juvenile plant progenies of *P. cineraria* in nursery was investigated for number and size of nodules. Nodules were observed only in 14 progenies after six months. There were differences in number and size of nodules in plants within and between progenies (Kackar *et al.*, 1990).

### Biochemical Variation

Solbrig *et al.* (1977) reported that the number and kind of flavonoids found in different species and provenances of *Prosopis* differed appreciably, but their occurrence did not seem to be related to, or selected by habitat characteristics, when examined along east/west transect through Arizona and Texas. Besides variation in morphological traits there are number of reports available on biochemical variation in phenolics, isoenzymes and protein of *Prosopis* species. Studies at the Institute on six *Prosopis* species revealed that each species had a characteristic phenolic pattern and the degree of similarity as indicated by number of common spots among different species was in close agreement with their classification based on morphological criteria and geographical distribution (Pancholy *et al.*, 1989).

The first report of genetic variation of crude protein content in *P. cineraria* was that of Gupta *et al.* (1984). They reported wide range of variability in protein contents of pods (without seeds) of *P. cineraria* from different provenances of Rajasthan. Maximum range was observed in Tonk provenance (8.92-15.05%, mean = 12.4±0.74) and minimum in Sikar provenance (8.92-9.97%, mean = 9.62±0.15). The range of crude protein in different trees from whole population studied was 8.05-15.05 per cent. Highest coefficient of variation was observed in Jodhpur provenance (44.82%) and the minimum was in Sikar provenance (4.44%). In general in semi-arid region the variability was low as compared to that in arid regions. Variability for quality traits in leaves of *P. cineraria* and *A. senegal* was reported by Gupta and Jindal (1985). Genetic variation in minerals,

crude protein and structural carbohydrates of foliage of young plants of *P. cineraria* has also been reported by Arya *et al.* (1995a).

Jindal *et al.* (1993) reported significant variation for crude protein, ADF, cellulose and hemicellulose in *T. undulata* in the leaf samples collected from Barmer and Jodhpur districts. Gupta *et al.* (1986) also reported variability for crude protein in leaves of nineteen lines of *Leucaena leucocephala* and it varied from 25.4 to 39.6 per cent. The phenotypic and genotypic coefficients of variation were 11.9 and 11.8 per cent, respectively. The heritability for crude protein content was high (0.98). However, genetic advance as per cent of mean was relatively low (24.2) indicating that selection for this trait may not be much effective. Solanki *et al.* (1985b) reported high heritability (82.5%) and genetic advance as percentage of mean (21.9) in for most of morphological traits *Leucaena leucocephala*.

### Provenance - Progeny Trials

For partitioning of phenotypic variability into genotypic and environmental components it is necessary to conduct progeny trials. The genotypic variation from such studies helps in better understanding of variability within and between progenies. Moreover, the components of variance derived from progeny trial data are necessary for computing various genetical parameters like heritability, genetic advance, etc. This information helps in planning proper breeding programmes and gains expected from them. The observation on progeny trials from juvenile stage till maturity helps in understanding of variations associated with development and can be of help in early selection.

#### *Prosopis cineraria*

Kaul (1965) established provenance trial of *P. cineraria* at Jodhpur but nothing was reported thereafter. Subsequent studies at Central Arid zone Research Institute, Jodhpur revealed significant differences among progenies for various seedling characters of 49 individual trees. Eleven superior trees were selected from different parts of Rajasthan and their seedlings were used for establishing a progeny trial (CAZRI, 1984).

Muthana (1980, 1982) also initiated study in 1977 at Jodhpur to determine the genetic variability for various growth attributes in *P. cineraria*. Two year old progeny trial indicated presence of considerable variation in mean height of the progenies, which varied from 20 to 65 cm. Three plants of Jodhpur provenance showed more than 100 cm plant height. First report on heritability in *P. cineraria* was published by Solanki *et al.* (1984d).

Seventy single plant progenies were raised in pots (four replications, ten seedlings per replication) and significant differences for root and shoot characteristics were observed upto six month stage. Genotypic coefficient of variation, heritability and genetic advance were generally high at one month stage and showed decreasing trend with growth (Kackar, 1988).

Estimates of family heritability, single tree heritability and genetic gain indicate that simple selection can be highly effective in this species (Solanki *et al.*, 1992a).

Progeny trial comprising of eleven half - sib plant progenies of plus trees identified during survey (one tree from each district) was established during 1984 in randomised block design having three replications with 14 trees per plot. Significant variation among progenies for tree height of two to six years has been reported (Jindal, 1998). High values of family, heritability and single tree heritability with and without blocks showed that improvement in height can be done by simple breeding methods such as mass selection. Variation in tree height, collar diameter and canopy shape is present in the material. Analysis of data on the basis of single plants after 12 years of establishment showed that height of best progeny was 4.12 m.

In an another progeny trial comprising of nine single plant progenies, analysis of data of growth height of first five years for various genetic parameters showed that progenies showed significant variation for plant height over years and heritability estimates ranged from 46.6 per cent for first year of growth to 85.7 per cent for fourth year of growth. High heritability was accompanied by high genetic advance in third, fourth and fifth year. The significant correlation between height recorded during different years indicated the possibility of selection of fast growing tree types after second year of establishment. The third progeny trial of *P. cineraria* comprising of 20 progenies was established in 1989 (CAZRI, 1989).

Provenance trials of *Acacia senegal*, *A. albida*, and *A. tortilis* subsp *raddiana* have been established at the Institute (CAZRI, 1984, 1986, 1988). Variation in seed germination and seedling growth among provenances of *P. cineraria* has also been studied at Hisar (Arya *et al.*, 1995).

### ***Tecomella undulata***

In 1984 progeny trial comprising of 11 progenies was established at the Institute. In 1986 another trial of 20 progenies was established. Tree height data of eleven half sib plant progenies established in 1984 over six years indicated that progenies showing good growth in the initial stages were not necessarily performing in subsequent years. There were significant differences among the progenies over all the six growth years. Estimates of family heritability, single tree heritability and genetic gains from family and mass selection indicated that the gains were low with both the selection methods. As components of variance tend to stabilise after fourth year of growth, selection done in the earlier years may not be rewarding. Low values of heritability and genetic gains from family and single tree selection suggested that there is need for other selection procedure for higher genetic gains for the tree height (Jindal *et al.*, 1992). Provenance trial of this species has also been recently established at Arid Forestry Research Institute, Jodhpur by Rai *et al.* (1995).

### ***Acacia* spp.**

*A. nilotica* sub sp. *cupressiformis* is found in Pali district and its concentration is very high around Sadri. During survey variation in height, dbh and compactness of crown was observed. Seed from eleven plus trees has been used to establish progeny trial of this sub-species during

1991. Our earlier studies on single plant progeny trial indicate that this sub-species can perform well under Jodhpur conditions and there is segregation with respect to compactness of crown. *A. nilotica* collections were also made from eleven provenances in Gujarat and a replicated trial was established during 1990.

Twelve progenies of *A. tortilis* - an exotic fast growing multipurpose tree species - were evaluated under arid (Jodhpur) and semi-arid (Pali) conditions. Provenance trial of *A. tortilis* sub sp. *raddiana*, has also been established during 1988-89.

*Acacia albida* is widely distributed throughout the dry zones of Africa and parts of the Middle East (Fagg, 1992). This species has a particular potential for community forestry in dry areas (Palmberg, 1981). In Sahelo-Sudanian zones *A. albida* is regularly associated with most intensively cultivated lands. According to Pelissier (1979), *A. albida* stands are critical to the lives of farmers dependent on rainfed cereal agriculture and breeding of domestic animals. Since last two-three decades information has been generated on agroforestry, silviculture, and various other aspects, but it was only during last decade or so that concerted research efforts were made on genetic resources and stock improvement (Bonkoungou, 1992).

Provenance trial of *A. albida* was established at Central Arid zone Research Institute, Jodhpur during 1988. There were significant differences among the seven accessions for tree height over all the seven years since their establishment. Mean provenance height after seven years was more than 4 m in all the accessions. Accession having maximum height during first year of establishment is also having maximum mean height after seven years of establishment. Flowering in 16 trees was observed for the first time in 1993-94 when trees were six year old. These trees were not from any specific provenance but were representing all the provenances. Since then number of trees have started producing seed upto 3 kg tree<sup>-1</sup> (CAZRI, 1996).

Most of the diversity collected during surveys or procured from other sources is in the form of progenies/accessions in the field. The conventional approach of germplasm collection and conservation in the form of single plant progenies or clones cannot be extended too far due to limitation of land and manpower. There is a need for adopting other conservation strategies like low temperature storage of seeds, pollen storage, *in vitro* collection and conservation, etc. Dilemma can be whether to store genetically improved stocks or just natural populations. The problem becomes simple if we actually know about the exact extent of genetic variability and try to preserve the same levels in genetically improved stocks.

### Nursery Technique Modified

In the genetic improvement programme initiated during 1983, in contrast to the conventional approach of using six month to one year old seedlings, which involves seed storage after collection and maintenance of nursery during hot months, seeds of *P. cineraria* collected in the middle or end of May were scarified with sulphuric acid and used for raising nursery. Transplanting of two month old seedlings was done during August immediately after rain. This

approach not only has given very high establishment, but also has many other advantages over using six month to one-year-old seedlings. As the roots do not grow too much, they do not coil and hence do not need clipping. As nursery is maintained only for two months or so and that too during monsoon season (June to August), there is economy of labour and precious water. Moreover seeds collected in May if stored upto November, get damaged by bruchids. Added advantage of immediately collecting and sowing the seeds, besides saving of one year, is that risk of seed mixing and loss of genetic purity gets minimized. This technique has been used successfully in *Tecomella undulata* and *Acacia* spp also ( Singh and Kackar, 1996).

### **Seed Orchards**

Under natural conditions pods of *P. cineraria* are eaten by grazing animals and seeds after passing through the digestive tract germinate readily. Over last few decades the increasing human and livestock population has led to cultivation of all sorts of lands and over exploitation of resources. *Prosopis cineraria* is lopped for fodder and such trees do not set seeds. Thus even though one can observe good population of *Prosopis* in many parts of the desert, the natural mechanisms of regeneration are getting hampered and the results over time can be devastating. The plant has ability to coppice under natural conditions. This mechanism of regeneration has some significance in long term survival of the tree. The importance of the tree demands that this tree should be included in afforestation programmes. Long life span of trees demands that genetically superior material should be used. Hence it is important to establish seed orchards. Seedlings raised from seed will show variation, but chances of establishment of plantlets raised from seed are more, especially while going for large scale plantation. For better establishment there is need to minimize biotic interference.

### **Seedling Seed Orchard**

Seed orchards of *Prosopis cineraria* and *Tecomella undulata* were established using plus trees. In *P. cineraria* seed orchard some of the trees had growth comparable to that of *A. tortilis* (Solanki *et al.*, 1984c). In the orchard having 93 trees, 40 per cent of the population had height more than 7 m and only 28 per cent of the population had height less than 5 m in 1995. Mean height population in the orchard was 5.78 m. Progeny trial of *P. cineraria* also established during 1984 comprises of collection from all parts of Rajasthan and hence can be taken as a representative sample of whole of the population. In this trial mean height was 2.49 m.

### **Clonal Seed Orchard**

To collect plus genotypes of *P. cineraria* and establish a clonal seed orchard, which at present has 200 plants, air layering technique was employed. Clones start flowering within an year; crossing/selfing, seed collection easy; and if not tailored, these attain bush type form. Root studies indicate that one of the root assumes the role of tap root.

It is evident that we need to have broad genetic base in seed orchards for production of genetically superior seed. There is need to produce information on outcrossing rates so as to select appropriate breeding strategies. At the same time it may be important to collect information on the pollinators which may also be getting affected by overexploitation of vegetal resources. In seed orchards, besides superior genotypes, it may be necessary to go for various cultural and management operations for better growth and health of plants.

Seed certification in trees has not got the direct attention. Instead of random seed collection, emphasis is now being given to collect seed from plus trees, or established plantation or seed orchards. Seed collection in trees requires some innovative approaches as many times tree density is low, seed is on higher branches, seed is available when climatic conditions are adverse.

Seed production can be enhanced by supplemental mass pollination, using growth hormones, checking gall forming insects and other resident pests. Pressure on demand for good quality seed can also be reduced by better post harvest care and improved nursery techniques. It is important to ensure that seeds are collected and cured at an early/appropriate stage. Seed storage after chemical treatment may reduce the damage due to insects. Scarification of hard coat seeds may significantly improve the germination rates.

## **Variation Components and Interrelationships**

### **Juvenile Progenies**

The fact that widely distributed forest tree species show genetic variation between geographical sources or provenances and between individuals of the same provenance has been well established from a large number of studies on seedlings and mature trees. Variance components have been analysed in juvenile progenies of *P. cineraria* (Kackar, 1988) and *T. undulata* (Jindal *et al.*, 1991). In *T. undulata* there was change of ranks of the progenies. Of the 10 tallest juvenile progenies of *T. undulata* at one month stage, only 5 appeared among the top ten at four month stage. In both the species heritability showed decreasing trend with age.

### **Juvenile to Mature Stage**

Components of variance normally take few years to get stabilised (Huehn *et al.*, 1987). Jindal *et al.* (1985b) reported the performance of progenies of 12 trees of *Acacia tortilis* under arid and semi-arid conditions. Fluctuation in variance components for height particularly upto second year of growth in twelve half-sib progeny trial of *A. tortilis* at two locations viz., Jodhpur and Pali, was observed. Variance components tended to stabilize from third year onwards suggesting that three years may be the minimum age for starting effective selection (Solanki *et al.*, 1992).

In *T. undulata* progenies showing good growth in the initial stages were not necessarily performing the same in subsequent years. Components of variance tended to stabilize after fourth year of growth. Hence selection done in earlier years may not be effective. Estimates of family



heritability, single tree heritability, and genetic gain indicated that the gains were low with both the methods. (Jindal *et al.*, 1992).

Solanki *et al.* (1984e) studied variability and heritability of height of *P. cineraria* from the age of 1 to 5 years. In all the growth stages there were highly significant differences in progenies. Progenies from Jodhpur area maintained relatively higher growth as compared to plant progenies from Bikaner. The heritability of height was 46 per cent in first year, 68 per cent in second year, 83 per cent in third year and 85 per cent in fourth as well as fifth year. The heritability values appeared to be stabilised at the age of three year. The medium to high values of heritability indicated that phenotypic selection will be fruitful. Solanki *et al.* (1984c) considering the six growth years as environments studied genotype x environment interaction in *P. cineraria* for height. Increase in height was found to be positively related to the total rainfall of the preceding year. The progeny JU-4 showed higher adaptability to all the environments and was stable too.

## Mature Stands

Solanki *et al.* (1985b) analysed variability for leaf characters in *Leucaena leucocephala* and reported G.C.V., P.C.V., heritability and genetic advance for leaves/branch, leaflets number, leaf area and fresh and dry weight of leaf, etc. Significant variation for all the characters except the number of leaf per branch was observed.

## Parent-Juvenile-Mature Progeny Interrelationships

The parent-progeny correlation and correlation of progeny with geographical location are relevant for identification of desirable mother trees and provenances. Another aspect of prime importance for a tree breeder is to make selection of desirable types as early as possible. For this juvenile-mature correlations have been worked out in number of tree species. Solanki *et al.* (1984d) studied correlation between height recorded in different years in *P. cineraria*. Second year height had a very high phenotypic correlation with third, fourth and fifth year. Similar trend was observed for third year with fourth and fifth year and fourth with fifth year. The genotypic correlation coefficient between any two year was more than 0.93. Thus from this trend it appeared that one could use with confidence the second year data to predict the performance of the families in third, fourth and fifth year.

Interrelationships of juvenile progenies and their parents represented by sixty mature trees of *P. cineraria* from even aged stands and 18 trees from various parts of Gujarat and Rajasthan demonstrated the absence of association eliminating the possibility of juvenile selection (Singh *et al.*, 1991). Interrelation of ten mother trees, their juvenile and mature progenies suggested that though the parent juvenile association is negative, but the interrelationship of parents with mature progenies was positive (Kackar, 1988; Solanki *et al.*, 1992).

## Correlation among Tree Components and Prediction Equations

Kaul *et al.* (1964) in their study on *Prosopis spicigera* (= *cineraria*) reported significant linear correlation between d.b.h. and pod yield; d.b.h. and seed yield; and pod yield and seed yield. After transforming the variable to log scale d.b.h. was found to be significantly correlated with weight of pods, tree height, length of clear bole and crown width. The transformed correlation between pod yield and d.b.h. though significant, was less than the untransformed linear correlation between the two variables.

In another study of *P. cineraria*, Kaul and Jain (1967) reported that d.b.h. was highly correlated with the weight of clear bole, weight of branches and the total fuel yield, whereas the length of clear bole was only related to the weight of the clear bole. The d.b.h. and length of clear bole were however independent of each other ( $r = 0.147$ ). Interrelationship of mimosine, crude protein and IVDMD in *L. leucocephala* was reported by Jindal *et al.* (1988).

Phenotypic and genotypic correlations have been worked out from progeny trials at seedling stage or mature trees in different tree species. Jindal *et al.* (1987a) studied inter-relationship between shoot dry weight and other components in the progenies of 34 plus trees of *Acacia senegal* from three month old seedlings. They studied root fresh weight, root dry weight, shoot length, root length, basal diameter, shoot fresh weight and shoot dry weight, and worked out phenotypic and genotypic correlations between different pairs of characters. Genotypic correlation coefficients were found to be higher than the corresponding phenotypic correlations. All correlation coefficients were positive and significant except of root length with shoot length and basal diameter with shoot dry weight.

Kackar *et al.* (1984) studied nineteen varieties of *L. leucocephala* and worked out phenotypic and genotypic correlation between different characters viz., number of leaves per branch, first order leaflets, second order leaflets, leaf area, green leaf weight and dry leaf weight. At the phenotypic level dry leaf yield was positively and significantly associated with green leaf weight (0.995) and leaf area (0.802). Association was also significant and positive between fresh leaf weight and leaf area (0.903). Correlation values among other pairs of characters were not significant. This revealed that leaf area and green leaf weight were important contributing characters for dry leaf weight. The genotypic correlation for fresh leaf weight and leaf area with dry leaf weight was 0.93 and 0.92, respectively.

Kackar (1988) has analysed correlations of morphological traits with biomass production at seedling stages from one to six month stage and worked out the prediction equations. He has also studied the interrelationships of height, dbh etc., of mature trees with fodder and fuel production and formulated prediction equations.

Prediction equations for seed production by a tree have been formulated in some cases. In *P. cineraria* earlier studies show that pod production could be predicted from dbh and seed can be predicted from pod weight. In *A. tortilis*, total seed weight could be predicted from total pod weight (Jindal *et al.*, 1990). The seed related traits were not significantly associated with

morphological traits in this species and these traits could not be used as predictors. In *P. cineraria* in even aged stands, 100-seed weight is significantly associated with tree height, collar diameter and dbh, this association however gets masked in natural populations possibly due to variable age and location (Singh *et al.* 1991). 100-seed weight also has positive association with progeny height in nursery. Thus selection for seed weight along with total seed production by a tree may lead to better germination and establishment in nursery. The other seed related traits like pod length, seed number etc. were not significantly associated with morphological traits implying that independent or simultaneous selection can be made for these traits.

#### Path analysis

Kackar *et al.* (1984) in their studies on path coefficient analysis (at genotypic level) in *Leucaena leucocephala* varietal trial, reported that fresh leaf weight had highest positive direct effect (0.815) followed by leaf area (0.211) on dry leaf weight. Although direct effect of leaf area was relatively low as compared to green leaf weight, its effect via green leaf weight was larger and positive (0.736). It revealed that leaf area is an important component character of dry leaf weight.

Jindal *et al.* (1987a) in their study on inter-relationship between shoot dry weight and seedling characters of three month old seedlings of progenies of 34 plus trees of *Acacia senegal* reported that direct effects of root dry weight and shoot fresh weight on shoot dry weight were higher and positive followed by shoot length and root length. Kackar (1988) has done path analysis for biomass and fodder production at juvenile and mature stages in *P. cineraria*.

## Breeding Systems

### *Prosopis cineraria*

The information on mating system and detailed reproductive biology is scanty. Parihar and Vir (1993) reported pollinating insects of this species. The degree of outcrossing rates can have an important bearing on conservation strategy both *in situ* and *ex situ* as well as genetic improvement of the species under consideration. Reproductive biology of this species has been studied by Singh (1997).

### *Tecomella undulata*

In *T. undulata* flowering like that in *P. cineraria* is asynchronous and occurs during November to February. In natural population flowers of red, yellow and intermediate colours are found. In the progeny trial comprising of eleven half sib plant progenies established at CAZRI, Jodhpur during 1984, besides variation in height, diameter at breast height (dbh), there was segregation for flower colour in ten progenies, suggesting the outcrossing nature of this species. Our observations showed that birds like purple sun bird (*Nectarinia asiatica*) visit the flowers for nectar and may be acting as pollinators.

Peak flowering period is from end of February to middle of March. The flowering duration varies from 59 to 103 days for individual tree and upto 135 days for the whole population. It has been observed that almost all the flower buds appearing in November, December and January fall before or after opening. Only a few of the flowers developed in February set fruits. Fruit set varied from 0.64 per cent for selfing to 3.94 per cent in cross pollination indicating the presence of self compatibility. Apomixis, an important mechanism for fixing heterotic advantage, was found to be absent (Jindal *et al.*, 1985c).

### ***Azadirachta indica***

Apomixis is absent and self pollination is dominant in this species. About 2 per cent of the flowers set into fruits, rest drop without fertilisation. Flowering occurs during March to May and flowers appearing in March and April drop without fertilisation and do not set fruits (Jindal and Vir, 1994a).

### ***Salvadora persica***

This species is also self compatible and apomixis is absent. Flowers appearing in November to February fall without fertilisation. Very few flowers appearing in March develop into fruits and take about two months for ripening (Jindal *et al.*, 1997).

## **Allelopathic Studies**

Allelopathic interactions of trees vs. trees and trees vs. crops of the region studied *in vitro* as well as in field. Five per cent aqueous extracts of *Azadirachta indica* and *P. cineraria* significantly slowed down the growth in seedling of sesame, moth bean clusterbean and pearl millet seedling in bioassay, while the extracts of *P. cineraria* and *T. undulata* had hardly any negative effect on germination and subsequent seedling development. During field trials moth bean, clusterbean and cowpea failed to germinate under *A. tortilis*. Five per cent leaf extracts of *A. tortilis* and *A. indica* significantly affected the growth of *P. cineraria* seedlings in petridishes. Already established *A. tortilis* and *A. indica* retarded growth height of *P. cineraria* trees and the pattern of effect was parabolic. (Jindal *et al.*, 1989, 1990; Singh *et al.*, 1991b, 1995)

## **Seed Production in Trees**

Seed production in trees is affected by age, genotype and environment. Variation in seed production was observed in *P. cineraria* and *A. tortilis*. In four-year old 35 trees of *A. tortilis*, the coefficient of variation for seed yield per tree was 116.9 per cent (Jindal *et al.* 1990a). In *P. cineraria*, on average a 30 year old tree produces 2-3 kg seed under 350-400 mm annual precipitation. Our observations show that seed production was highly variable over years. This has led to many beliefs and natives predict rainfall in the subsequent months on the basis of amount of flowering and pod formation in *P. cineraria*. Sufficient variability in seed and seed

related characteristics has been observed in all the species under study. In some trees pods or seed form the part of economic yield as well. For example, pods of *P. cineraria*, fresh or preserved, are used as vegetable, seeds of *A. senegal* also form part of vegetable. The significance of pod and seed production in such tree species in a genetic improvement programme automatically gets enhanced. During surveys natural variability has been collected and preserved as germplasm accessions or progeny trials (Solanki *et al.*, 1992). Influence of seed size of *P. cineraria* seeds on their germination was studied by Manga and Sen (1995) and concluded that seed traits were positively associated with seed germination.

### **Nitrogen Fixing Rhizobium for Trees**

Nitrogen limitation in most soils of arid and semi-arid regions is a principal problem hindering high biomass production in these areas. The leguminous trees have the advantage that in infertile soil, they can be self-sufficient for their nitrogen supply by virtue of their symbiotic association with rhizobia fix nitrogen. But these legume trees can be utilised to their fullest extent only if they occur in successful symbiotic relationship with efficient, high nitrogen fixing strains of *Rhizobium*. A study made by Pancholy (1991) showed that native rhizobial strains isolated from arid soils of west Rajasthan produce poor quality, low number nodules fixing nitrogen in insufficient amounts. Systematic work on the genetic improvement of rhizobia nodulating desert tree legumes started only six years back where studies were undertaken to biochemically, microbiologically and morphologically characterise rhizobia of *Prosopis cineraria* and *Albizia lebbek*. Azide resistance was also studied in arid zone tree legume rhizobia by Pancholy (1993) because this character has been found to be directly associated with high nitrogen fixing efficiency of rhizobia. Sodium azide resistant mutants that fixed higher amounts of nitrogen (showed 29-48% more per cent shoot N as compared to control) have been isolated for *P. cineraria* (Pancholy, 1996). Rhizobial strains having high competitive ability were also isolated for *P. cineraria*, *Leucaena* and *Acacia* (Pancholy, 1994, 1997). Studies have also been conducted to locate the genes for competitiveness through plasmid curing studies and it was inferred that factors controlling rhizosphere competence in these tree species might be chromosome borne (Pancholy, 1997). Auxotrophic mutants requiring adenine, valine, tryptophan, histidine and arginine were isolated from rhizobia of *P. cineraria*. Five thermotolerant mutants have been isolated from a rhizobial strain PC-3 of *P. cineraria* following EMS mutagenesis. All the five mutants showed growth at 40°C. Per cent shoot data revealed that three of the isolated mutants (PC-3a, PC-3c and PC-3d) caused 33.2, 40.7 and 36.1 per cent increase, respectively in shoot N over the wild type control. Pokhriyal *et al.* (1990) identified some fast growing leguminous trees for nitrogen fixation.

## Biochemical Genetics

In trees very few morphological markers are available and characters like height diameter at breast height (dbh), etc. are strongly influenced by environment and age. As isoenzymes are co-dominant and stable and hence can serve as good markers, programme on biochemical genetics was initiated at this Institute in 1993 with the goal of understanding extent and pattern of genetic variability, level of heterozygosity in natural populations, and mating systems of arid zone tree species. There is hardly any information available on arid zone trees on these aspects. Due to lack of morphological markers and long life span of arid zone trees, isoenzyme markers are the only effective tool for estimation of outcrossing rates.

Eventhough most of the angiosperms and gymnosperms from European countries have been studied for isoenzyme variability and these markers have been used to estimate the outcrossing rates, there are only isolated reports on use of isoenzyme markers from India. Mating system analysis in natural populations of *Acacia nilotica* subspecies *leiocarpa* and subspecies *kraussiana* has been done by workers from Tropical Forest Research Institute, Jabalpur (Mandal *et al.*, 1994; Mandal and Ennos, 1995).

At this Institute isoenzyme markers were identified and used for studying variability in natural stands, within progenies and between progenies of arid zone tree species. There were marked differences in the peroxidase isoenzyme pattern within and between progenies of *Prosopis cineraria* (Solanki *et al.*, 1992a). The polymorphic loci detected in *Prosopis cineraria* and data collected from 52 plants has been used to estimate outcrossing rate in this species using Expectation Maximisation algorithm procedure. Polymorphic locus was also detected in peroxidase isoenzymes in *Simmondsia chinensis* (Jojoba) - a dioecious plant. This locus had no association with sex of the plant. Developmental changes in isoenzyme pattern in different stages of *in vitro* differentiation from callus to complete plantlet in datepalm have also been studied (Singh and Kacker, 1994).

## Vegetative Propagation

It is an important tool for genetic improvement and establishment of clonal orchard/plantations. Vegetative propagation in *Prosopis cineraria* from root suckers was reported by Rao (1953). Propagation by air layering in this species was achieved by Rawat *et al.* (1982-83) and Solanki *et al.* (1984a, 1986). The technique essentially involves removing of bark from girdle, applying rooting hormone and covering it by moss or clay. The experiments over a decade at the Institute have clearly demonstrated seasonal variation and best results are obtained during monsoon. As rainfall pattern is highly variable, success in rooting by air layering also varies over years. Air layering technique developed for clonal propagation of superior genotypes has been used for establishment of clonal seed orchard.

Vegetative propagation by rooting the stem cuttings is the easiest approach. Success in this area was reported by Arya and Tomar (1989) and Arya *et al.* (1994). Rooting from 30 to 35 per

cent was observed in stem cuttings from 8 year old trees treated with 1000 mg l<sup>-1</sup> IAA + IBA + 2,4-D and 4000 mg l<sup>-1</sup> of NAA + IBA + thiamine. The rooting per cent by these treatments was 50 and 60 per cent, respectively when stem cuttings were taken from 6-month old seedlings. Seasonal variation in rooting, and the effect of plant age and auxin treatment on rooting response has been studied by Arya *et al.* (1993, 1994).

*Acacia albida* is an important tree for agroforestry and has shown good growth in Indian arid zone. There are reports that this species flowers rarely (Ahmed, 1987). Its vegetative propagation has been achieved by Harsh and Muthana (1985) and Ahmed (1987). In the provenance trials established in CAZRI in 1988 regular flowering and seed production has been observed after seven years of establishment.

## **Micropropagation**

### ***Prosopis cineraria***

Rapid multiplication through tissue culture has been attempted in number of arid zone trees. Goyal and Arya (1981) reported differentiation in *Prosopis cineraria* using hypocotyl segments. These workers in 1984 achieved the same by bud culture. The detailed account of clonal propagation of *Prosopis cineraria* as well as other important arid zone tree species *Ziziphus mauritiana*, *Tecomella undulata*, *Aegle marmelos* and *Eucalyptus* were reported by Arya and Shekhawat (1986). Puri *et al.* (1992) achieved *in vitro* regeneration of *Prosopis cineraria* using epicotyl as explant. *In vitro* plantlets of *Prosopis cineraria* from juvenile and mature explants has been reported by various workers (Nandwani and Ramawat, 1993). Shekhawat *et al.* (1993) studied the effect of various factors like genotype, morphology, location season of explant collection, media composition, etc. during *in vitro* clonal propagation of *Prosopis cineraria*.

Work on micropropagation was also initiated at this institute in 1985. Success has been obtained on *in vitro* culture of *Prosopis cineraria* using both shoot and root segments as explants (Kackar *et al.*, 1991, 1992), *Simmondsia chinensis* (Jojoba) using coppice shoots as explant (Kackar *et al.*, 1993), *Salvadora oleoides* (Jal) using immature embryos as explants (Kackar *et al.*, 1997) and *Phoenix dactylifera* (Date palm) using callus produced from apical meristem of offshoots (Kackar *et al.*, 1989). Nodal segments from actively growing branches of five year old elite tree of *P. cineraria* when cultured on modified Murashige and Skoog, 1962 medium containing 3 mg/l each of naphthoxy acetic acid and naphthyl acetic acid produced axillary shoots within 7 to 10 days. These shoots when cultured on modified MS medium containing 3 mg/l of NOA developed tap roots in 25-30 days. The shoots from *in vitro* cultured plantlets could be further cut into 3-5 nodal segments, each of which produced complete plantlet on modified medium containing 3 mg/l NOA (Kackar *et al.* 1991).

Root segments from 2 to 4 month old seedlings and also from 5 year old elite tree could also be used successfully for micropropagation. 1.0 -1.5 cm long root segment when cultured on modified

MS medium containing 3 mg/l NOA produced adventitious shoots, their number being more in explants from seedlings (5 to 20 shoots) than from adult tree (3-8 shoots). These shoots when cultured on the same medium produced complete plantlets (Kackar *et al.*, 1992).

Profuse callus could be obtained on MS medium containing 0.25 mg/l NAA and 4.5 mg/l kinetin using cotyledonary leaves as explants. Callus development initiated after a week and the development was better in dark.

There are numerous reports on *In vitro* regeneration and multiplication of various tree species, but the number of reports on species hardened and successfully transferred to the field are very scanty. This task becomes more difficult in arid zones where climatic conditions are extreme and only limited period of monsoon can be considered favourable for transplantation of *in vitro* raised and hardened plantlets. Vitrification of shoots, impaired stomatal development and functioning, poor development of wax, inadequate photosynthetic efficiency, undesirable root system are among the frequently mentioned causes leading to death of plantlets during transfer from test tube to the soil. Success has been achieved at this Institute in field transfer of *Prosopis cineraria* and work on hardening of other tree species is in progress.

### ***Tecomella undulata***

Micropropagation in *Tecomella undulata* has also been achieved by various workers. Arya and Shekhawat (1986) described the procedure of clonal multiplication of this species. Rathore *et al.* (1991) propagated it by using nodal shoot segments as explant; Nandwani *et al.* (1995) described the method for *in vitro* propagation through cotyledonary nodes; and Bhansali (1993) micropropagated this species using axillary and terminal shoot buds from 10-15 year old trees.

### ***Salvadora* spp.**

Micropropagation of *Salvadora*, an important non-edible oil yielding tree found growing on saline and sodic soils in Rajasthan and coastal area of Gujarat, has also been achieved. *In vitro* micropropagation of *S. oleoides* has also been achieved at Central Arid zone Research Institute, Jodhpur using immature embryos as explant (Kackar *et al.*, 1997). A programme on tissue culture of *S. persica* was initiated at National Chemical Laboratory, Poona to multiply high yielding trees. Initially a technique for micropropagation mature trees was developed which was later on utilised to propagate elite trees (Rao, 1987). In a non-replicated small scale trial comprising of 15 plants each from tissue culture raised plantlets and seedlings, first flowering was observed in control plants after 20 months which was eleven months earlier than in tissue culture raised plants (Mascarenhas *et al.*, 1987). These workers reported greater uniformity and greater crown diameter in plants raised through tissue culture. *Salvadora* trees are known to grow for over 100 years. Consequently, the initial cost of plants is not important since the end product is the seed and the annual gains will cover the initial cost (Mascarenhas *et al.*, 1987). Protocols for micropropagation of *Salvadora* are available, but no commercial level propagation has been attempted possibly because raising plants through tissue culture involves additional cost, the consumers are sceptical



about the cost benefit ratio of using such plants. Besides this, micropropagation in trees is not easy. Thirdly, field establishment of tissue culture raised plants in saline and sodic soils under arid conditions may not be very easy. The present scenario of no commercial level exploitation of useful scientific information is the outcome of such limitations on the side of producer as well as consumer.

Biotechnological methods can be successfully exploited for large scale production of superior trees derived through genetic improvement - all being exact duplicates of the original. This is bound to increase the economic yields of the forests. It may not be possible to achieve the same results using conventional methods in the short time. One objection which is often raised is that clonal forestry will lead to annihilation in the event of a disease outbreak. This problem can be overcome by using number of unrelated superior genotypes.

There is not only need to collect more germplasm but also to find ways and means to conserve it at low temperature or by adopting techniques like pollen storage and *in vitro* conservation. In situ conservation, wherever possible, needs to be considered by various agencies.

Information must be generated on mating system in different species under different agroclimatic conditions. This information is important for designing long term breeding programmes and devise methods for germplasm collection and conservation.

Many of the trees found in arid zone are leguminous. There is need to study rhizobia and vesicular arbuscular mycorrhizae (VAM) fungi associated with various tree species. More information need to be collected on different insect pests and relative losses caused by these to enable the breeders to undertake work on selection of resistant/tolerant types.

Protocols for *in vitro* micropropagation have been developed but success in hardening and field transfer such plantlets is limited. Research on this aspect needs to given due attention.

For need-based research the local needs for timber, type of wood required for local handicrafts and various industries must be looked into.

Tree species and types suitable for integrated farming systems will be needed as in arid zones most of the trees will be grown on farmers' fields. Allelopathic effects and root studies for better tree crop interaction thus also need more emphasis.

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# INTEGRATED PEST MANAGEMENT IN PERENNIAL PLANTS

M.P. Singh, R.Raj Bhansali, R.K. Kaul and R.S. Tripathi

Work on plant protection aspects was initiated at the Institute in the late sixties. The early work was restricted to entomological investigations, which encompassed perennial crops and other vegetation as well. With the establishment of Plant Pathology laboratory about a decade later, investigations on diseases of perennial plants began to be undertaken. Nematology was the third discipline augmented to the plant protection group, in mid eighties. Research on rodents was started at CAZRI during late sixties. ICAR awarded an All India Coordinated Research Project on Rodent Control during 1977 with CAZRI as headquarters. Today, CAZRI is a leading Institute in the country, also recognised abroad in the field of rodent research. The multidisciplinary approach of the Institute provided opportunities to the plant protection scientists to work in projects with broader perspectives. The plant protection group has been contributing in various activities as per the mandate of the Institute.

## ***Entomological Investigations***

Entomological studies have been carried out on the perennial vegetation of arid, semi arid and dry sub humid regions. The studies covered forage crops, fruit crops and the forestry plants. The early work reported from the region on locusts, though has a relevance to the arid land agriculture, is not being considered, as these studies were carried out in a different context. Pruthi and Bhatia (1952) gave an account of the peculiarities of the insect fauna of Rajasthan desert and discussed the share of insects in the maintenance of the desert. Pradhan (1959) reviewed the ecology of arid zone insects. Roonwal and Bose (1964) detailed the termite fauna of Rajasthan.

## **Forage Plants**

Livestock has been the main occupation of the inhabitants of western Rajasthan, and forages their principal natural resource. This region is known to be the seat of origin of many a good species of forage grasses. These plants support the populations of a variety of insects, many of which are of agricultural importance. The insect associates of grasses were largely overlooked in the days of abundance of grasslands. With the dwindling of the area under grasses, the pest load on the remaining forage vegetation is increasing. Kushwaha and Jain (1962) provided information on some forage insect pests of Rajasthan. Kushwaha (1972) dealt with the termite pests of grasses along with the fruit trees. Pal (1974) reported *Geocoris jucundus* as a predator on lucerne aphids. Pal (1975) recorded the pests of desert grasses and legumes. Kushwaha and Bhardwaj (1977)

compiled the information about the forage and pasture insect pests of Rajasthan. Sachan (1978) carried out studies on the insect pests of important grass species under irrigated and rainfed conditions. Parihar (1980) carried out investigations on the population ecology of termites in grassland ecosystem. The studies carried out about grasshoppers at CAZRI has been presented in the form of a monograph (Parihar, 1987). Parihar (1995) reported additions to the grasshopper fauna of Rajasthan. Singh (1997) described the major insect pests of pasture grasses and legumes and their management. Singh and Parihar (1997) collated information about the more common insect pests in silvipastoral systems. The salient findings of the investigations carried out during 1978-80 are being presented below:

### **Incidence, abundance and succession of insect pests on forage grasses and legumes**

The more important taxa associated with forage plants were: *Myloccerus* spp., *Amrasca* spp., *Cicadulina* spp., *Empoasca* sp, *Aphis craccivora*, *Clavigralla scutellaris*, *Nezara viridula*, *Nysius* spp., *Oxyrachis* spp., *Clovia* sp., *Amsacta* spp., *Utethesia pulchella*, *Dorylus* spp., *Haplothrips* spp. and *Odontotermes* spp. The abundance of the weevils, *Myloccerus* spp. was observed to keep pace with the growth of the host grasses. Nitrogenous fertilisers on *Cenchrus setigerus* without any phosphatic supplement attracted higher population of the grey weevils, but the differences in injury to host due to variation in insect population was insignificant (CAZRI, 1978).

The grasshoppers were observed around the fields almost round the year. The population build up of the weevils began in mid July, culminating in the first fortnight of August. The jassids started increasing from mid August, but their population was thin before winters set in. Harvester ants started appearing by end of September, but the maximum activity was exhibited in October and February.

### **Loss estimation studies**

Losses due to different pests were variable under different situations. Despite lower population of weevils on rainfed grass plots, as compared to the irrigated plots, greater foliar injury was witnessed in the former. The moderate injury losses were mostly made good by rapid foliar growth.

### **Chemical control trials**

Experiments with ten then commonly used insecticides against *Myloccerus maculatus* revealed superiority of methyl parathion and quinalphos over others (CAZRI, 1979).

### **Forestry Plants**

Woody and non woody forest plants have been studied for their pest problems. Pal (1970) reported a few new records of Scarabaeid beetles damaging forest nursery seedlings. Pal and Sharma (1970) made observations on the vertical distribution of *Anacanthotermes macrocephalus*. Pal (1976) carried out study on the relative abundance of scarabaeid beetles on light trap. Pal and Kushwaha (1976) reported occurrence of *Deilephila nerii* as a serious pest on Kaner, an avenue plant. Roonwal (1977) reviewed the work on termite ecology in the Indian desert ecosystem.



Sachan (1977) discussed the morphological, physiological and behavioural adaptations in insects while describing the ecology of the insect pests in the arid regions.

Parihar (1981) presented the work on termite pests of vegetation in monographic form. Singh and Satyavir (1988) reported the occurrence of *Homoeosoma* sp as a pest on *Euphorbia antisyphilitica*. Singh *et al.* (1989) reported the coleopterous pests of forest plants in the Indian desert. Singh *et al.* (1991) described the insect pests of jojoba in the arid regions of Rajasthan. Singh (1991) reported the observations on the pest complex of *Balanites aegyptiaca*. Parihar (1993a) studied the insect fauna of *Prosopis cineraria*, while Parihar and Satyavir (1993) described the pollinating insects on the same host. Satyavir and Parihar (1993) reported the insect pests of *Acacia senegal* and *Acacia tortilis* in the Thar desert. Satyavir and Jindal (1994) reported fruit infestation of *Acacia tortilis* by *Bruchidius andrewesi*. Parihar (1994a, b) wrote on termite pest management in arid zone and on gall makers in *Prosopis cineraria*. Satyavir *et al.* (1994) studied the appearance of insect pests on select genotypes of Rohida. Verma and Satyavir (1995) studied the field insect pests of *T. undulata*. Gupta *et al.* (1995) described the potential of neem for rural development.

Parihar and Toms (1995) studied some aspects of faunal diversity of Tenebrionids in Rajasthan. Parihar and Singh (1996) reported observations on insect pests and flower visitors on *Tecomella undulata*. Satyavir and Verma (1996) described the insect pests of leguminous trees in agroforestry. Satyavir (1996) reported bruchid infestation of legume trees in the Thar desert. Singh and Harsh (1996) reported *Denticera divisella* infesting *Euphorbia antisyphilitica* in the arid zones. Singh (1997a, b, c, d) has described various aspects of management of insect pests in agroforestry, silvipastoral systems, and fruit and forest plants.

Parihar (1997) evaluated the natural resistance of timber and fuelwood against the termites. Singh and Parihar (1997) described the methods employed to manage the insect pests in silvipastoral systems. Parihar and Singh (1998) wrote on the gall making insects in *Prosopis cineraria*. Satyavir and Jindal (1998) described field infestation of *Caryedon serratus* on pods and seeds of *Prosopis juliflora*. Singh (1998) reviewed the injurious Hexapoda associated with *Prosopis* spp.

## Fruit Plants

### Ber (*Zizyphus mauritiana*)

**Incidence studies :** The major and minor pests inflicting injury to ber have been identified and period of activity studied. Among the major pests were included the ber fruitfly, *Carpomyia vesuviana* Costa, bark eating caterpillar, *Indarbela quadrinotata*, and the Scarabaeids (the dominant species belonging to the genera *Adoretus*, *Anomala* and *Lachnosternä* [*Holotrichia*]). Minor pests included *Myloccerus* spp., leaf mites (mainly *Tetranychus annecki*), and also some eryiophid mites causing galls, the lac insect *Kerria* sp., the butterfly *Azonus ubaldus*, bug *Scutellera nobilis* and plant hoppers *Oxyrhachis* sp. and *Oxycarenius* sp. The ber fruit borer,

*Meridarchis seyrodes* has not been observed to occur in western Rajasthan. At Kota, some fruits with pink larvae inside were spotted. Pal and Kushwaha (1976) reported *Julodia beesoni* as a new record on ber. Whereas the major pests occur regularly, the minor pests-most of them polyphagous in feeding habits-inflct considerable injury only under certain conditions. A number of other local insect species adapt to ber during the rainy season and after.

**Pollinator studies:** Ber is an exclusively insect pollinated crop. A thorough study of the insect pollinators on ber has been made, including their relative abundance, frequency of visit, duration of activity and pollination efficiency, etc. (Singh, 1984a). The more important species serving as pollinators for ber in western Rajasthan were *Apis* spp., *Musca domestica*, *Physiphora* spp., *Chrysomia rufifacies*, *Eristalinus* sp., etc.

**Loss estimation and cultivar evaluation:** The extent of injury due to major pests on different cultivars of ber have been estimated. Sachan (1974) studied the varietal susceptibility of ber fruits to the damage of *C. vesuviana*. The available germplasm has since been evaluated for extent of infestation due to fruitfly, bark eating caterpillar, chafers, mites and birds. Golas, Kaithli and Dandan were highly susceptible to fruitfly attack, while Ilaichi was found to be moderately resistant and Tikadi resistant (Singh and Vashishtha, 1984). On the other hand, both Gola and Ilaichi were found to be susceptible to the attack of bark eating caterpillar (Singh, 1984b). The chafers inflicted maximum injury to Jogia and Gola foliage (Singh, 1982a). Katha and Ilaichi cultivars suffered more injury of the mites. The birds caused higher losses to Bagwadi and Aliganj cultivars while Kadka received the minimum bird injury (Singh and Vashishtha, 1995).

**Chemical control trials:** Insecticidal efficacy has been tested against all the major pests and some minor pests too. A schedule has been evolved for the fruitfly *Carpomyia vesuviana*, and timing of application of insecticides standardised (Singh and Pareek, 1981). In normal rainfall conditions the first spray with 0.05% endosulfan should be done in mid October, under conditions of Western Rajasthan. This should be followed by another spray of the same insecticide or other, three weeks later. The third spray could very well be obliterated under these conditions. For the bark eating caterpillar, treatment with dichlorvos (0.05%) or monocrotophos (0.04%) dipped cotton swabs was found to be the best (Singh, 1983a). The other methods of application, like injection of the insecticide with used disposable syringe and painting or spraying of the feeding site of the caterpillar were also attempted and found effective. The holes after treatment should invariably be plugged with clay.

**Residue analysis:** Dissipation of endosulfan and carbaryl residues from foliage and fruits of ber under conditions of Jodhpur has been studied (Singh, 1989c). Residues of 0.05 and 0.10 per cent endosulfan sprays dissipated below tolerance level within four days of application on foliage. In case of the fruits, the residues of endosulfan were reduced to level below the safety limit in less than four days. More than 90 per cent of the initial deposit of endosulfan could be removed by dry rubbing or washing of ber fruits, upto one day after treatment. 0.1 and 0.2 per cent carbaryl sprays on ber foliage imparted deposits which were below the tolerance level. On fruits, the

residues of the same strength of carbaryl were reduced to maximum residue limit before three days. Dry rubbing and washing of carbaryl treated ber fruits led to more than 90 per cent removal of the toxicant upto one day after treatment.

**Resistance studies:** Large variation was observed existing in the extent of infestation of fruitfly *Carpomyia vesuviana* Costa in different ber cultivars evaluated (Singh and Vashishtha, 1984). Under free choice conditions, the fly indicated preference for oviposition on varieties like Gola. The process of antibiosis was assumed to be in operation when the development of the egg and maggot was hindered in different cultivars, of course to different extents (Singh, 1984c). It was observed that generally the cultivars preferred for oviposition offered little hindrance to larval development, while the cultivars on which limited oviposition was recorded in field, exhibited fairly high degree of antibiosis. Studies were undertaken to identify the factors governing the resistance to fruitfly in ber. Of the many factors considered, no single factor was found to be solely or largely responsible for governing the resistance or susceptibility. In breeding programme for resistance to fruitfly *Carpomyia vesuviana*, the F<sub>1</sub> generation fruits obtained through crosses made between resistant and susceptible parents were evaluated for the extent of fruitfly attack. There was a high degree of retention of the resistance characters in the hybrid made through crosses between Seb and Tikadi. As the F<sub>1</sub> hybrid fruits bore other undesirable traits, back crosses with one of the parents was undertaken, and the resultant fruits of the back cross generation with required traits are being evaluated for the extent of fruitfly infestation.

**Attractants:** A large number of natural and synthetic compounds and mixtures were tried in isolation and combinations to assess their effectiveness in attracting the fruitflies. While the flies of the genus *Dacus* responded to many a compounds including methyl eugenol and conventional attractants, no positive response was incited from the adults of the ber fruitflies.

**Biological control studies:** Two parasites viz., *Bracon fletcheri* and *Biosteres vandenboschi* have been found parasitising maggots/pupae of *Carpomyia vesuviana* flies, the latter one being a new record for the region (Singh, 1989). The degree of parasitization, however, was very low.

**Ecological studies:** The bionomics of the ber fruitfly were studied in detail. Two types of pupae were found existing - the short cycle and the long cycle pupae. From the short cycle pupae, adult emergence commenced after two to three weeks of pupation, continuing for upto eighteen weeks. From the long cycle pupae, emergence of adult fruitflies occurred from 28 to 36 weeks of pupation, only after a long aestivation period extending across the hot summer months (Singh, 1983b). Only one generation of the fruitfly was observed completed on *Zizyphus mauritiana*. Peak emergence of adults from the pupae of the last generation during and after the rainy season and the onset of flowering in *Z. mauritiana* not before end of August to September indicated possibility of completion of another generation on fruits of wild bushes of *Zizyphus nummularia*. There being only a limited amount of pulp available on the fruits of *Z. nummularia*, survival of only a limited number of individuals could be expected. However, it appeared to be a useful phase in population propagation and survival.

### **Pomegranate (*Punica granatum*)**

Pomegranate appeared to be relatively free from pest attack in western Rajasthan. Aphids, mites and grey weevils have been observed to be the more common pests here. Incidence of Anar butterfly was not as common as in most other areas where pomegranate cultivation is done. Aphids mostly attack the tender parts of new growth, restricting the growth of the plant while devitalising it through sap sucking. A water jet spray of moderate force could thin the aphid population in large colonies. Mite attack rendered the plant acquire a rusty look with twisting of the younger leaves. The symptoms resembled that of zinc deficiency and could be confused for the latter. The grey weevils of *Myloccerus* genus cut the edges of the leaves. The injury could be serious in the early establishment phase of the sapling. In the grown up plants, the injury was observed to be limited to lower leaves or fresh growth. Castor semi-looper, *Achaea janata*, defoliated the anar plants occasionally. Trials for insecticidal efficacy against this pest revealed higher effectiveness of quinalphos and fenitrothion (Singh, 1982b). A few parasites resembling tachinids were recovered from the larvae/pupae of this insect while rearing the same in the laboratory. Water suspension of the body fluids of field collected diseased larvae sprayed on healthy semiloopers developed no visible disease symptoms in the final instar larvae. When the final instar semiloopers were fed with food treated with this suspension, reduced feeding activity was observed. Such larvae pupated normally, but the adult emergence was little reduced compared to the pupae formed of the larvae that were not fed the treated diet.

### **Goonda [Lasora](*Cordia* spp.)**

The life history of *Diaphorina* sp., a pest of *Cordia dichotoma* was studied by Verma *et al* (1973). The results of control trials have also been presented. At the Central Research Farm of CAZRI, unidentified jassids and psyllids were found sucking sap from tender parts and from the leaves of *Cordia myxa*. Affected leaves were curled inwards. Honeydew secreted by the sucking insects often led to development of sooty mould. In the nearby areas of Jodhpur, excessive secretion of honeydew was observed falling on ground. Leaf galls were also observed.

### **Datepalm (*Phoenix dactylifera*)**

The scale insects *Parlatoria* sp. and termites *Odontotermes* sp. have been observed to be the pests of significance in the arid and semi-arid datepalm growing tracts. In the dry stored dates infestation of an unidentified lepidopteran and some coleopteran pests have been observed.

## **Pathological Studies**

### **Fruit Plants**

#### **Ber (*Ziziphus mauritiana*)**

The major diseases of ber are powdery mildew (*Oidium erysiphoides*, f. *zizyphi* or *Macrosphaera alphitoides* f. sp. *zizyphi*) and collar rot (*Colletotrichum*, *Fusarium* and

*Rhizoctonia*) on grafted seedlings (Mitter and Tandon, 1930; Mehta, 1950; Kumar *et al.*, 1978; Raj Bhansali, 1991); The powdery mildew can be controlled effectively by spraying dinocap, carbendazim, triadimorph, methyl thiophenate (0.1%), or wettable sulphur (0.2%) 2-4 times at 15-20 day interval starting from first appearance of disease. The time of spray could be related with increase in humidity (above 70% ) with light rains or mist and temperature (below 10°C) and cool nights, which favours powdery mildew incidence, for effective control. One spray of dinocap (0.1%) soon after initiation of new growth after pruning is an effective prophylactic measure. Powdery mildew affected galls of ber and a weed *Euphorbia hirta* locally known as 'Dudhi' should be removed from orchards as fungus survives on them during adverse conditions (Saini and Singh, 1989). CAZRI Gola, Jogia, Mundia, Rashmi and ZG-3 have shown greater tolerance to the disease in arid environment.

Collar rot occurs on young (4-6 moth-old budded) seedlings of ber. The disease could be managed by using sand, clay and farm yard manure free from disease propagules for filling polythene tubes. Sterilised soil mixture and good drainage system of polythene tubes can minimise the mortality of grafted seedlings (Raj Bhansali, 1991). Drenching of copper oxychloride (0.2%) or carbendazim (0.1%) 2-3 times can control mortality of seedlings.

#### **Pomegranate (*Punica grtanutum*)**

Fruit spots caused by *Colletotrichum*, *Alternaria*, *Cercospora*, *Drechslera* and *Pseudocercospora* are responsible for considerable damage to pomegranate trees in arid and semi-arid areas (Raj Bhansali, 1991; Pareek, 1997a, b). Bacterial leaf and fruit spots (*Xanthomonas campestris* var. *punicae*) also cause heavy losses to orchards. Fungal diseases could be controlled by 4-5 sprays of mancozeb, or ziram or copper oxychloride (0.2%) starting from flower initiation or initiation of disease. Heavy rains, high temperature 35°C and high humidity (above 75%) favour disease development. Bacterial leaf and fruit spot diseases can be reduced by giving 3 sprays of 250-500 ppm streptomycin sulphate.

#### **Datepalm (*Phoenix dactylifera*)**

Graphiola leaf spot (*Graphiola phoenicis*), black scorch (*Thielaviopsis paradoxa*) and off-shoot disease (*Botryodiplodia theobromae* and *Diplodia phoenicum*) are major diseases causing significant losses to datepalm cultivation (Djerbi, 1983; Raj Bhansali, 1989a). Graphiola leaf spot and black scorch diseases can be controlled by 4-5 sprays of copper oxychloride (0.4%) or carbendazim (0.2%) at 15 days interval starting from October onwards (Raj Bhansali, 1989b). Removal of old infected leaves before rainy season minimises the disease incidence. Khadrawy, Bintaisha, Barhee and Hayani cultivars have showed moderately resistant reaction in arid and semi-arid conditions (Raj Bhansali, 1989b). Mortality due to off-shoot diseases can be minimised by regular spraying of copper oxychloride or bordeaux mixture to detached suckers in nurseries. The dip treatment of suckers by 1% bordeaux mixture or 0.2% copper oxychloride before transplanting in field also helped in reducing mortality as well as in establishment in field (CAZRI, 1985).

## Forage Plants

Smut (*Ustilago vilfae*) is destructive disease of sewan grass (*Lasiurus indicus*) in the desert parts of western Rajasthan (Raj Bhansali, 1989c). The disease was first identified by Agarwal *et al* in 1977 in extreme arid conditions, causing serious seed losses. It is a seed and air borne disease.

## Forestry Plants

The major diseases of Khejri (*Prosopis cineraria*), Rohida (*Tecomella undulata*) Kumat (*Acacia senegal*), Israeli babul (*A. tortilis*), Babul (*A. nilotica*), Khara Jal (*Salvadora persica*), Mitha Jal (*S. oleoides*) and Neem (*Azadirachta indica*) seedlings are root and trunk rots, witches broom and die-back. The occurrence of various diseases on forestry trees in different rainfall regimes has been worked out based on epidemiology and incidence of pathogenic diseases (Bakshi, 1976, Dwivedi, 1993; Raj Bhansali and Jindal, 1997).

### Nursery diseases

Damping-off of seedlings at nursery stage is caused by diverse group of pathogens belonging to the genera *Rhizoctonia*, *Fusarium*, *Pythium*, *Phytophthora*, *Sclerotium* and *Verticillium*, and bacteria. Poor management of nursery plants cause heavy mortality of seedlings in *A. nilotica*, *T. undulata*, *A. indica* and *Capparis decidua* (Bakshi, 1976, Raj Bhansali, 1997). Management of diseases can be achieved by cultural and chemical control methods. Seed treatment with dithiocarbamates, carbendazim, quintogene, mancozeb (2g kg<sup>-1</sup> seed), and streptocycline sulphate (soaking seeds 1g/10 litre). Drenching of seedlings with carbendazim 0.05% for 2 times at 15 days interval has been proved effective to check spread of disease. Proper drainage and sterilised soil help in maintaining disease-free nursery plants.

### Foliar diseases

Leaf spot, die-back and rust can be checked by 2-3 sprays of copper oxychloride or mancozeb or captafol or zineb 0.2% at 15-20 days interval on young trees of *T. undulata*, *A. lebbek*, *Eucalyptus* and *A. indica*. Witches broom of *Salvadora* and little leaf disease of *Eucalyptus* can be minimised by regular pruning of diseased twigs and spraying insecticide with tetracycline hydrochloride 300-500 ppm.

### Root rot

Root rot disease is primarily caused by *Ganoderma lucidum* in *P. cineraria*, *Acacia* species, *A. lebbek*, *Salvadora* spp. and *A. indica*. Cultural practices are effective than chemical control methods to manage the disease in mature trees. Pulverisation and exposing the soil to solar radiation during summers can minimise the attack. The affected trees/dead tree residues including roots and fruiting bodies of fungus should be removed and burnt before raising new plantation. Raising of non-host trees like *Ailanthus* in between susceptible hosts reduces the risk of *Ganoderma* attack. Construction of isolation trenches (0.3 m wide, 0.7 m deep and 1.5 m long)

across the line prevent the spread of disease from affected trees (Bakshi, 1976). Chemical control is not economical as once attack commences, disease spreads widely and easily in soil.

### Trunk rot

Canker, anthracnose, sooty mould, die back and heart rot are common diseases occur in arid zone forestry trees. Heart rot or wood rot is most damaging stem disease in *A. tortilis*, *A. nilotica*, *P. cineraria*, *A. lebbek*, *S. oleoides* and *A. indica*. The disease is caused by *Fomes*, *Phillinus* and *Inonotus* species belong to family polyporaceae (Raj Bhansali, 1997). The disease could be managed by avoiding injury checking illicit lopping and proper dressing by wound paints (Copper based fungicides). Fungal fruiting bodies should be removed, collected and burnt to check spread of disease (Raj Bhansali and Jindal, 1997).

## Nematological Studies

Incidence of plant parasitic nematodes on fruit and forest trees of arid region has been observed more on crops grown under irrigated conditions. Surveys have shown occurrence of diverse species of plant nematodes on these trees. On Ber, *Tylenchorhynchus* sp.; on date palm, *Tylenchorhynchus* sp., *Hoplolaimus* sp., *Pratylenchus* sp., and *Meloidogyne* sp.; on pomegranate *Meloidogyne* sp., *Tylenchorhynchus* sp. (CAZRI, 1987); on citrus, *Helicotylenchus* sp., *Tylenchorhynchus* sp., and *Criconeoides* sp.; and on papaya, *Meloidogyne* sp., *Helicotylenchus* sp., and *Tylenchorhynchus* sp. (CAZRI, 1986) have been recorded. Amongst the fruit crops the lowest incidence of nematodes has been observed on Ber.

On trees of arid region not much is known about the nematode associations. Difficulty in collecting samples from deeper zones of the roots has been a major limiting factor in precise estimation of nematode fauna. However, surveys of tree nurseries have revealed the presence of *Pratylenchus* sp., and *Tylenchorhynchus* sp. on *Prosopis cineraria*; *Meloidogyne* sp. and *Pratylenchus* sp. on *Acacia nilotica*; and *Tylenchorhynchus* sp. on *Tecomella undulata*, *A. tortilis*, *A. samia*, *A. annura*, and *A. salicina* (Kaul, 1998). Similarly, arid shrub jojoba has also been found to support species of *Pratylenchus* and *Tylenchorhynchus*.

Tree nematodes being less studied, the extent of damage caused by them to trees is not known. On the other hand, amongst the fruit plants grown in arid regions, pomegranate has been observed to be severely damaged by root knot nematode, *Meloidogyne* sp. Many a times nematode infected nursery plants are difficult to establish under field conditions. The problem is more serious on plants that are transplanted in a season approaching summer. In established orchards of pomegranate, heavy infestation by *Meloidogyne* leads to symptoms such as chlorosis of leaves, sparse foliage and less fruit set. During summer months the affected plants often show drying of leaves and die back of twigs. Commonly grown varieties of pomegranate i.e. Jalore seedless and Ganesh have been observed susceptible to this nematode. Raising of nursery plants in nematode

free soil and application of carbofuran @ 15-20 g plant<sup>-1</sup> as basin treatment on already established plant (above 3 years of age) has been found effective for the management of this nematode.

## Rodents

Rodents, being free living mammals, are always a serious threat to the perennial crops at all stages of plant growth i.e. nursery to maturity. Since these plants are available in the field throughout the year, rodents find it an ideal habitat for shelter and multiplication, resulting in a serious loss of fruit, fodder and other forest produce. Rodents' serious impact on desert vegetation, orchards, rangelands is easily discernible throughout the tract, as a result of their gnawing, debarking, cutting and feeding activities (Prakash, 1963; Rana and Jain, 1984; Jain and Tripathi, 1988a).

## Species Composition

Of the eighteen rodent species recorded in the Indian arid zone, sixteen wild species are found to inhabit the orchards, forest plantations and grasslands. either in sandy, rocky or gravelly areas (Prakash *et al.*, 1971; Tripathi *et al.*, 1992; Rana *et al.*, 1994). The two most common commensal rodent species viz., *Rattus rattus* and *Mus musculus* have been reported to frequent the nurseries located near residential premises.

## Horticultural Crops

Observation revealed occurrence of five rodent species in the orchards of ber, pomegranate and datepalm. Indian gerbil, *Tatera indica* was the predominant pest species (61.2-79.2% occurrence), followed by five striped squirrel, *F. pennanti*, an arboreal species (9.5-22.2%). Other species trapped, were *M. hurrianae*, *Millardia meltada* and *G. ellioti*.

## Forest and Grass Fields

Although 17 species of rodents have been reported in the natural habitats (Table 1), only two were trapped in the Central Research Farm of CAZRI during the last five years in silva and grassland fields. They are *T. indica* (70.0-75.0) and *M. hurrianae* (25.0-30.0%). Since such fields do not experience any interculture operations, these serve as an excellent abode for rodents throughout the year, which migrate to nearby crop fields during cropping seasons causing colossal losses to the standing crops.

## Distributional Patterns and Habitat Specificity

Based on our observations, an association between rodents and tree species have been established (Table 2). It has been noticed that some species are specific to a particular habitat, while others are found in more than one habitat. *Gerbillus gleadowi* and *Rattus cutchicus* are highly habitat specific, since the former inhabits sand dunes only and the latter is found only on rocky habitats.



## Rodent Damage

### Horticultural crops

Rodents, specially *F.pennanti*, have been observed to cause 29.0% damage to ripe fruits of pomegranate (Patel *et al.*, 1995). Studies on squirrels' damage to various pomegranate cultivars revealed that Khog and Jalore seedless were more suitable for arid areas because they exhibited least fruit damage by vertebrate pests (less than 10 %). On the other hand, Bassein seedless

Table 1. Rodent species inhabiting perennial cropping systems of arid zone

Family	Rodent species	Major problem in
Hystricidae	<i>Hystrix indica</i> Ker	Forest trees and shrubs
Sciuridae	<i>Funambulus pennanti</i> Wroughton	Nurseries, orchards, forestry plantation, Kitchen garden etc.
Muridae		
sub-family : Gerbillinae	<i>Meriones hurrianae</i> (Jer.)	Forestry, pastures and orchards
	<i>Tatera indica</i> (Hard.)	Forestry, pastures and orchards
	<i>Gerbillus gleadowi</i> Murray	Sand dune plantations
	<i>G. nanus indus</i> Thomas	Sand dune plantations
Sub-family : Murinae	<i>Vandeleuria oleracea</i> Bennet	Forest trees
	<i>Rattus rattus</i> Linn.	Nurseries
	<i>Rattus cutchicus</i> (Wro.)	Forest trees on rocky areas
	<i>Millardia meltada</i> (Gray)	Orchards
	<i>Rattus gleadowi</i> (Gray)	Pastures, forestry and orchards
	<i>Mus musculus</i> Linn.	Nurseries
	<i>Mus platythrix</i>	Pastures and forestry
	<i>Mus cervicolor</i> (Hod.)	Pastures and forestry
	<i>Golunda ellioti</i> Gray	Pastures, forestry and orchards
	<i>Nesokia indica</i> (Gray and Hard.)	Forestry plantations
	<i>Bandicota bengalensis</i> (Gray)	Forestry plantations and orchards

was highly vulnerable to squirrels, resulting in more than 50% fruit damage. Other cultivars viz., GKKV-1, G-137, Jodhpur Red, P-26, Ganesh, Dholka and P-23 recorded moderate damage (12.7-19.7%). Similarly in nursery, sprouting ber was damaged to the tune of 8.3 - 80.0% by *T. indica* and *F. pennanti*. Most of the damage was noticed on third day of seeding (Jain *et al.*, 1994). *M. hurrianae* and *T. indica* have also been observed to feed on fruits. Their burrows in the ber orchards during fruiting stage ranged between 600-791 per ha.

### Forestry plantations

Rodent damage to forestry plantations is of two types : (i) debarking, and (ii) slicing. The first type of damage has been observed in *Albizia lebbbeck*, *Prosopis juliflora*, *Acacia tortilis* and *Parkinsonia aculeata*. During debarking, the rodents, mainly *M. hurrianae*, *T. indica* and *M. melitada* remove the bark of main shoot and lateral branches just above the ground (upto 15 cm) resulting in significant reduction in tree growth. Slicing activity results in cutting of the trees just below the ground surface (Prakash, 1976; Rana and Jain, 1984). This activity has been reported from bets of great Rann of Cutch (Gujarat) and Bikaner and Nagaur districts of Rajasthan. A new intruder, *Nesokia indica* was observed to cause complete death of 4-10% trees of *A. tortilis*, *P. juliflora* and *A. nilotica* in Nagaur district (Jain and Tripathi, 1988b; Tripathi and Jain, 1990; Jain *et al.*, 1995). *N. indica* being a mesic rodent is a native of Punjab, Delhi, U.P., etc. However, it was first noticed inhabiting forestry plantation in Nagaur during 1988. Prakash *et al.* (1971) reported this species from fruit orchards of Sriganganagar. It has a peculiar burrow system, 85-150 cm deep with branching extending to the base of several trees.

Table 2. Predominant rodent pest species associated with forest trees

Tree Species	Rodent pest species
<i>Albizia lebbbeck</i>	<i>M. hurrianae</i> and <i>T. indica</i>
<i>Prosopis cineraria</i>	<i>M. hurrianae</i> and <i>G. gleadowi</i>
<i>P.juliflora</i>	<i>M. hurrianae</i> , <i>T. indica</i> and <i>N. indica</i>
<i>Acacia senegal</i>	<i>M. hurrianae</i> , <i>T. indica</i> <i>G. gleadowi</i> and <i>N. indica</i>
<i>Parkinsonia aculeata</i>	<i>M. hurrianae</i> and <i>T. indica</i>
<i>Azadirachta indica</i>	<i>H. indica</i> , <i>T. indica</i> and <i>R. rattus</i>
<i>Anogeissus pendula</i>	<i>H. indica</i> , <i>F. pennanti</i> , <i>R. cutchicus</i> , <i>M. platythrix</i> and <i>M. cervicolor</i>

### Range grasses

Rodents, *M. hurrianae*, *T. indica* and *G. gleadowi* dig up the sown seeds of *Cenchrus ciliaris*, *C. setigerus* and *Lasiurus indicus* and later on feed on them almost to the roots of the fodder. The intake of grass seeds by *M. hurrianae* is much greater than by other rodents. In the monsoon season, the rodents feed on the unripe inflorescence of grasses and when unable to reach them, they cut at the base of plants. Field rodents have been found to devastate some 40 acres of *L. indicus* and 27 acres of *C. ciliaris* and *C. setigerus* in an experimental pasture of Bikaner. At a population level of 477 gerbils per ha in range area, it was estimated that rodents required about 1040 kg of feed per ha, where as, the total productivity of this grassland was only 1210 kg/ha, which mean that almost nothing was left by the gerbils for livestock ((Prakash, 1963; Jain and Tripathi, 1988a).

## Rodent Pest Management

Based on the findings on rodent pest ecology, behaviour, damage propensities and control techniques, an effective technology for their management has been evolved (Rana and Jain, 1984; Jain *et al.*, 1993).

Active as well freshly opened burrows of rodents should be surveyed and prebaited for 1-2 days. For prebaiting pearl millet grains smeared with 2% arachis oil are rolled deep in all such burrows @ 8-10 g per burrows. After 2-3 days of prebaiting, the same burrows must be poison baited with 2% zinc phosphide, using the same bait material and oil as used in prebaiting i.e. pearl millet grains and arachis oil @ 6-8 g/burrow. The poison bait must be, as a rule, rolled deep in the burrows to avoid any secondary hazard. After 4-7 days of this treatment, all the burrows should be plugged and on the next day the reopened burrows indicating the residual rodent population should be baited with bromadiolone (0.005%). These two treatments have longer efficiency than the solo treatments of either rodenticides (Tripathi *et al.*, 1996). The population rebuild up is also significantly slower (Table 3).

Table 3. Efficacy of rodenticidal treatments in *ber* orchards

Treatments	Post treatment live burrows (% age of pretreatment ) after days							
	3	15	30	60	90	120	150	180
Zinc phosphide (2.0%)	14.6	16.7	27.1	32.5	52.1	65.0	104.2	97.7
Bromadiolone (0.005%)	21.2	5.9	11.8	14.8	29.1	29.4	44.0	44.0
Zinc phosphide (2.0%)+ Bromadiolone (0.005%)	12.5	16.1	10.7	5.5	8.9	13.4	26.8	22.3

These two operations are recommended to be carried out at least twice a year i.e. (i) during May-June, and (ii) during November-December. Detailed calendar of operation is given in Table 4. In the nurseries too, the same operation should be resorted to as a pre-requisite for establishment of nurseries and afterwards on a regular basis i.e., twice a year. However, in nurseries and fruit orchards, trapping of rodents also proves quite effective.

Table 4. Calendar of operations for Rodent Management\*

Day	Activities
Day 1	Plugging of burrows, estimation of requirements of bait material, manpower etc. Removal of weeds, garbage etc.
Day 2	Identification of live burrows and prebaiting.
Day 4	Zinc phosphide (2.0%) baiting.
Day 5	Collection and disposal of dead rodents in pits.
Day 8	Plugging of burrows.
Day 9-10	Bromadiolone (0.005%) baiting in reopened burrows.

\*Time : May-June and November-December

## Gaps and Future Lines of Work

Whereas the plant protection scientists have carried out research in accordance with the Institute's mandate and to cater to the requirements of the farming community by and large, there still remains a good deal of work to be done. The aspects to be covered include basic, applied and strategic research activities. Pest and disease situation changes with change in the cropping patterns, farming systems, environmental conditions and a host of other factors. Major changes have occurred in the arid and semi arid regions of western Rajasthan in the last couple of decades. The plant protection scientists ought to take stock of the changes and modify their management strategies accordingly. Some of the areas that warrant priority attention are listed here:

- To conduct regular surveys for assessing the pest and disease induced losses in perennial crops and plantation vegetation.
- To study the changes in pest and disease situation due to Indira Gandhi Canal and due to cultivation in previously uncultivated areas elsewhere.
- To undertake studies on the parasitic and predatory insects and microbes which could be utilised for pest population suppression.
- To develop pest and disease free and resistant plants through biotechnological tools.
- To develop rapid and accurate immuno-diagnostic techniques for screening viruses and phytoplasmic pathogens.
- To develop environment friendly methods of pest and disease management.
- To document the insect, nematode rodent and microbial biodiversity in representative arid and semi arid areas
- To study the dynamics of pests and diseases in the major farming systems, including their transigrations.

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S.K. Kaushish, H.C. Bohra, B.K. Mathur and A.K. Patel

Man and animals are complementary to each other. To keep themselves alive, mankind has to depend on animals to meet its various requirements like milk, meat, eggs, hides, wool, etc. The animals have also been used for ploughing fields, drawing water from wells, transportation, manure for enhancing crop productivity, dung for cooking food, etc. Domestic animals like cattle, buffaloes, sheep, goats, camels, horses and donkeys are indispensable in Indian rural life. Livestock is integral part of rural economy in India. Thar desert is the most thickly populated deserts of the world. According to 1951 livestock census there were 25.5 million livestock and 0.254 million poultry birds, which increased to 47.8 and 3.0 million, respectively in 1992. Nineteen per cent of the state income is contributed by animal wealth. It is estimated that livestock sector provides employment to two-third population in arid region (Anon., 1997).

Drought occurrence has less effect on livestock production. It has been estimated that during a drought year while agricultural production falls to less than 10 per cent of production of a favourable year, the production of wool and milk is still over 50 per cent of that of good year. Moreover this production is not meant solely for self consumption but, has traditionally been exported out of region in the form of raw products. Livestock farming by its very nature offers, therefore, a scope for commercialisation and has been recognised as an instrument of drought proofing (Anon., 1997).

## **Cattle**

### **Tharparkar Cattle**

#### **Tharparkar breed of cattle needs to be conserved in the Indian desert**

Once common in most parts of the country, the Tharparkar pure blood is rare now. Good specimens of the Tharparkar breed of cattle are rarely seen even in Jodhpur and Jaisalmer districts, considered to be the home of this breed. A detailed survey has shown that the advantage of crossbred cows over pure Tharparkar, are greatly disturbed by the susceptibility of the crossbred to heat, their high cost of management and health cover (Mathur and Mittal, 1988).

Tharparkar cattle breed is well adapted to arid conditions and is resistant to diseases and is stable, when allowed to graze freely in summers, even in extreme deserts, without any ill effects in production (Mathur *et al.*, 1991a).

A fervent plea is made to conserve the useful Tharparkar breed of cattle, which over the years has stabilised and adapted itself to the desertic region having scarce feed, fodder and water. The Institute has attempted to establish this breed around the villages of Jodhpur city through various extension programmes. A small herd of Tharparkar cattle was established in the year 1989 to demonstrate the productivity and comparative importance of this breed to the farmers of the Jodhpur zone and to conduct various scientific researches to develop management practices to exploit optimum production and reproduction potential of this breed.

#### **Feed supplementation in grazing cattle of arid region**

During the lean period from December, the average daily gain was negative in the heifers of Tharparkar and Rathi breeds of cattle, maintained at the stocking rate of 1.5 ha per animal. Animals exhibited the signs of debility and malnutrition, followed by marked boney prominences and lacrimation during January. Provision of *Lasiurus* hay, supplemented with concentrate feeding and parental administration of vitamin-A, along with feeding mineral mixture from February onwards, improved the general health status and average daily gain of the experimental heifers (Mathur *et al.*, 1991b).

#### **Effect of improved management on cattle productivity**

The effect of improved management on the productivity of Tharparkar cattle was studied. Fourteen Tharparkar cows were divided into two equal groups, one group was maintained under traditional management simulating village conditions of this region, concentrate feeding was given to only lactating cows and very costly feed ingredients such as til oil, methi grain and *gur*, etc. were given to post parturient cows for 15 days. No reproductive health measures were taken in this group. The other group was maintained on improved management, whereas, the animals received concentrate feed regularly according to their physiological stage, as per the standard norms. They were given regular vitamin mineral mixture and ecbolics (Replenta or Uterine tonic) just after parturition. Regular gynaecological examinations were undertaken in these animals. The productivity of Tharparkar cattle in terms of lactation milk yield, lactation length, dry period, inter-calving interval, milk fat, solids not fat (SNF) and total solids (TS) were found better in cows maintained under scientific management than those under traditional management (Patel *et al.*, 1994).

The average lactation yield under improved management was 1606 kg in a lactation of 293 days. The average peak yield was 9.67 kg in a day. The age at first calving was less than 3 years, which is similar to that of cross-bred cattle in India. Average calving interval and dry period were 364 and 76 days, respectively. No adverse effect of summer stress on the fertility was observed as 80 per cent cows conceived between April and August. The milk composition of Tharparkar cows was influenced by season. The highest milk fat content was found in winter season, followed by autumn, rainy and summer season. However, no seasonal effect was observed on milk SNF under arid conditions (Patel *et al.*, 1997a).

### Effect of season

In the arid region, four seasons namely winter (November to February), summer (March to June), rainy (July to August), and autumn (September to October) are found as per climatic variations. Generally, the productivity of any animal is influenced by the season, either directly or indirectly. All possible productive and reproductive parameters of Tharparkar cattle were studied as per different seasons. The studies showed that the higher milk production performance was found in those cows which calved during rainy and autumn seasons than those in summer and winter seasons (Patel *et al.*, 1997a). Cows which calved during winter, had shorter lactation length and cows which calved during winter season showed lower dry period and calving interval than those in summer, rainy and autumn seasons (Mathur and Patel, 1997). Winter season was found to be better for milk production, its quality and quantity. The fat percentage of milk obtained during winter and autumn seasons was higher than that obtained during summer and rainy seasons. Total milk solids showed similar pattern, while solids not fat were more or less similar in all the seasons (Patel *et al.*, 1994).

### Effect of period

The animal productive and reproductive traits were analysed for six years from 1990 to 1996. The milk production performance was not influenced by period. However, the reproductive performance, in terms of dry period and calving interval, was reduced over the years. The findings showed that reproductive efficiency can be enhanced by improved management practices as the heritability of the reproductive traits are low (Patel *et al.*, 1997a).

### Feeding of tumba (*Citrullus colocynthis*) seed cake - a non-conventional feed resource

In an attempt to bridge the gap between demand and supply of concentrates and to make ration economical, an attempt was made to explore the possibility of utilisation of non conventional feeds. Keeping this in view, assessment of palatability and nutritive value of tumba, (*Citrullus colocynthis*) seed cake was undertaken.

It was observed that the cattle feed having 25 per cent tumba (*Citrullus colocynthis*) seed cake when fed to Tharparkar and Rathi cattle has no adverse effect on growth, reproductive and productive performance. Tumba seed cake can safely be fed to pregnant cows. It is a cheaper source of protein and is normally used as a fuel for furnaces and thus wasted. This technology results in a net monetary saving of around 18-20 per cent without impairing the productivity of the animals (Mathur *et al.*, 1988, 1989, 1991).

### Adaptability

Tharparkar breed of cattle is well adapted to arid environmental stresses. The heat tolerance co-efficient values of free grazing animals of this breed ( $88.88 \pm 1.92$ ) was equal to animals of Rathi breed ( $89.87 \pm 2.51$ ). During summer season, there was an increase in pulse rate and respiration rate, these parameters were found to be the highest in June and lowest in January.

The daily water consumption per 100 kg live weight was also highest (13.27 L) during May and lowest (5.62 L) during December (Anon., 1991c).

### Stall feeding of lactating cattle by restricting grazing exercise in arid region

In a 30-day feeding trial, 8 pleuripera lactating Tharparkar cows were divided into two equal groups of 4 animals each, a control and a treatment group, with an average body weight of  $389.0 \pm 31.87$  and  $340.8 \pm 13.5$  kg, respectively. The control group animals were grazed on *Cenchrus* pasture for 8 h daily, while treatment group animals were provided with weighed quantity of chaffed *Cenchrus* grass and were solely stall fed. Animals of both the groups were in 3-4 month of lactation and were watered once daily *ad lib*. Animals of both the groups were fed cheaper concentrate mixture having low cost tumba (*Citrullus colocynthis*) seed cake as per their requirement with an average of 4 kg/head/day. The concentrate mixture having approximately 19 per cent CP consisted of Tumba seed cake (25%), pelleted cattle feed (65%) and cotton seed cake (10%).

Average daily dry matter intake of *Cenchrus* grass was 4.3 kg in treatment group. The average monthly milk yields of control and treatment groups were  $206.86 \pm 42.33$  and  $253.36 \pm 28.99$  L, respectively. The average fat and SNF percentage of control and treatment group were  $3.09 \pm 0.42$ ,  $8.03 \pm 0.09$  and  $3.23 \pm 0.23$ ,  $8.39 \pm 1.0$ , respectively. Quantity of milk was significantly higher in treatment group and also the quality of milk in term of fat per cent and SNF per cent were on higher side, showing better utilisation of energy and nutrients in terms of production by stall fed cattle (Mathur *et al.*, 1997a).

### Rathi Cattle

Rathi cattle are native of Bikaner region. This breed is a milch type, brown in colour and of large size. A small herd of Rathi cattle was maintained at RRS, CAZRI, Bikaner, for studying its productive, reproductive and adaptability performance under improved management in its native tract. The Rathi cattle attained highest ( $322.9 \pm 13.17$  kg) and lowest body weights in October and August ( $246.31 \pm 1.90$  kg), respectively. They attain puberty when they attain weight between 208 to 302 kg. During pregnancy, animals gained around 53 kg in body weights. Animals started losing body weight after calving and it continued till 90 days after parturition. With the increase in the number of parity, the animals performed better in respect of birth weight, intercalving period, service period and body weight at service (Kaushish *et al.*, 1998).

The highest rectal temperature ( $39.9^{\circ}\text{C}$ ) was observed in the month of June and lowest in January ( $37.1^{\circ}\text{C}$ ). Diurnal variations were observed in RT, PR, and RR. These physiological parameters increased as per ambient temperature (Prasad *et al.*, 1989).

### Body weight and its relationship with fertility

The average body weights of Rathi cattle were the lowest ( $246.31 \pm 1.90$  kg) in August and the highest ( $322.9 \pm 13.17$  kg) in October. Animals started gaining weight during September and

January, after that the body weights started declining. The Rathi heifers can be bred successfully when they attained body weights between 208 and 302 kg. Around 57 per cent heifers could be bred successfully, when they attained an average body weight of 227.5 kg (Kaushish *et al.*, 1997a).

**Birth weight :** The average birth weight of calves was observed to be  $19.67 \pm 0.69$  kg. It was higher ( $20.67 \pm 1.09$ ) in case of male than the female calves and the differences due to sex were significant (Kaushish *et al.*, 1997a; Kaushish *et al.*, 1998).

**Placenta:** The placenta on an average weighed  $2.4 \pm 0.27$  kg. They were heavier in case of males ( $2.67 \pm 0.46$  kg) than in female births ( $2.18 \pm 0.14$  kg). The differences due to sex were significant. The placenta weight was positively correlated with birth weight (Kaushish *et al.*, 1997a).

**Expulsion of placenta:** A cow on an average took  $254.6 \pm 29.49$  min for the expulsion of placenta. A cow which gave birth to female calf, took longer time ( $295.0 \pm 50.59$  min). The heavier placenta takes shorter time for expulsion. The differences due to sex of the calf for this stage were significant. It can be concluded that sex of offspring affects the weight gain during pregnancy, birth weight and time taken for expulsion of placenta in Rathi cows. The average values for weight gain during pregnancy, body weight and placenta weight were more in case of male offspring, however, the average time taken for expulsion of placenta was more in case of female offspring (Kaushish *et al.*, 1998).

#### **Effect of supplementation on age at maturity**

First calving occurred in Rathi breed after a long time. To reduce this, a group was daily fed 5 kg mustard green and 2 kg concentrate. While control group was given 1 kg concentrate only. Both the groups, in addition to 6 hour grazing were also given chaffed *L. indicus* hay (3 kg/head/day). Fifty per cent of the heifers settled within 3 months, 67 per cent within 4 months and 83.4 per cent within 5 months. During this period none of the animals in control group came to heat (Anon., 1993).

#### **Dominance pattern**

A study was conducted to establish the dominant status in the social hierarchy of a herd of free grazing Rathi breed of Zebu cattle. The study was conducted for a period of 3 consecutive years under arid region at Bikaner. The animals were pastured together for the entire period of experimentation, except during parturition and illness. It is clear from the results obtained, that the body weight of animal play a dominant role in determining the dominant status of this breed. Even in small group, there may be frequent changes in social hierarchy which is likely to be influenced by physical or physiological factors affecting the behaviour of the individual animal of the group or the whole group collectively. The productive performance of animals may also be influenced by dominant status of the group which is also related with the nutritional status of the animal. It was observed that the male calves begin to dominate female calves at one year of age

and within the sex, combination of body weight and age is responsible for this dominance (Prasad *et al.*, 1996).

### Grazing behaviour

Grazing behaviour of Rathi cows was studied for 6 days between August 15 to 20, 1990 under range conditions of Bikaner. Body weight of cows averaged  $267.33 \pm 9.17$  kg and per day milk production averaged  $3.85 \pm 0.29$  kg. Cows were provided pelleted cattle feed at the rate of 2.0 kg per cow every day at the time of evening milking. They were allowed grazing for 8 hours between 8.00 AM and 4.00 PM daily and were offered water before and after grazing time with no water being supplied in between. The grazing was done in well protected range plot measuring 4 ha in size and having *Lasiurus indicus*, *Cenchrus biflorus*, *Tribulus* species, *Dichanthium annulatum*, *Panicum antidotale*, *Aristida funiculata* and *Cymbopogon jwarancusa* as major contributory grasses and *Prosopis cineraria* trees interspersed in between. The cows were followed closely to count the number of bites between pauses which was then summed over hourly intervals. Similarly, the time lost in activities other than grazing was noted for each pause going beyond one minute duration. The study revealed that the maximum and minimum number of bites were  $1913.33 \pm 55$  and  $929.33 \pm 210.74$  which were taken during first hour (8-9 AM) and fourth hour (11 AM - 12 Noon), respectively. Similar trend was observed in case of gross number of bites per minute. Cows lost minimum ( $4.50 \pm 0.43$  min) and maximum ( $27.0 \pm 4.98$  min) time during first and fourth hour of grazing. Difference due to hour of day was highly significant. There was a within animal variation for the time spent on activities other than grazing. The animals did not differ with respect to their water intake. The number of bites per minute of effective grazing time was similar in initial cool hours and hot afternoon hours (Prasad *et al.*, 1995).

### Incidence of milk letdown in primiparous Rathi cows

Lactation behaviour of 15 primiparous Rathi cows having normal health and udder confirmation was observed individually from their initial stage of lactation. Almost all cows were sensitive to their udder handling in the beginning of their lactation. Out of these 15 cows, 12 became adapted to hand milking operations within a week. There were no problem associated with the letdown of milk in these cows when calves were allowed to suckle their dams. In 2 cows the letdown of milk were recorded. The first letdown occurred when calf was allowed to suckle which ceased after some time. The second letdown was noticed when calf was again allowed to suckle the cow. Thus in 2 peaks all the milk could be taken out. The milk yield of this cow was only partially affected. The other cow did not accept her calf and was very difficult to be milked. Although this cow continued to yield milk upto 7th month of lactation but it could never expressed her true production potential. Out of these 15 cows, one was extremely sensitive and never allowed her calf to approach for suckling. When all attempts to make her calf familiar with her failed, then daily attempts were made to milk her after putting into crate. This treatment for

one month could not induce letdown of milk. This cow conceived within 3 months of parturition (Prasad *et al.*, 1989a).

### **Effect of post service gain and parity**

The averages for weight at service and weight at calving were  $228.4 \pm 3.99$  and  $302.7 \pm 9.49$  kg, respectively (Kaushish *et al.*, 1990). After calving, they were heavier by 7.2 kg than the weight at breeding. As the parity increased, the intercalving period and service period decreased and birth weight of calves and weight at service of cows increased. Lesser the post service gain, lower were birth weight, placenta weight and gestation period. As the gestation period increased, the weight of calves at birth and placenta weight increased (Anon., 1992a).

### **Effect of feeding *Prosopis cineraria* leaves**

One group of adult cattle (Dry) and a group of lactating cows, each belonging to Rathi and Tharparkar breed of cattle were maintained, exclusively on *Lasiurus indicus* hay and animals of the other group were provided *khejri* leaves as supplemental feed. In these animals rectal temperature, respiration and pulse rate were monitored. These parameters were significantly higher in the afternoon (15.00 h) as compared to the morning (8.00 h) values and these increases were less pronounced in animals which were given *khejri* leaves. These parameters were however, higher in Tharparkar cattle than in Rathi cattle (Anon., 1990).

### **Biochemical parameters in cattle**

A correlation between urine sodium (Na) and body weight and water intake has been observed in Rathi and Tharparkar cattle. In Rathi cattle, the animals which excrete less urinary Na have low body weight and water intake than the animals which excrete higher levels of urinary Na. In Tharparkar cattle, the animals which excrete less urine Na have high body weight and high water intake than the animals which excrete higher Na in urine.

Several of the plasma and urine parameters were measured in animals of different age groups (2 to 3 months, 8 months and 2 year old) of Rathi cattle. The plasma proteins, globulins, urea, inorganic phosphorus and creatinine registered increases to the extent of 13, 41, 24, 35 and 18 per cent, respectively, from 2-3 months to 2 years of age. The increases in all these parameters indicate adjustment of these animals to the desert environment.

### **Cattle in rural area**

Villages around Bikaner were surveyed to collect information on reproductive status of Rathi cattle and non-descript breeds that are predominantly found in the area. Age at first calving in cows averaged 48 months. Lowest age at first calving reported was 36 months. Service period averaged 8-9 months and intercalving period averaged 22.2 months. The incidence of reproductive disorders were as high as 15-18 per cent in cows. An oestrus followed by repeated breeding, matritis, vaginites, etc. were also reported. These disorders were mainly due to

nutritional deficiencies which resulted in delayed maturity, long intercalving intervals and lower productivity (Anon., 1991b).

#### **Cattle in urban area**

Rathi cattle along with crosses of Red Dane, Jersey and Holstein were most commonly seen in Bikaner city. Age at first calving ranged from 2.5 to 5 years in Rathi and 2 to 3 years in cross-bred cows. Nutritional status had significant effect on age at maturity. Intercalving interval ranged from 14 to 22 months in Rathi cows and from 13 to 22 months in cross-bred. Service period ranged from 3 to 10 months in Rathi as well as cross-bred cows. Artificial insemination was not common. Owners either kept their own bull or hired them. Incidences of repeat breeding were 10 to 15 per cent in Rathi and cross-bred cows. Pre- and post-partum prolapse of uterus was common in 8 to 10 per cent cows. Rathi cows had nearly twice as high incidence of prolapse of uterus compared to crossbreds. Prolapse of uterus was also reported to be heritable to crossbreds. Prolapse of uterus was also reported to be heritable to certain extent in Rathi breed (Anon., 1991b).

#### **Body weight at maturity**

The Rathi heifers could be bred successfully at Bikaner when body weights varied between 208 and 302 kg. Around 57 per cent heifers could be bred successfully when they attained 227.5 kg weight (Anon., 1992b).

#### **Effect of different phases of reproduction**

At Bikaner the Rathi cows gained 52.95 kg body weight during their gestation period. After calving they were heavier by 7.2 kg than the weight at breeding. They lost body weight upto 90 days during lactation and then gained weights (Anon., 1992b).

#### **Effect of parity**

The birth weights of the calves increased with parity of the cows at Bikaner. They weighed  $21.37 \pm 0.37$  kg at first calving, and  $21.70 \pm 0.44$  kg at third calving. The average intercalving period was  $15.7 \pm 0.82$  months. It was  $16.5 \pm 1.32$  months between first and second calving and it decreased to  $14.58 \pm 0.35$  months between second and third calving. It was negatively correlated with parity. The trend was similar with service period. It decreased from  $228.07 \pm 34.14$  days in primiparous cows to  $152.50 \pm 20.65$  days in multiparous cows. Weight at service also increased with parity of the cows (Anon., 1992b).

#### **Effect of weight at service**

The cows below 240 kg at service gave birth to significantly heavier calves ( $21.15 \pm 0.82$  kg) as compared to those which weighed between 281 and 300 kg at Bikaner. Gestation period, intercalving period and service period were negatively related with the weight at service (Anon., 1992).



### **Effect of post-partum gain**

Studies at Bikaner indicated that lesser the post service gain, lower were birth weight, placenta weight and gestation period. However, it was reverse with intercalving period (Anon., 1992b).

### **Effect of gestation period**

In studies conducted at Bikaner placenta weight and birth weight were positively related with gestation period. The cows which carried calves for a longer period also took longer to conceive, hence the intercalving period was also longer in such cows (Anon., 1992a).

### **Body weights of Rathi cattle and calves**

The body weights of 14 Rathi cows were recorded from April 1993 to March 1994 at Bikaner. The highest (262.1 kg) weight were observed in September and lowest (256.4 kg) in June. The weight decreased after September. There were rains in July (160.5 mm) and September (51.7 mm) which probably influenced their body weights. The body weights were recorded at birth and thereafter, at 3 month intervals, upto one year age, at Bikaner. Male calves were heavier than female calves at all the ages. They weighed 17.0, 49.7, 70.5, 84.0 and 106.3 kg at birth, 3, 6, 9 and 12 months of age, respectively. Male and female calves at birth weighed 17.8 and 15.3 kg, respectively (Anon., 1994a; Kaushish *et al.*, 1998).

### **Seasonal changes in body weights in Rathi heifers**

Monthly changes in body weights of 12 Rathi growing heifers (2-3 year old) revealed that on an average they gained 44.5 kg upto January 1993 from 210.7 kg in April 1992. Thereafter there was loss in body weight. The body weight gain was the highest in October, followed by gain in September and August.

### **Effect of age at breeding on post-service gain and weights during lactation in Rathi cattle**

In a study at Bikaner 33.3, 22.2 and 44.4 per cent heifers conceived when they were less than 40, between 41 and 45, and above 45 months in age and they weighed 240.5 kg, 246.5 kg and 259.8 kg, respectively at conception, the respective groups gained 17.8, 52.0 and 45.7 kg during gestation. Cows in all the groups lost weight upto 3 months of lactation and after that, a slight gain was observed in weight (Anon., 1994a).

### **Effect of starvation on milk production in Rathi**

When the lactating cows were neither given supplementary fodder nor concentrate for 2 months during September and October and were kept on grazing alone at Bikaner, the milk production was reduced to 30 per cent. On resuming concentrate and fodder, the milk production increased to 81 per cent of the pre-starvation milk yield level. After July, there was one shower in early September (Anon., 1994a).

### **Physiological norms of Rathi cattle**

Physiological norms, such as rectal temperature (RT), pulse rate (PR) and respiration rate (RR) were recorded at weekly intervals at 7.30 AM and 3.00 PM at Bikaner. In addition to these, ambient temperature and relative humidity were also recorded at these times. The highest (39.7°C) and the lowest (37.1°C) RT were in June afternoon and January morning, respectively. Diurnal variations were observed in RT, PR and RR, the magnitude of which was high from April to September. This corresponded to high ambient temperature (Anon., 1994a).

### **Adaptation**

Tharparkar cattle were found to be well adapted to the environmental stress. The heat tolerance coefficient values ( $88.88 \pm 1.92$ ) of this breed were equal to those of Rathi breed ( $89.87 \pm 2.51$ ). The highest and lowest respiration rates were recorded in April and January, respectively. The pulse rates were the highest in June and lowest in January. The daily water consumption per 100 kg live weight was the highest (13.27 L) during May and the lowest (5.62 L) during December. It was observed that changes in respiration and pulse rates help in thermoregulation.

Rathi breed of cattle had significantly higher per cent packed cell volume, haemoglobin and total body water in comparison to Tharparkar breed of cattle, suggesting better adaptational capabilities of Rathi cattle in desert environment of Bikaner region.

### **Kankrej Cattle**

#### **Performance of Kankrej heifers on traditional management**

A herd of 16 heifers and one male calf of Kankrej breed of cattle was kept on traditional management prevalent in rural areas around Bikaner for 18 months. Animals were maintained on *Lasiurus indicus* dominated pasture at a stocking rate of one animal per 1.5 ha. During lean period in addition to grazing, animals were given pelleted concentrate mixture and *Lasiurus* hay. *Ad lib* water was provided twice a day. During 18 months, average body weight gain per animal was 67 kg. Up to the age of 4.5 years, none of the heifers exhibited signs of oestrus. The male calves also did not show any symptoms of maturity upto the age of 4.5 years in spite of their company with the heifers all the time. It may be concluded that the growing Kankrej heifers must get adequate nutrition to mature at an early age (Anon., 1991a).

### **Buffaloes**

Buffaloes like to wallow in water. Earlier it was thought that buffaloes do not adapt to hot arid climate. During the past forty years buffalo population of Rajasthan increased from 3.0 to 7.7 millions. In arid districts of Rajasthan there were 0.722 million buffaloes in 1951 which increased to 2.297 millions in 1992. People have developed liking for buffalo milk. More work should be done to study their adaptability to hot arid conditions.

## **Seasonality and Diurnal Variation in Parturition in Buffaloes**

### **Season of calvings**

Maximum number of calvings (49.9%) took place in rainy season followed by autumn (24.1%), winter (12.4%), spring (7.5%) and summer season (6.1%). The trend indicated strong seasonality of calving in Murrah buffaloes (Kaushish and Prasad, 1991).

### **Sex ratio**

There is a marked variation in sex ratios between seasons with male female (M:F) ratio varying from 0.58 in summer to 1.25 during rainy season (Kaushish and Prasad, 1991).

### **Time of parturition**

Maximum calvings (39.3%) took place in second 6 hours of the day (6.00 to 12.00 h) followed by 31.6, 24.0 and 5.1 per cent during morning (0.00 to 6.00 h, 12.00 to 18.00 h and 18.00 to 24.00 h), respectively (Kaushish and Prasad, 1991).

## **Factors Affecting Body Weight of Murrah Calves**

### **Effect of sex**

The male calves were heavier at all the ages, however, the differences were significant at 3 months of age only. The growth rate was highest between 9 and 12 months of age (Kaushish, 1997).

### **Effect of year**

Significant differences due to year were observed in body weights upto 9 months of age. The interaction between year and sex were significant at 6 months of age.

### **Effect of season**

The effect of season of birth were not observed at birth and 3 month of ages, but was significant at 6, 9 and 12 month of ages (Kaushish, 1997).

From this study it can be concluded that there is not significant differences in birth weights due to sex and season of birth. However, birth weights upto 9 months were significantly affected by the year birth.

### **Buffaloes in rural and urban areas**

The age at first calving in buffaloes of rural sector averaged 55 months in comparison to an average 48 months in urban sector. The service period ranged from 10 to 12 months in rural areas and 2.5 to 8 months in urban areas. The intercalving periods were 20 to 22 months in villages around Bikaner city in comparison to 13 to 20 months in Bikaner city. Although the incidence of silent oestrous/anoestrus were observed in buffaloes of both the places, however, these incidences were significantly higher in rural sector. Incidence of repeat breeding were as high as 50 to 60 per cent in buffaloes managed in villages and as low as 10 to 20 per cent in buffaloes managed in city.

This study indicated that the scope for rearing-buffalo in urban areas of arid region is far better than rural areas (Anon., 1991b).

## Sheep

India ranks fifth among the sheep rearing countries in terms of numbers but occupies tenth position in wool production. Average per head per annum wool production of our sheep is 1.2 kg but varies from 4.0-5.0 kg in some advanced countries. Sheep rearing in our country is in the hands of the poor people, who occupy very low status in the society. Low income from the present day strains of sheep, unorganised markets for the produce and poor quality pastures also contribute to the poor interest in the sheep rearing. Shepherds follow age old practices of sheep management which not only effect the capacity to produce but also reduce the productive life span of the sheep (Kaushish, 1991a).

About 51 per cent of the total sheep population of this country is found in southern plateau. Half of the sheep in this region, specially in the coastal areas, produce no wool and rest produce extremely coarse, hairy and coloured fleece. Similar is the quality of wool in the breeds of sheep in the eastern region. Except for Bennur and Nilgiri, they are hairy. These two are only carpet wool producing breeds of this region. The sheep of this area are mainly reared for meat production. Indian sheep are well known as superior carpet wool producers. The best carpet wool producing animals are found in the north-western arid and semi-arid parts of India. About 15 per cent of the total wool produced is above 40's count and rest is used for carpet manufacturing. In the north-western arid region approximately 23 million kg wool is produced annually. The average wool production per animal per annum is about 1.5 kg, whereas in India average wool production per sheep per annum is less than 0.84 kg. The total wool production in temperate Himalayan region, Deccan plateau and from eastern region is 3.0, 7.2 and 1.4 million kg, respectively. These breeds except Malpura, Sonadi, Muzaffarnagari and Jalauni, produce medium to fine carpet wool. Marwari in north-west and Bellary/Deccani in the south comprise the most popular breeds (Kaushish, 1992).

## Animal Production on the Rangelands

Fair type desert grasslands have a carrying capacity of one adult cattle unit (ACU) or five Marwari weathers per ha on year round basis. Sown pastures of *C. ciliaris*, *C. setigerus* and *L. indicus* recorded 300 per cent more animal production. Relative grazing capacity in sandy soil was 4.5 sheep/ha for *C. ciliaris*, 2.5/ha in *C. setigerus*, 4.1/ha for *Panicum antidotale* and 6.9/ha for *L. indicus*. These values spiralled up about two-fold when the above grasses were cultivated on loamy soil.

Hay conservation, for stall feeding, results in better management with increase in body weights during lean season of normal rainfall years and no negative impact on vegetation was observed.

Grassland management by putting more than one kind of animals has been found beneficial as it allows the utilisation of diversified forage species more efficiently. Combined sheep-goat grazing, based on carrying capacity in *Zizyphus* dominated grasslands have been found very useful.

Provision of drinking water and preservation of forage for the lean periods/years are other important considerations in improving the productivity of rangelands. The Institute has done useful work on all these aspects.

### **Ecological Distribution of Sheep Breeds in Rajasthan**

The ecological distribution of different breeds of sheep, in relation to the available grazing land and pasture types in Rajasthan, has been worked out and an Atlas of Sheep Ecology, comprising 10 maps, has been prepared. This is the first attempt of its kind in India (Sen *et al.*, 1981). The breed character of Rajasthani breeds of sheep have been described in detail by Acharya (1982).

### **Breeding Sheep for Finer and Heavier Wool**

The desert is the home for some of the hardiest breeds of sheep in the country but the quality and quantity of wool yielded by these animals is generally too poor to ensure any worthwhile income to the stockowners. Attempts have been made to develop a biochemical approach to sheep production to obviate the delay inherent in the time consuming conventional method of selection based on performance tests. Studies conducted on three biochemical polymorphic traits in the blood of six indigenous desert sheep breeds point to haemoglobin A ( $Hb^A$ ) and low glutathione ( $GSH^h$ ) type animals as producers of heavier wool and low potassium (LK) and  $Hb^A$  type animals as yielders of comparatively finer fibres, in comparison to animals of any other traits examined.

### **Non-seasonality of Sexual Rhythm in Desert Adapted Sheep**

An information of considerable potential application emerging from this study relates to the non-seasonal nature of reproductive characteristics in both male and female Marwari sheep and possibly in other breeds also. This physiological flexibility makes it possible to plan breeding programmes in accordance with climatic variations, feed resources availability and market demand.

### **Physiological Investigations on Heat and Water Stress in Sheep**

Availability of drinking water being the most critical limiting factor for survival in the desert, a detailed comparative study of the physiological responses of different desert sheep breeds to imposed heat and water stress has been made. These studies have pointed to the unusual ability of the desert breed (e.g. Marwari) to maintain circulation even when faced with considerable

haemoconcentration. When water intake was reduced to below 75 per cent of the normal daily requirement, there was a steady decline in the body water stores. On an average, there was an 18 per cent loss in body weight in all the breeds after remaining without water for 3 days during winter and 25 per cent during summer. Interestingly, the digestibility of crude fibres has been found to be increased in water restricted sheep while nitrogen balance does not seem to be affected due to water stress. The rate of passage of feed is slow in water restricted sheep in comparison to normally hydrated animals.

The desert sheep apparently relies on reduced urine and faecal water output as the means for combating water stress. This, along with their ability to derive sustenance from poor quality forages helps in maintaining animal productivity in this region. Studies conducted at this Institute so far point to the physiological superiority of the Marwari breed of sheep over the other breeds studied in maintaining productivity under desert conditions.

Prolonged intermittent (twice weekly) watering does not have any adverse effect on animal production in terms of body weight, wool growth and lambing performance of ewes of the Marwari and Magra breeds. Water restricted (watered twice weekly) animals of both the breeds consumed less than half the quantity of water consumed by the daily watered groups. Thus, with a flock of 100 adult sheep, about 6,500 L of drinking water could be saved per month by resorting to a twice weekly watering schedule. The daily watering of sheep would, therefore, appear to be a dispensable practice atleast in the management of desert adapted breeds.

### **Effect of Every Fifth Day Watering on Body Weight, Blood and Urine Biochemical Constituents**

One group each of Marwari goats and Marwari sheep was watered every 5th day (Group I) and the other group (Group II) was watered *ad lib.* daily. The sheep and goats of group I lost 7 per cent and 4 per cent weight, whereas, body loss was 10 per cent and 18 per cent in respective species between November and March. The group I sheep and goats consumed water at the rate of 3.4 per cent and 3 per cent of their body weight/day, while the group II sheep and goats consumed water at the rate of 8.5 per cent and 9.2 per cent of their body weight/day, respectively.

Blood haemoglobin, PCV (%), total plasma proteins, albumin, globulin, A/G ratio, inorganic phosphorus, and urea; and urine electrolytes like Na, K have remained near normal in Group I sheep and goats. The wool and hair production in Group I animals also did not change. No difference was observed in wool and hair yield in these groups.

### **Responses of Shorn and Unshorn Sheep to Heat Exposure**

Respiration rate of shorn animals was generally higher in the morning and afternoon. During hot period reverse trend was observed as it was higher in unshorn animal. Rectal temperature was 38.9°C in the morning and increased to 40.2°C during noon followed by slight decline to 39.8°C in the afternoon. The skin temperature of the shorn animal was generally higher than their unshorn counterparts and the differences were marked during noon recording. During peak hot

period although the respiration rate of unshorn animal was higher than the shorn counterpart, but their rectal temperatures were lower indicating better heat tolerance (Kaushish *et al.*, 1995a).

### **Responses of Sheep to Solar Exposure**

Hogget of native Nali, Chokla and their crosses with Rambouillet and Soviet Merino were used in the experiment. Three animals from each breed were maintained in shade or sun during summer. After first recording, the animals of sun and shade groups were exchanged and the observations were continued. The respiration rate, rectal temperature, skin temperature and fleece temperature 1 and 2 cm above the skin were higher in the solar exposed group as compared to the animals maintained in shed and higher at 16 and 13 h than at 9 h. In general the rectal temperature of the crossbred animals was lower than the native; lower in Merino x Nali and highest in Nali. It is concluded that the animals maintained under hot sun experienced greater stress as compared to the animals under shade. It also appeared that in crossbreds the thermolytic mechanism was activated at a lower ambient temperature resulting in their higher respiration rate and lower rectal temperature (Kaushish *et al.*, 1989).

### **Salinity Tolerance in Sheep**

The upper safe limit for salinity of the drinking water for desert sheep is around 4000 ppm. Intensive studies carried out at Institute indicate that the desert sheep's productive and reproductive traits do not suffer any change from long term ingestion of water varying in salinity level from 300 ppm upto 4000 ppm total soluble salts. This would suggest that prolonged brackish water ingestion in this range of salinity may not be affecting the productivity of desert livestock adversely.

### **Tolerance of Desert Sheep to Nitrite and Magnesium Salts**

The upper safe limit of sodium nitrite for desert sheep breeds in drinking water is 1 g/l. The desert sheep can tolerate magnesium sulphate in drinking water in concentration upto 4 g/l without any apparent ill effect. These findings are of practical significance for farmers keeping small flocks of sheep as they have to water their animals during summer months from wells which contain appreciable amounts of these salts in certain arid districts.

### **Association of Urinary Sodium Levels with Drinking Water Requirement and Body Weights of Animals**

The sheep and goats of low urinary sodium levels have less drinking water requirements than the animals of higher urinary sodium levels. With regard to body weights, the trend was reverse in sheep and goats. The low urinary sodium type animals have low water intake, body weight and urine volume than the high urinary sodium type animals.

A positive correlation exists between urine sodium levels and body weight and drinking water requirements in Marwari sheep. The correlation of sodium levels was negative with body weight, but was positive with water intake in Marwari goats.

### **Influence of Two Blood Biochemical Polymorphic Traits on Wool Quality and Quantity of Marwari Sheep**

In a flock of Marwari sheep, two types of animals were found to exist: low potassium (LK) and high potassium (HK); and low erythrocyte reduced glutathione ( $G-SH^h$ ) and high erythrocyte reduced glutathione ( $G-SH^H$ ). Further, the animals which had either of the following blood, polymorphic combinations were selected. The combinations of blood polymorphic traits were:

Group - A	(1) LK-G-SH <sup>h</sup>	(2) LK-G-SH <sup>H</sup>
Group - B	(1) HK-G-SH <sup>h</sup>	(2) HK-G-SH <sup>H</sup>

As the wool quality of Group B animals was very rough and hairy type, these animals were kept out of the experiment. The number of crimps was significantly high in LK-G-SH<sup>h</sup> animals than in LK-G-SH<sup>H</sup> animals. The wool yield was also comparatively higher in LK-G-SH<sup>h</sup> animals (16g/kg body weight.) than in LK-G-SH<sup>H</sup> animals (13 gm/kg body weight.). Interestingly, the body water turnover rate was lower in LK-G-SH<sup>h</sup> animals than in LK-G-SH<sup>H</sup> animals, indicating that LK-G-SH<sup>h</sup> animals were also relatively more adapted than LK-G-SH<sup>H</sup> animals to desert environment.

### **Body and Wool Growth and Wool Quality of Sheep**

Studies on the association of inherited blood potassium polymorphism and wool quality and production were further extended for isolation and segregation of homozygous LK ( $K^L K^L$ ) and heterozygous LK ( $K^L K^h$ ) from within the low blood potassium (LK) type Marwari sheep. The high blood potassium (HK) type animals were eliminated from the experiment as these animals produce rough and hairy wool, and moreover, their wool production potential is more or less similar to homozygous LK animals. Maintenance of HK animals is, therefore, uneconomical. Homozygous LK animals bear significantly good quality wool of 29 (u) with 70 per cent modulation, while the heterozygous LK animals bear rough quality wool of 42 (u) with 97 per cent modulation. However, the heterozygous LK animals produce relatively more wool (average 0.75 kg/clip) than the homozygous LK animals (average 0.64 kg/clip). Erythrocyte potassium concentration in homozygous LK animals is significantly low (23 mEq/l) in comparison to heterozygous LK (27 mEq/l) animals. No correlation between fibre diameter and wool yield could be established. However, a significant correlation between the staple length and wool yield has been observed.

On an average, the wool of Marwari sheep contains 1.02 per cent wax material. Homozygous LK animals are equally adapted to desert conditions as heterozygous LK animals.



## Seasonal Body Weight Changes

Monthly changes in body weights of Magra and Marwari sheep at Bikaner revealed that the Magra animals were heavier. Marwari animals lost body weight till July, gaining thereafter till January (Anon., 1992b).

## Sheep Production under Drought Conditions

The effect of drought on wool production was studied in ewes and rams of Chokla and Nali breeds. They were maintained under free range conditions of arid region from spring season of 1986 to spring season of 1989. Water was provided once *ad-lib.* throughout the study. During the most severe drought period in summer 1987 all these sheep were provided with free lopping of *Prosopis cineraria*. In autumn 1987, each animal was provided with 150 g of supplementary feed to keep them alive. In all, 6 shearing records of this flock were analysed. Nali rams and ewes produced higher greasy fleece in comparison to that obtained from Chokla breed. The effect of period and season on greasy-fleece yield in both the breeds was highly significant. Due to cumulative effect of drought, the production of greasy fleece was lowest during spring 1988 in both the breeds. However, this reduction in yield was slightly higher in Nali than in Chokla, and in rams than in ewes (Mathur *et al.*, 1989; Kavia *et al.*, 1990; Mathur *et al.*, 1991c).

## Physiological Responses of Sheep and Goats to Exercise Stress under Arid Conditions

The water intake was higher in exercise group of sheep and goats during summer and winter seasons. The body weights of both could not be maintained during summer season. Significant diurnal differences were observed in rectal temperature, pulse rate and respiration rate. The rise in rectal temperature was more in the afternoon in exercise group. The differences in rectal temperature, pulse rate and respiration rate between summer and winter seasons were significant. The rectal temperature was lower in goats than in sheep. Differences in rectal temperature between groups were non-significant. It can be concluded that under arid conditions of Rajasthan, Magra sheep and Marwari goats can safely be grazed within 8 km from their watering point without any ill effect on their health when the average atmospheric temperature is around 44°C (Kaushish and Mittal, 1994).

## Effect of Mineral Mixture Supplementation

The body weight of lambs and kids (Marwari, Marwari x Parbatsar and non-descript), maintained on mineral mixture weighed 25-30 kg, whereas, those not given mineral mixture weighed only 14-16 kg at 6 months of age. Treated sheep yielded higher wool (0.9 kg) as compared to non-treated (0.6 kg) in half yearly clips. The treated goats gave 160-180 L of milk as compared to untreated (90-100 L) goats in one lactation. The fat content of treated goat milk was as high as 6 per cent. The treated animals matured 7-8 months earlier as compared to non-treated animals.

## Effect of Supplementation during Pregnancy

This information is based on 20 Chokla synthetic sheep, 1-1½ year old. Each animal of Group 2, 3, 4, and 5 was given 250 g of concentrate mixture which had 7, 10, 13, and 16 per cent DCP, respectively. The total digestible nutrients were kept at 70 per cent. The cholesterol levels at breeding varied from 162.6 to 210.2 mg/dl among groups. It increased with the advancement of gestation. The mean glucose level among group ranged from 28.8 to 47.9 mg/dl at different stages of pregnancy. It was higher at breeding and decreased just before parturition. The mean total serum protein level was highest (5.98 g/dl) at breeding and lowest (5.03 g/dl) just before parturition. The serum protein and albumin levels showed decline with advancing gestation. The total serum protein and globulin levels at three months of gestation differed significantly from those at breeding and at five months of gestation (Kaushish *et al.*, 1995).

## Palatability and Nutritive Value

Palatability trials on evaluation of feed preference of straws of various bajra cultivars, viz., CZP-82, CZMP-2, CZFP-3, CZH-726 and MH-179 in sheep were conducted. The sheep, on an average, daily consumed 791 g, 371 g, 508 g, 441 g straws of respective cultivars. Their palatability were of the order of 2.7, 1.7, 2.1, 1.9 and 1.6 per cent, respectively. Green forage of CZP-82 was most palatable, and on 14-day feeding period, the animals, on an average, gained 1.2 kg on this forage. Evaluation of nutritive value of local and hybrid cultivars of pearl millet indicated 539 g and 473 g DMI/sheep/day, respectively, and palatability and plasma nitrogen level in sheep on both the straw were 1.9 g DMI/100 kg/day and 12 g/L, respectively. However, the DM digestibility of straw of local bajra cultivar (55.3%) was slightly higher than that of the hybrid cultivar (54.7%) (Mathur and Bohra, 1993).

Feed preference of *P. cineraria*, *P. juliflora*, *Z. nummularia* leaves and bajra straw were conducted in sheep. The sheep had highest preference for *P. cineraria* leaves, followed by *Z. nummularia* and chaffed bajra straw. The *P. juliflora* leaves were least preferred by the sheep. When offered a mixture of 10, 15, 20, 30 and 40 per cent *P. juliflora* leaves with *P. cineraria* leaves, the sheep consumed the mixture containing minimum level of *P. juliflora* leaves. High intake of *P. juliflora* leads to increased voluntary water intake. These leaves, though, contain appreciable quantity of protein (21%), but due to its low palatability, these leaves could not serve as a good animal fodder. It can only be fed to animals in mixture with bajra straw or *P. cineraria* leaves, not exceeding 10 per cent level in the mixture. The sheep, on an average, consumed *Acacia senegal*, *A. tortilis* and *Hardwickia binata* leaves at the rate of 2.2, 2.9 and 2.1 per cent of their live weight, respectively. Their digestibility coefficients of the dry matter were of the order of 55.9, 45.3 and 47.7 per cent, respectively. The sheep fed *A. senegal* leaves consumed water daily @  $8.6 \pm 0.94$  per cent of their live weight and four times ( $4.0 \pm 0.29$  L) of daily feed consumed by these animals.

Nutritive value of *A. leucophloea* leaves were assessed in sheep. The DMI and palatability of these leaves were  $7.58 \pm 18.1$  g/sheep/day and  $2.43 \pm 0.09$  g DMI/100 kg body weight/day, respectively, and the DM and OM digestibilities were of the order of  $40.5 \pm 1.50$  and  $36.1 \pm 1.77$ , respectively. The sheep offered these leaves remained on negative nitrogen balance ( $-2.6 \pm 0.066$  g N/sheep/day), and per kg DM intake daily consume  $2.5 \pm 0.41$  L water. The results of this study indicated that *A. leucophloea* leaves could not be considered a feed better than most of other desert top feeds (Bohra and Mathur, 1997).

### **Nutritive Value of Non-conventional Feed - Tumba (*Citrullus colocynthis*) seed cake**

*Citrullus colocynthis*, locally called as tumba, is abundantly growing in the sandy soils of arid western Rajasthan. Its seeds are rich in non-edible fats and cake, which is due to its bitterness, left after extraction of oil from the seeds, could not be consumed by the animals. A technique involving 12-h soaking of tumba cake in water and fed to animals after decanting the supernatant, has been developed. This has resulted into removal of the bitterness of the cake and facilitates its palatability and acceptability in the animals. A feeding trial on supplementation of tumba cake was conducted on Marwari sheep. For this purpose, sheep, which were maintained on chaffed bajra straw were offered 200 g of treated tumba cake daily. The dry matter intake and palatability rating in the experimental animals were of the order of 704 g DM/sheep/day and 2.5 kg/100 kg body weight/day, respectively. The dry matter digestibility, plasma urea and urinary nitrogen losses in the experimental animals were, 44 per cent, 15.2 g/L and 3.6 g/sheep/day, respectively. For the comparison, the plasma urea levels in the sheep on *Cenchrus* pasture were of the order of 11 g/L. The results indicated the advantages of supplementation feeding of tumba cake in Marwari sheep.

### **Nutritive Value of *P. cineraria* and *Z. nummularia* Leaves**

*Prosopis cineraria*, the kind of the desert trees, provides a appreciable quantities of nutrients to desert livestock: stall fed as well as corralled, through its leaves and pods. Leave of both the plants viz. *P. cineraria* and *Z. nummularia* consumed as such by the range foraging livestock as a browse or offered to them as lopping. Freshly lopped branches are sun-cured, stored to feed penned animals. Fresh leaves are rich source of water. *P. cineraria* and *Z. nummularia* leaves, on dry matter basis, contain appreciable quantities of crude protein but apparent dry matter digestibility in the sheep were 38.9 and 51.6 per cent, respectively. The digestible crude (DCP) value of these feeds were merely 4.5 and 5.6 per cent, respectively. Low DCP value of these leaves is attributed to their higher tannins content. Hemicelluloses (HC) of *P. cineraria* leaves are more (74.2%) digestible than that of the *Z. nummularia* leaves (60.3%). Low HC digestibility of the later is liked with its higher lignin (11.0%) leaves than that of *P. cineraria* leaves (7.8%). The study indicated that tannins adversely affects crude protein digestibility, but the lignin the carbohydrates, specially the hemicellulose fraction of the feeds (Bohra, 1980).

### **Palatability and Nutritive Value of *Salicornia begallovii* in Sheep**

*Salicornia begallovii*, commonly known as Salicornia, is halophytic annual. It can be cultivated under saline well water (1.25% TSS) or sea water (3.5% TSS) under flood irrigation. The arid parts of this plant can be chopped and offered to the animals. Feeding trials conducted revealed that freshly chopped *Salicornia* biomass having upto 50 per cent of *Cenchrus ciliaris* based diet was fairly accepted by sheep. On dry matter basis, *Salicornia* biomass (SB) contained 12.2 per cent crude protein, 45.9 per cent ash and 41.5 per cent sodium chloride. Dry matter digestibility (DMD) and nitrogen retention (NR) in sheep offered *C. ciliaris* based diet contained 75 per cent chopped SB were 54.2 per cent and 1.22g N/animal/day, respectively, whereas, in sheep offered *C. ciliaris* alone, the DMD and NR values were of the order of 38.1 per cent and -4.71 g N/animal/day, respectively. The sheep on 75 per cent SB diet consumed 4.2 L water and excreted 3.21 L urine daily, whereas, the control offered chaffed *C. ciliaris* straw consumed 2.7 L and excreted 1.7 L urine daily. It indicated that the freshly chopped SB can constitute upto 50 per cent of *C. ciliaris* based diet of sheep. Level of *Salicornia* in sheep diet can be further augmented by offering the SB after squeezing by passing through two rollers to remove excess sodium chloride retained in cell-sap (Bohra *et al.*, 1997).

### **Sheep Rearing Provides Livelihood for Many in Bikaner District - An Economic Analysis**

An attempt has been made to study the management practices of sheep growing and utilisation of wool produce to examine the cost benefit ratio in sheep farming. On an average, Rs. 2385.43 were spent on a flock of 100 sheep during the year. The expenditure on flock was higher at Kanasar followed by that in Tejrasar. The net income from a flock of 100 sheep per year comes to be Rs. 16006 in the case of grazier as an engaged labourer, the net income from this flock during the year comes to be Rs. 10006 from a flock of 100 Magra sheep (Kaushish, 1994).

### **Performance of Sheep in Farmers' Flock**

The experimental stock consisted of 1987 adults sheep in farmers flocks, comprising 1665 native, Malpura (85 male and 1580 female) and their 172 quarterbreds with Rambouillet (25 males and 147 females). During March the average body weight of these animals was 27.8 kg which decreased to 27.1 kg in June and increased thereafter to 27.8 kg during October. Males were heavier than females, as the breeding rams were given preferential treatment in management and supplementary feeding. The greasy fleece yield of adult animals was higher (633 g) in March followed by that in October (541 g) and was lowest in June (516 g). The staple length of four monthly harvested wool in native and crossbred sheep was 4.89 and 4.58 cm, respectively. Cross breeding resulted in reduction in fibre diameter in quarterbred population compared to native. It was concluded that under field conditions the grazing sheep exhibit seasonability of body weight with loss during summer and regain during lush and comfortable months (Kaushish *et al.*, 1994a).

## Goat

### The Goat and Desertification

The goat is extremely well adapted to the arid environment. It grows faster, breeds more efficiently, can tolerate higher salt loads, needs less water and has liking for a wider variety of feeds including many weeds, than the sheep. These, considered with the fact that the goat is mainly a browser and the sheep a grazer, suggest a relevant role of the former in the desert ecosystem. The Institute has been suggesting that the goat is not necessarily the most important biotic factor involved in desertification. The deep-rooted bias against the goat may not be wholly justified on scientific grounds and its proper place in the agro-system of the desert needs to be redefined, particularly in view of the goat's potentialities to meet the protein gap in the country (Shankarnarayan *et al.*, 1985).

### Water Use Economy in Desert Goats

The water use economy of desert goats, both during normal watering and after 96 h deprivation, was studied during summer. The findings indicate that dehydration in these animals induces urea recycling almost immediately.

When maintained under intermittent or partial watering schedules after the monsoon till the next summer, the desert goats usually gain in body weight. The percentage increases in body weight of normally watered and 75 per cent water restricted desert goats over a 10 month period were almost similar (58-59%), while there was a decline in the percentage increase (47.47) in body weight in animals watered on every 4th day. The average water consumption of the 4th day watered animals was about 3 L/100 kg/day. Thus an estimated 235 of these goats may be maintained if watered every 4th day on the water ration of 100 daily watered animals.

The Marwari breed of desert goat has shown maximum economy in water use in comparison to other types of animals examined.

### Renal Water Conservation and Body Fluid Balance in Water Stressed Goats

During period of water restriction, desert goats conserve water by reducing the urine volume. This is apparently brought about by a lowered glomerular filtration rate (GFR). The GFR values in the animals, which were maintained on a water ration amounting to 1/4 of the normal during summer, was only 1/3 of the normally hydrated animals. When water deprived, these animals maintained plasma volume and extracellular fluid volume, but lost gut and cell water, indicating that the blood gets priority over the body's other fluid compartments in this animal. Thus, the goat is akin to the camel in maintaining the fluidity of the blood during water stress.

Even when drinking relatively saline (1.5 per cent NaCl) water for more than three weeks, Barmer goats maintained normal plasma and blood volumes indicating normal circulation of blood.

## Cardio-Respiratory Responses of Goats

This studies was conducted on 6 adult bucks each belonging to Kuchhi, Jhakrana, Marwari, Sirohi and Beetal breeds of goat. The physiological norms were recorded at 7.30 a.m. and 3.00 p.m. The average temperature, pulse and respiration rates ranged from 37.7 to 39.9°C, 65.58 to 81.54 and 17.51 to 30.36, respectively and significant difference were observed between season and times. The breeds, season and time had significant affect on respiration rate. The pulse was affected by breed and season only (Kaushish *et al.*, 1990). The phenological responses of goats to thermal stress has been reviewed extensively by Kaushish (1985).

## Effect of Water Restriction and Thermal Stress on Physiological Norms

For the study 18 male goats of Beetal and Black Bengal breeds were used. Six goats from each breed were divided into 2 groups. In one group water was not withheld, whereas, it was withheld for 36 h in other group before exposure to thermal stress ( $43^{\circ} \pm 0.5^{\circ}\text{C}$ , RH 55%). Increase in all the 3 body responses was seen under thermal stress. Maximum respiration rates were observed when goats attained rectal temperature between  $40.3^{\circ}\text{C}$  and  $40.5^{\circ}\text{C}$ . The rectal temperature level at which maximum respiratory frequency was observed, was lower when the animals were under combined stress of thermal exposure and water restriction. Significant differences were observed between breeds and groups in pulse and respiration rates (Kaushish *et al.*, 1987).

## Effect of Water Restriction and Thermal Stress on Body Water Compartments

This studies was conducted on 5 to 6 months old male kids (9 Beetal and 9 Black Bengal), which were exposed to  $43.0 \pm 0.5^{\circ}\text{C}$  in a chamber for 2 h. The exposure was given under 2 sets of condition viz. with availability of water prior to exposure and with non availability of drinking water for 36 h. Variance due to breed and different intervals of sampling were not significant for all the serum electrolytes studied. The variance interaction of interval of sampling with breed and also treatment groups were also non-significant. The fall in sodium and potassium was not significant. The serum chloride concentration increased in experimental groups. There was significant increase in chloride on exposure. Slight fall was also observed in protein level in G-2, but significant rise was observed when thermal exposure was coupled with water restriction. All the three body water compartments estimated were found increased after the heat exposure treatment. This study indicated that non-availability of drinking water for 36 hours do not change the response pattern of the both the breeds (Kaushish *et al.*, 1993).

## Effect of Heat and Water Stress on Cortisol Level in Goat

This studies was conducted on 5 to 6 months old male kids, (9 Beetal and 9 Black Bengal), which are exposed to  $43.0 \pm 0.5^{\circ}\text{C}$  for 2 h. The blood hormonal estimation was done in above mentioned breeds. Cortisol concentration in control, thermal stress and thermal stress coupled with water stress groups were  $17.6 \pm 2.68$ ,  $54.3 \pm 1.71$  and  $38.5 \pm 5.13$  ng/ml in Beetal and  $48.1 \pm 3.60$ ,

43.7±5.32 and 55.5±5.72 ng/ml in Black Bengal goats, respectively. Significant increase in cortisol level was observed in Beetal on exposure to thermal stress, but the increase was non-significant in Black Bengal. It is concluded that Black Bengal were more adapted to hot humid conditions than Beetal (Kaushish *et al.*, 1997b). This study indicated that non-availability of drinking water for 36 hours do not change the response pattern of the both the breeds (Kaushish *et al.*, 1993, 1997b).

### **A New Breed of Goat from Rajasthan Desert**

The Institute has, for the first time, produced quantitative data to draw the attention of animal specialists to a little known breed of milch goat from Rajasthan desert, the "Parbatsar breed". This breed has distinctly superior potentialities as a milk yielder for the desert region. Hence, propagation of this goat breed has been recommended.

### **Performance of Various Goat Breed under Arid Conditions**

The productivity and adaptability of various goat breeds like Marwari, Parbatsar, Shekhawati, Jhakrana, Kutchhi, Barbari and Jamunapari under desert conditions were studied. These breeds were found to be non-seasonal in their reproductive behaviour. The incidences of oestrus were very low in case of Jhakrana and Jamunapari goats (Mathur and Mittal, 1990; Kaushish *et al.*, 1990).

### **Body Weights of Marwari Goats and Kids**

Body weights of Marwari goats were the highest (33.80 kg) in November and remained unchanged from October to March. The weights were the lowest (28.2 kg) in June. The body weights of Marwari kids at birth and subsequently at 3, 6, 9 and 12 months of age were 2.3, 6.1, 9.1, 10.0 and 11.8 kg, respectively. The male kids were heavier than female kids at birth and at 12 months of age, although their growth rate was slower upto 9 months of age (Kaushish *et al.*, 1994).

### **Performance of Marwari Goats on Degraded Pastures**

A flock of 8 does, 5 female kids and 2 bucks of Marwari breed was maintained on degraded *Lasiurus indicus* pasture for one year at Bikaner. On this pasture some plants of *Ziziphus nummularia*, *Capparis decidua* and *Prosopis cineraria* were present which worked as a source of browse. No supplemental feed was provided to these animals at any stage and they were watered once daily *ad libitum*. All the experimental animals remained in good health and their body weight gains were comparable to their counterparts maintained at normal *Cenchrus* pasture at Jodhpur. The libido scores of both the bucks were excellent. All the 8 does showed clear symptoms of oestrus with regular oestrous cycle conceived and produced 8 viable kids with normal birth weights. The pre-weaning survival and growth rates were also comparable. This

indicated that Marwari goats can be maintained on degraded pasture lands without supplemental feed atleast for one complete production cycle (Anon., 1991a).

### **Productive and Reproductive Performance**

This information is based on 73 goat which belonged Kuchhi, Marwari and Beetal breeds of goats. The average age at puberty, first conception and first kidding ranged from  $311.2 \pm 5.43$  to  $560.0 \pm 6.52$ ,  $387.4 \pm 3.75$  to  $605.9 \pm 4.59$  and  $509.4 \pm 3.45$  to  $760.3 \pm 4.50$  days, respectively. The average values for service period and kidding interval were shortest  $157.00 \pm 1.30$  and  $305 \pm 4.56$  days, respectively in Kuchhi. The post-partum interval and getting interval were shortest in Kuchhi and longest in Beetal. The tugging and concentration were higher in Kuchhi (Kaushish *et al.*, 1994).

### **Effect of Supplementary Feeding**

In a combined flock of Jhakrana and Barbari goats, the supplementation with 250g concentrate per animal/day was found to be more beneficial in terms of milk yield and body weight gain in comparison to those goats which were only maintained on grazing under silvipastoral system.

The reaction time and time taken for first service were consistently lower and the number of does covered during half an hour was higher in bucks which were given supplementary feeding. The fertility status of these bucks was assessed by the number of does conceived and number of does actually kidded. The average values of these three parameters were higher in treated bucks (96, 90 and 80%) than in control bucks (86, 80 and 75%).

### **Seasonal Body Weight Changes**

Average body weights of the Marwari goats, recorded at Bikaner varied between  $25.0 \pm 1.42$  kg and  $26.9 \pm 1.33$  kg during this period. The body weights declined after March ( $26.4 \pm 1.60$  kg) till August ( $25.5 \pm 1.37$  kg), after which the body weight increased (Anon., 1992b).

### **Season of Kidding**

Effect of season on kidding was observed in Marwari, Parbatsar and Shekhawati goats. Goats which kidded during autumn season performed better than those which kidded in winter season in terms of milk yield and body weight gains after kidding. The autumn born kids were significantly heavier than winter born kids. The pre-weaning survival and growth rates of the former group of kids were higher than the corresponding values of the latter.

### **Effect of Supplementation on Productivity of Desert Goats**

An impact of supplementation of 250 g concentrate ration daily in the goats maintained on 8-h grazing on *Cenchrus* pasture were studied. During the study period, the body weight reduction was more pronounced in non-supplemented than in supplemented goats, and none of the non-supplemented goats had kidding between September 1988-March 1990, whereas, among



supplemented goats, one animal gave birth twice, and others had single kidding. The experiment shows advantages of concentrate supplementation over foraging on ranges alone.

Feed lot experiment conducted on kids of desert goats indicated that stall fed goats gained more than the kids maintained on only 8-h grazing on *Cenchrus* pasture. The stall fed goats showed early maturity as one kid of this group conceived, while none could conceive in the control group (Mathur and Abichandani, 1991).

### **Economics of Supplementary Feeding to Marwari Goats**

When comparing the traditional system of Marwari goat rearing, i.e., maintaining on exclusive grazing with semi-intensive system for a period of more than 5 years. The animals were divided in 3 groups as under :

Group I (Control)	Free grazing/browsing, daily <i>ad lib.</i> watering
Group II	As above + supplementary feeding
Group III	Free grazing/browsing, intermittent watering (watering on every third day) + supplementary feeding

It has been observed that by supplemental feeding of goats with a pelleted concentrate feed having 18-20 per cent crude protein @ of 250 g to 400 g/day and to a group watered after every 2 days, farmer can be benefited by following economic traits, age at first kidding was reduced by 6 months, body weights were maintained even during lean period, milk yield could be increased by 20 per cent, kidding percentage was increased with a net gain of one kidding in span of 2 years; thus 3 kidding in two years, increase of twinning was 90 per cent more in goats provided with supplementary feeding than that in the control group (Mathur and Abichandani, 1993).

### **Introducing Jamunapari Blood for Improvement in Productivity of Marwari Goats**

Marwari goats are native of arid western region of Rajasthan. This is a medium sized breed. The economic characters of this breeds are milk, meat and hair. It produces less milk in comparison to that from other Indian breeds like Jamunapari. An attempt was made to improve the overall productivity of Marwari goats by using germplasm of Jamunapari breed. The half bred ( $F_1$ ) animals showed better performance in comparison to dam's breed in milk and growth aspects. The 90-days and total lactation yield of MxJ ( $F_1$ ) goats (67 and 108 L) was higher than that from Marwari goats (51 and 83 L). The peak yield was also found to be higher (1.9 L) in MxJ ( $F_1$ ) than in Marwari (1.0 L). The fat content of milk was also found to be higher in MxJ ( $F_1$ ) goats (more than 3.5%) than in Marwari goats (about 2.5%). The body weight of male goats was higher in MxJ than in Marwari, however, female kid growth rate was more or less similar in both the genotypes. The twinning percentage was found higher in Marwari goats when they were crossed with Jamunapari buck, about 25 per cent twins were born, while in Marwari, only 5 per cent twins were born (Mittal *et al.*, 1989).

### Feeding and Adaptability Trial

A short term experiment was conducted to evaluate the feed conversion efficiency for growth in three genotypes, Marwari, Jamunapari and their crosses. Studies revealed that dry matter and water intake per kg body weight was higher in MxJ crosses than in Marwari kids, although the differences were non-significant. Higher feed conversion efficiency (wt gain/kg dry matter intake) was found in Marwari kids (102.6 g) than either in Jamunapari (86.4 g) or half bred kids (81.5 g). Rectal temperature and pulse rate were higher in MxJ (F<sub>1</sub>) kids than in Marwari, although the differences were non-significant. PCV was also lowest in crossbred kids. Total plasma protein was almost similar in the three genotypes. Studies suggested that half-bred kids comparatively were less adapted to arid conditions (Patel *et al.*, 1996).

### Acceptability Trial of Salicornia

The acceptability trial of green *Salicornia* fodder with different levels in the ration of male kids of Marwari breed was conducted. *Salicornia* (*Salicornia bigelovii* Torr) is a leafless, annual halophyte (salt tolerant plant) with green jointed succulent stems, which may be used as animal feed. Eight Marwari male kids, 6 month old with an average body weight of about 14 kg were taken for the present investigation. The experiment was conducted for a period of three weeks at CRF, Jodhpur. The experimental animals were divided into four groups having two animals in each group. In all the four groups i.e., T1, T2, T3 and T4 the different levels of *Salicornia* fodder mixed with dry leaves of *Ziziphus nummularia* were feed to the animals at the level of 0, 10, 25 and 50 per cent, respectively. Water was available *ad libitum* to the experimental animals. The daily feed intake (g/kid) and water intake (L/kid) along with weekly body weight were recorded. The daily feed intake per animal was  $522.2 \pm 17.6$ ,  $586.9 \pm 27.6$ ,  $608.7 \pm 13.3$  and  $575.9 \pm 16.04$  g for T1, T2, T3 and T4 groups, respectively. The corresponding values for daily water intake were  $1.15 \pm 0.06$ ,  $1.30 \pm 0.06$ ,  $1.24 \pm 0.08$  and  $1.11 \pm 0.07$  L for respective groups. The daily feed and water intake was found higher in T2 and T3 group, where the animals were fed 10 per cent and 25 per cent level of *Salicornia* in their ration. The higher body weight gain per animal was also found in T2 and T3 groups (1.6 and 1.3 kg) than T1 and T4 groups (0.9 and 0.7 kg). The results of the present study indicates that 10 per cent and 25 per cent level of *Salicornia* green stem fodder are acceptable in the ration of kids. No adverse effect of *Salicornia* feeding was notices on general health of the kids in any experimental groups (Patel *et al.*, 1997b).

### Performance of Introduced Goat Breeds in Comparison to Local Marwari Breed

Three breeds of goats, namely, Parbatsar, Jhakrana from Rajasthan and Jamunapari from U.P. were brought to the Institute to study their productive and reproductive performance in arid conditions in comparison to local Marwari goats. Though the performance of Jamunapari breed is the best in the country, but in arid conditions, this breed showed reduced kidding percentage and twinning rate, and farm born kids showed slow growth rate, although they gained body weight till

the age of 2-3 years. Between Parbatsar and Jhakarana breeds, Parbatsar breed showed better performance in arid conditions in terms of lactation yield and body weight gain. The fat percent in milk of Parbatsar goat was also high (about 4.5%) which was the lowest (2.5%) in Marwari goats. Jamunapari breed had also higher fat content (4.3%). The kidding interval was lowest in Marwari goats (254 days) while Jamunapari breed had longest kidding interval (351 days) and Parbatsar and Jhakarana had between 300 to 325 days. The study revealed that Marwari goat's performance was better in terms of kidding rate and reproductive efficiency, but for milk production purpose, Parbatsar breed had better performance amongst all.

### Incidences of Diseases

A flock of about 200 goats consisting of does, bucks and kids of Marwari, Parbatsar, Jhakarana, Jamunapari and crosses of Jamunapari x Marwari were maintained at Central Research Farm, Central Arid Zone Research Institute, Jodhpur. Animal above 3 months of age were separated into male and female groups and sent daily for 5-6 hours grazing/browsing on *Cenchrus* dominated silvipastoral range. No stall feeding was done except those under treatment. Animals were watered daily *ad lib* only once after return from grazing. The incidences of occurrence of diseases recorded yearly according to hierarchy is respiratory tract infection, gastrointestinal tract infection/infestation, ectoparasites (ticks and mange), tympany after grazing in extreme summers, contagious ecthyma, lameness in Jamunapari crosses, eye opacity in bucks during August-September and blood protozoan infection particularly babesiosis. The animals were treated depending upon symptoms and clinical examination. Preventive measures were adopted for ecto and endoparasitic infestations (Mathur *et al.*, 1997b).

### Nutritive Value of Desert Feeds and Fodders

#### Nutrients content of desert vegetation

Among various desert vegetation analysed for different nutrients level, the *Acacia nubia* leaves contained as much as 35.6 per cent crude protein, followed by that in *Delonix regia* (21.5%), *Parkinsonia aculeata* (17.5%), *Atriplex condenses* (17.1%), *Albizia amara* (15.4%) leaves. Young resprouted *Zizyphus nummularia* leaves contained 21 per cent crude protein, whereas, leaves of mature plant contained only 12.5 per cent protein. The *Leucaena leucocephala* (Subool) leaves on dry matter (DM) basis contained 14.2 per cent crude protein, 13.8 per cent ash and 0.91 per cent acid insoluble ash. Among herbs, *Crotalaria burhia* shoots contained 8.2 per cent crude proteins. The flowers and young shoots of *Capparis decidua* were rich in both crude proteins (26.3% and 23.2%, respectively) and performed water (80% and 49%, respectively). Among grasses, *Brachiaria ramosa*, sprouting and matured *Cyanodon dactylon*, *Dichanthium annulatum*, *Cymbopogon jwarancusa*, *Aristida mutabilis* and *Cenchrus prieurii* had 9 per cent, 9 per cent and 4.9 per cent, 1.7 per cent, 2.8 per cent, 4.1 per cent and 4.7 per cent crude protein, respectively. Analysis for evaluation of monthly variations in performed water in fresh, and crude

protein content of oven dried *Acacia senegal*, *A. tortilis*, *Albizzia lebbek*, *Prosopis cineraria*, *Tecomella undulata* and *Zizyphus nummularia* leaves indicated that, on an average (9 months average from March to November), they contained  $56.9 \pm 1.72$  per cent,  $59.8 \pm 8.60$  per cent,  $59.2 \pm 2.00$  per cent,  $60.1 \pm 3.70$  per cent,  $56.2 \pm 2.59$  per cent and  $64.7 \pm 3.52$  per cent, performed water, respectively, and  $17.1 \pm 0.64$  per cent,  $15.7 \pm 0.53$  per cent,  $21.0 \pm 1.00$  per cent,  $13.0 \pm 0.33$  per cent,  $14.5 \pm 1.38$  per cent and  $16.2 \pm 1.40$  per cent crude protein, respectively. Fresh *Z. nummularia* leaves contained as high as 86.3 per cent performed water and 27.8 per cent crude protein. Fresh *P. cineraria* leaves, collected in November, had 60.3 per cent performed water and 13.8 per cent crude proteins, whereas, the leaves of same trees shed on the ground contained as low as 5 per cent performed water and 6.3 per cent crude protein (Bohra, 1989a).

### Chemical composition of pods of desert trees

Desert trees provide considerable quantity of nutrients through leaves and pods. The chemical analysis of tree pods indicated that half-ripened pods of most of the desert trees contained protein more than their fully matured pods. Half ripened *Acacia senegal* and *Albizzia lebbek* pods contained 22.6 per cent and 22.3 per cent crude protein, respectively. Except *A. senegal*, *Parkinsonia aculeata* and *Prosopis juliflora* pods, most of the desert trees contain tannins (Bohra, 1989b).

### Detanning of *P. cineraria* leaves

Our earlier studies indicated that the tannins, a polyphenolic, which is present in several desert top feeds and affects dry matter digestibility in general and crude protein digestibility of the feeds in particular, can successfully be removed by sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) treatment. Further refinement of the technique was required. For the effective treatment, the *P. cineraria* leaves should be incubated in the treatment solution, at least for 12 h period, and the appropriate feed: treatment solution ratio was found to be 10:75. The *P. cineraria* leaves, which on DM basis contained  $12.9 \pm 0.38$  per cent crude proteins and  $38.6 \pm 0.71$  per cent tannins, by treatment with 1 per cent, 2 per cent, 3 per cent, 4 per cent and 5 per cent aqueous  $\text{Na}_2\text{CO}_3$  solutions lost 87 per cent, 90 per cent, 91 per cent, 92 per cent and 93 per cent tannins, respectively, and for removal of maximum tannins by 1 per cent  $\text{Na}_2\text{CO}_3$  solution can be achieved by soaking the leaves at least for 16-20 h. This results in removal of about 85 per cent of tannins originally present in the leaves (Anon., 1995a).

### Micro-minerals status of range foraging desert sheep and goats

Studies on Micro-minerals status of desert sheep and goats, maintained in Guda Bishnoiyan village common grazing ranges, predominantly having *Capparis decidua* and *Prosopis cineraria* revealed that plasma of these animals had  $39.3 \pm 4.77$   $\mu\text{g/ml}$  and  $14.1 \pm 18.0$   $\mu\text{g/ml}$  zinc, respectively. This indicated that these animals had considerably higher levels of plasma iron and

zinc than their critical levels (iron, 1.82  $\mu\text{g/ml}$  and zinc, 0.4  $\mu\text{g/ml}$ ) reported in the plasma of these animals.

Further studies were undertaken to compare plasma micro-mineral levels in the plasma of goats maintained on 8-h grazing on *Cenchrus pasture* (A) and those provided with 200-250 g concentrated supplement (B). On an average, plasma of A and B animals had  $1.10 \pm 0.044$  and  $1.21 \pm 0.048$   $\mu\text{g/ml}$  copper, respectively,  $8.45 \pm 0.585$  and  $10.75 \pm 0.072$   $\mu\text{g/ml}$ , iron respectively, and  $3.19 \pm 0.299$  and  $3.48 \pm 0.083$   $\mu\text{g/ml}$ , zinc, respectively, but plasma manganese levels in these animals were below 0.02  $\mu\text{g/ml}$ , indicating that goats foraging on either *Cenchrus pasture* or/and supplemented 200-250 g concentrate ration did not have deficiency of all elements except that of manganese (Bohra *et al.*, 1988).

### Chemical composition of agricultural by-products

14 various types of crop residues were analysed for their crude protein and organic matter levels. On an average, leaves of moth, til and of moong on dry matter basis contained 11.4 per cent, 13.0 per cent and 15.4 per cent crude protein, respectively, and of the straws of guar, moong and til were 8.1 per cent, 9.8 per cent and 3.0 per cent, respectively. Organic matter content of til chaff was as high as 96 per cent. The crude protein content of bajra straw was 6.3 per cent, but due to its high ash content it could not be considered as a good feed for the livestock. Crude protein contents of til and moth straws were 3.0 per cent and 8.0 per cent, respectively. The organic matter contents of most of the agricultural by products varied from 90 to 96 per cent with an average dry matter content of about 90 per cent. Although the til straw is a poor source of dietary crude protein, its high organic matter content made this feed a dietary energy source for desert livestock. Nutritive value of such feeds can be improved by urea treatment or by the unconventional silage technique.

### Formulation of multi-nutrient block for supplementation feeding to desert livestock

Attempts have been made to formulate, and evaluate impact of supplementation of densified multi-nutrient block, prepared by compaction of various nutrients rich ingredients viz. molasses, urea, mineral mixture, common salt, fibrous feed (wheat bran, chaffed *C. ciliaris* straw or powdered ardu leaves) with a suitable binder (cement, bentonite, guar gum, guar churi or gypsum). Blocks are offered to the livestock as a supplement after drying in the open sun or in animal feeds solar cooker.

These blocks are well accepted by sheep, goats cattle and buffaloes. Block supplemented sheep have shown better body weight gain than their counterparts maintained on pasture alone. The buffalo has shown more licking than that of the cattle. Block supplemented sheep showed elevated blood haemoglobin, plasma albumin and urea levels than non-supplemented sheep. This preliminary trial indicated scope of the use of multi-nutrient block as supplementation of limiting nutrients to the livestock of arid western Rajasthan.

### **Identification of specific environmental conditions of arid regions for feasibility of silage making**

Experimental data indicated that the natural epiphytic bacterial flora responsible for lactic acid fermentation, is less in arid regions due to adverse environmental conditions, and therefore, ensiling without addition of lactobacillus culture is not able to produce sufficient amount of lactic acid. Besides surplus fodder of arid regions, which mainly constitute dry grasses, often contains lesser amounts of protein and carbohydrates required for silage fermentation (Panchoły and Mali, 1994a).

### **Standardisation of suitable ensiling process of surplus fodder of arid region**

Addition of over fermented butter milk at a specific cell concentration of lactic acid bacteria acted as starter culture for lactic fermentation and sufficient lactic acid was produced even at later stages of fermentation. Addition of urea at the rate of 1 per cent (DM basis) to the green fodder resulted in a silage with a CP content of 11-13 per cent as compared to 6-7 per cent without urea addition. Molasses added at the rate of 8 per cent (DM basis) permitted sufficient sugars for the fermentation process besides providing sufficient residual sugar in the silage. Non-availability of molasses in remote arid region could be overcome by using animal grade jaggery in quantities comparable to molasses. Therefore, the most suitable combination for ensiling in arid regions was addition of 1 per cent urea, 8 per cent molasses, 6 per cent LAB at CFU of  $1.8 \times 10^6$  (Panchoły and Mali, 1994b).

### **Non-conventional silage for arid regions and during famines and scarcities**

Animal Microbiology group has developed a non-conventional silage to be used as animal feed in arid regions and during period of famine and natural calamities of other regions for solving feed and nutrition deficiency problems.

The major difference between traditional and non-conventional silage technology is that the traditional require green fodder crops with high protein and carbohydrate levels, whereas, the non-conventional silage can be made from crops harvested at matured stage, poor quality grasses, agricultural by-products like straw, stovers, etc., weeds, tree leaves with incriminating taste, texture, etc., and even organic waste.

Since the non-conventional silage making process harnesses microbial energy, it is easy, affordable and does not require heavy inputs. Dry grasses, *C.iliaris*, *L. indicus*, pearl millet, *P. typhoides*, leftovers of *Cyamopsis tetragonoloba* and *Phaseolus vulgaris*, *Prosopis cineraria* leaves and *Ziziphus nummularia* leaves, etc. have been ensiled at both experimental and field lands with and without combinations. The non-conventional silage fed to milch animals at 40 per cent level, replaced 70 per cent concentrates or alternatively increased 40 per cent milk production, as well as improved fat content of milk by 30-40 per cent. It was readily acceptable, saved space for fodder storage, improves taste, texture and aroma. etc. The cost of production comes to only 7-10 paise per kg ((Panchoły and Mali, 1994c, 1997).

### Utilisation and recycling of organic wastes

Organic wastes of animal origin, specifically cow dung and sheep and goat dropping (SGD), are a very good source of nitrogenous protein and carbohydrates. Only the objectionable odour and taste makes them unsuitable for any use except as manure. However, through microbial fermentation, Animal Microbiology group of this division has achieved 25-50 per cent inclusion of cow dung and sheep and goat droppings in the non-conventional silage, resulting a major benefit of 3-4 fold increase in crude protein levels of the premix. The fermentation process kills pathogenic bacteria, removes objectionable odour by lactate fermentation and improves palatability with premix fodder and molasses homogeneously. Recycling organic waste this way helps in treatment of agricultural effluents and further helps in overcoming the fodder deficit in arid regions. The silage is palatable and is readily accepted by the animals (Pancholy and Mali, 1992, 1994d).

### Urea treatment of poor quality fodder/fibrous agricultural residues (FAR)

Kadbi and wheat straw has been treated with 4 per cent aqueous solution of urea in covered stack system and it has been found that it can be selected as second choice of poor quality feed treatment of arid regions, the first choice being the non-conventional silage. Urea treatment is easy and fast process and within a fortnight, a 3-fold increase in crude protein content and improved texture of fibre for digestion can be obtained. It does not require any infrastructure.

### Biodelignification of fibrous agricultural residues using native strains

Screening and strain improvement of promising white rot fungi from native soils is in progress to formulate a biological treatment process suitable to arid extremities.

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## ENERGY MANAGEMENT BY NON-CONVENTIONAL ENERGY SOURCES

P.C. Pande, Harpal Singh and N.M. Nahar

In the context of rural economy, energy is basically needed for cooking food, heating of water, lighting of houses at the domestic front while in agricultural sector energy is required for field operations, pumping water, spraying of insecticides, post harvest activities and running of agro and cottage industries. In addition, energy is also required for running TV in community centres, refrigerator and other equipments in rural hospitals, lighting of streets and providing potable water. As many villages are not connected to electric grid, the farmers are not able to avail its general benefits. The agricultural and allied operations are contemplated through the use of tractors requiring diesel or animals to be provided with fodder. In the domestic front, due to inadequate supply of LPG, people use energy sources like fuel wood, biomass, kerosene, coal and diesel. The problem is more severe for the arid regions due to scarce biomass and non-availability of hydro power. Although, there have been attempts to solve the energy problems through enhancement in electricity production, oil and natural gas explorations, import of petrol, diesel etc., there was more concern regarding energy sources after the oil crisis in 1973. It was considered essential to use the available resources efficiently and judiciously and to utilise the alternative sources of energy to meet the energy requirements. This provided an impetus to R&D activities in different organisations at Jodhpur like Central Arid Zone Research Institute (CAZRI), Defence Laboratory (DL) and Magni Ram Bangad Memorial (MBM) Engineering College. The efforts have resulted in the development of several devices based on solar and other sources of energy.

### ***Potential of Energy Resources***

The arid region is blessed with renewable sources of energy like solar energy, wind power and biogas. The average value of solar energy in arid region varies from 5.8 to 6.3 kWh m<sup>-2</sup> day<sup>-1</sup> (Garg and Krishnan, 1973; Mani and Rangarajan, 1982). In certain pockets like Phalodi there is a potential to use wind power (Krishnan and Garg, 1975). Further, it was estimated that solar energy of 1 per cent of land area, wind power of 5 per cent of land area and biogas (80 per cent collection efficiency) can provide 1504 kWh year<sup>-1</sup> energy per capita in arid region while the average per capita total energy consumption of India is 170 kWh year<sup>-1</sup> (Gupta *et al.*, 1988). In a survey of an arid village Jhanwar, the consumption of fuel for cooking was found to be 68.4 per cent of firewood and 28.6 per cent of animal dung (Gupta *et al.*, 1990) causing an annual

consumption of 960 tonne of firewood and 524 tonne of dry animal dung in that village. The availability of woody biomass in arid region is limited having only  $1.54 \text{ t ha}^{-1}$  in arid zone of Rajasthan compared to  $5.84 \text{ t ha}^{-1}$  in arid areas of Punjab,  $5.78 \text{ t ha}^{-1}$  in Haryana and  $5.19 \text{ t ha}^{-1}$  in Gujarat (Gupta *et al.*, 1992) indicating the need of alternative to firewood, especially in arid region.

The requirements of tractor and animal power in arid zone were projected by considering the prevalent agricultural and allied practices (Singh *et al.*, 1995). It revealed that about 50 per cent area can be sown by tractor, 18.5 per cent by bullocks and 26.3 per cent by camel. The coverage varies with the number of days of utility of animals and tractors. Considering both agriculture and transportation, the benefit-cost ratio for tractor, camel, single bullock and pair of bullocks have been worked out to be 1.39, 1.06, 0.85 and 0.86 respectively for maximum utility. If operator's cost is excluded, i.e., if the owner himself is the operator, the benefit-cost ratio for tractor, camel, single bullock and pair of bullocks comes to 1.52, 1.43, 1.30 and 1.07, respectively. The annual consumption of diesel was estimated to about  $8.4 \times 10^7$  litres for running tractors and that of fodder to  $5.4 \times 10^9$  kg to feed the animals. There is utility of animal dung in biogas plants. The biogas has potential to provide fuel for cooking, lighting the houses and running mechanical devices. Considering the population and 75 per cent collection efficiency of cattle and buffalo dung in arid region, it was estimated that it can generate 1.4 million  $\text{m}^3$  biogas which is equivalent to  $5.3 \times 10^6$  kg firewood. In addition, it will give organic manure containing  $1.23 \times 10^6$  kg nitrogen (Pande and Gupta, 1997). It has also been indicated that the integration of biogas and solar energy in an arid village can meet the basic energy requirements for domestic purposes (Mann *et al.*, 1980; Thanvi *et al.*, 1987).

## **Solar Energy Utilisation**

Research work was carried out on the development of solar devices viz., solar dryer, still, cooker, candle device, water heater, and integrated systems for multiple uses. Studies on alternative materials for reducing cost and increasing the life of solar devices were given emphasis. Research work on the development of suitable green house was also carried out. On the other hand, development of thin film solar cells for producing low cost solar cells was undertaken and solar PV systems for plant protection were developed. Studies on the solar PV pump operated drip irrigation system for growing orchards was initiated. Efforts were made for the dissemination of the developed solar gadgets. The research highlights and salient features of the developed solar devices are described in the following section.

## Solar Thermal Applications

### Solar Cookers

Considering the shortage of fuel for cooking and the deleterious effects of tree felling and cow dung burning on the fragile ecosystem of arid region efforts were made to develop a suitable solar cooker to supplement the energy demand. The solar cookers can be used for boiling rice, lentil, vegetables; roasting groundnut, potato, etc., baking vegetables and preparing *Bati* and other local food like *kheech* and *kheer*. With the use of such cookers one can save about 30-40 per cent of fuel requirement.

In earlier attempts, performance of five different solar cookers viz., hot box, solar oven, solar steam cooker, NPL paraboloid and step reflector concentrator types were compared. In this study the solar oven was found to provide the best results (Garg *et al.*, 1978a). Efforts were made to optimise the design of the solar oven. However, there were problems due to the need of tracking the solar oven towards the sun after every half of an hour and moreover it was bulky which caused inconvenience to the user. Attempts were therefore continued to evolve a practical design and following solar cookers were developed.

- (a) Two mirror box type solar cooker which does not require sun tracking for three hours and can be used to cook food for 4-5 persons (Gupta and Purohit, 1986). However, the window of the cooker is horizontal which receives less radiation during winter affecting the performance.
- (b) Solar cooker with tilted absorber in which food can be cooked on inclined surface and therefore the performance is better during winter months (Nahar, 1997). Provisions are there to tilt the device and special cooking pans are fabricated to hold the material on inclined plane.
- (c) Stationary solar cooker which does not require sun tracking due to optimum length to width ratio (Pande and Thanvi, 1987). This device can be tilted in different months, to receive maximum radiation through out the year and food could be cooked in stationary mode two times even during winter.
- (d) Community solar cooker which is suitable to prepare food for 80 persons in mess, temples, hostels, etc. (Nahar *et al.*, 1993). Such solar cookers have been adopted by army and Air Force Women Welfare Association, Jodhpur for their use in mess.
- (e) Solar cooker for animal feed (Nahar *et al.*, 1994a) which has been made by using clay, horse excreta, pearl millet/wheat husk and locally available commercial materials. With this device animal feed can be cooked by 3 p.m., the time at which feed is required. This does not require any attention during cooking and saves a good amount of firewood used otherwise for animal feed cooking.

In this context the other research work includes the design of a solar cooker which can be fixed on south facing window and can be operated from the inside (Annual Report, CAZRI, 1994). Attempts have been made to use transparent insulation material (TIM) for enhancing the efficiency of solar cooker (Nahar *et al.*, 1994b).

## Solar Dryers

The solar dryer is a convenient device to dehydrate fruit, vegetables, grains and industrial products efficiently while eliminating the problems of open courtyard drying like dust contamination, insect infestation and spoilage due to rains. Following forced and natural circulation type solar dryers were designed, developed and tested.

- (a) The forced convection type dryer comprises six solar air heaters (13.4 m<sup>2</sup> area), an electric blower and a drying bin. The blower makes the air to pass through the interconnected solar air heaters. The hot air enters in the drying bin, heats the material and takes the moisture out through the exit (Garg *et al.*, 1978b; 1980a). Extensive studies were carried out on solar air heaters in late seventies and early eighties. A standard test rig was developed to carry out the performance evaluation of solar air heater. Four different types of solar air heaters were fabricated and their performance were compared with the standard test set up. The solar air heater with iron scraps in between the duct was found to be most efficient (Pande *et al.*, 1979). The effect of different insulation materials, single and double glazing were also studied and regression equations providing the relations between efficiency and normalised temperature elevation were developed (Pande, 1980a). However, considering the intermittence of electricity which is required to run the system, the dryer required modification. A mixed mode dryer was developed which can be used both in natural and forced convection mode (Thanvi and Pande, 1989a). Due to constraints of irregular power supply, more emphasis was given on the development of natural circulation type dryers.
- (b) A solar cabinet dryer (basal area 1.5 sq m) which was found to reduce the drying time of chillies by 50 per cent compared to open drying (Garg and Krishnan, 1974). The temperature inside the dryer was observed to increase sometimes beyond 60°C which is not suitable for dehydration of fruits and vegetables.
- (c) An Improved solar dryer with chimney (basal area 1.68 sq m, capacity 15 kg) which has the facility of auto temperature regulation through enhanced circulation of air. This dryer was found to maintain the air temperature within the limits and dehydrate the products still faster (Pande, 1980b). The dryer is suitable for drying sugar and cacheu coated aniseeds and tobacco powder in addition to other fruit and vegetables.
- (d) Inclined solar dryer for maximum energy capture (capacity 10-12 kg) which can be tilted from 4 to 49° from horizontal to receive more solar radiation throughout the year. In this device the product can be stacked on inclined plane and can be dehydrated 20 per cent faster while costing 30 per cent less compared to solar cabinet dryer (Pande and Thanvi, 1982).

- (e) Low cost solar dryer with alternative materials like PVC sheet, bamboos, dried pearl millet husk, etc. (Thanvi and Pande, 1987, 1988a, 1990a). The durability of materials remained a problem.
- (f) Inclined solar dryer of optimum design with tilting arrangements for different capacities ranging from 10 to 100 kg (Thanvi and Pande, 1989b; Thanvi, 1994). The dryer was extensively tested for drying onion, garlic, coriander, salt coated aonla, spinach, okra, carrot, magnesium carbonate (used for making talcum powder), etc. Some powdered products from solar dried materials were developed for instant use. Based on this design a solar dryer of 400 kg capacity has been installed in village Kankani.

The dryers are finding increasingly more acceptability due to export potential of dried products like garlic, onion, instant *chatni*, etc. An energy analysis indicated that one can save some 290 to 300 kWh m<sup>-2</sup> equivalent energy by the use of these dryers (Thanvi and Pande, 1989a) besides accruing benefits of higher price of the dried product during off season.

## Solar Stills

Solar stills are useful devices for production of distilled water, required in batteries and laboratories. It can also be used to provide potable water in remote places. Initially CS&MCRI, Bhavnagar did a lot of work in this field and there have been demonstrations of large scale applications of these double sloped solar stills for providing potable water in village Avania in Gujarat and in Bhaleri, Dist. Churu in Rajasthan. However, the operational and maintenance problems deter the progress. Attempts were made at CAZRI, Jodhpur to optimise the design of double sloped solar still by considering different designs and the effects of climatic and operational parameters on the performance of solar still (Garg and Mann, 1976) and to solve the operational problems by pretreating the brackish water to prevent scaling and algae growth (Gupta *et al.*, 1990). However, it was found that the productivity of the double sloped solar stills was only 1-2 l sq m<sup>-1</sup> day<sup>-1</sup> during winter months compared to 3-3.5 l m<sup>-2</sup> day<sup>-1</sup> in summer. The productivity of single sloped solar still was increased during winter by 27 per cent with the use of additional reflector in single sloped solar still (Thanvi and Pande, 1980). More emphasis was given to improve the design. A stepped basin tilted type solar still was developed in which the productivity does not vary with season of operation (Thanvi, 1985). A detail experimental study was carried out on the energy balance of a small step basin type solar still which indicated that the convectional loss with in the still accounts for 4.7 per cent while the radiation loss from the water to glass amount to 13.5 per cent, the heat loss through the base of the stills 5.9 per cent while the heat used in actual evaporation of water works out to be 45.3 per cent. The heat losses due to reflection from glass and absorption with in the glass amounts to 20 per cent. The unaccounted 10.6 per cent losses were due to vapour leakages and side losses (Thanvi and Pande, 1988b). The stepped basin tilted type solar still of optimum design with alternative materials was developed and tested (Thanvi and Pande, 1990a). It was found to provide about 3-3.5 l sq m<sup>-1</sup> day<sup>-1</sup> distilled

water. Another solar still was developed and installed in an electric grid station for the maintenance of batteries (Thanvi and Pande, 1989c). The solar stills developed at CAZRI were adopted by railways and army units for getting distilled water.

### Solar Water Heaters

Hot water is required for domestic purposes like bathing, washing of clothes and utensils. It is also needed in textiles and dairy industries. A lot of fuel can be saved by using solar water heaters. The water heaters were used for space heating in cold desert of Leh (Gupta and Chopra, 1976).

Both collector-cum-storage and natural circulation type solar water heaters have been studied at CAZRI. A collector cum storage type solar water heater was developed earlier (Garg, 1975). The device was found to provide 100 L hot water of 50-60°C in the winter evening and 40-45°C next day morning after covering the device with insulating cover. The effect of boosters on the performance of such water heaters was studied in detail (Pande *et al.*, 1978). Further improvements were made in the design by optimising the air gap and insulation thickness (Nahar and Gupta, 1988). To reduce the cost, cylindrical water heaters were also attempted (Nahar and Malhotra, 1984) but weathering of the PVC remained a problem.

In the natural circulation type solar water heater the major problem of the unsatisfactory performance of float valve was considered and a completely sealed pressure tank made of 16 gauge G.I. sheet was used and connected to mains through a non return valve (Nahar and Gupta, 1985). This facilitates to keep the tank horizontal and thus makes the unit more compact. The energy saving from such water heaters (100 L capacity) was worked out to equivalent to 2526 kg of firewood or 167 kg of LPG.

Based on the CAZRI design, solar water heaters of different capacities ranging from 100 to 1000 L have been developed and installed in Guest houses, hotels, etc.

For cloudy days, a solar cum electric water heater has been designed and fabricated. The absorber area of flat-plate collector is 1.9 m<sup>2</sup> and storage tank has 100 L capacity. The storage tank has been provided with electric immersion heater of 1000W and connected with thermostat. The heater can provide 100 L of hot water at 60-70°C in the evening which can be retained to 50-60°C till next morning on clear days.

Solar water heaters, using concrete natural surface without glazing at top surface and insulation at base were developed. Aluminium pipes were embedded on the top absorbing surface for water heating (Chaurasia, 1997). The maximum temperature under stagnant condition was 42°C in December and 44°C in January. The application of black board paint on the absorbing surface increased the water temperature by 3.5°C as compared to that obtained without paint.

The economic evaluation of solar water heaters have been carried out (Nahar, 1992a) by considering equivalent savings in alternative fuels viz. firewood, coal, kerosene LPG and electricity. The payback periods have been calculated at 10 per cent annual interest rate, 5 per



cent maintenance cost and 5 per cent inflation in fuel prices and maintenance cost. The payback periods for 100 L capacity natural circulation and collector-cum-storage type solar water-cum-heaters varies between 1.57 to 10.80 years and 1.10 to 6.5 years respectively. The payback periods are in increasing order with respect to fuels, firewood, coal, electricity, LPG and kerosene.

## Other Applications

Efforts were made at CAZRI, Jodhpur to develop suitable polyhouses with a view to providing conducive conditions of optimum temperature and humidity for hardening saplings raised through tissue culture (Gupta *et al.*, 1994). Their applications for growing mushrooms have also been explored. In addition, such solar devices were developed which could be used to generate supplementary income. In this connection, while it was explored to extract oil from eucalyptus leaves and to prepare bootpolish with especially designed solar systems, the following devices were developed.

### Solar candle machine

A simple solar system, popularly called as solar candle machine, was designed, developed and optimised for melting wax to manufacture candles (Chaurasia *et al.*, 1983; Chaurasia, 1988a; Chaurasia and Gupta, 1989). Such a small size solar candle machine (absorbing surface area about 0.5 m<sup>2</sup>) can produce 10-16 kg a day candles during summer and 6-9 kg during winter. This machine is simple to operate and can be installed at home or field where solar radiations are freely available. Besides saving the fuel, it also reduces the vaporisation losses, labour and production cost of candles.

The technology has been taken over by the National Research Development Corporation of India, New Delhi for its exploitation and commercialisation and a contract was signed between ICAR and NRDC in July 1989. Since then NRDC has been issuing the licenses to private entrepreneurs on a lumpsum fee. A capital of Rs.12000 is sufficient to start this solar candle business and is useful to villagers and poor people to supplement their income.

### Solar device for rose water production

A device for making rose water was developed (Thanvi and Pande, 1989d). This unit has the following features: (i) Arrangement to keep the system at optimum tilt, (ii) Especially designed stepped basin for keeping the rose petals and water conveniently even on inclined position, and (iii) Openable cover which facilitates the cleaning operation. The device having an efficiency of 21.4 per cent supplies 3.7 L of rose water in 3 days during winter.

### Solar tea boiler

This device can boil 15 to 18 L of water and milk enabling one to prepare 125-150 cups of tea in a day. The device may find utility in office canteens and tea stalls (Nahar, 1987).

### **Dual and multipurpose solar appliances**

It has been observed that solar water heaters are useful only during winter and solar cookers are not useful during monsoon months and intermittent days. Moreover solar dryers are useful during harvesting season only. With a view to using the same device throughout the year for one or other purposes, dual and multipurpose solar energy appliances have been developed. It includes work on solar water heater cum steam cooker (Garg *et al.*, 1978c), a step basin type solar water heater cum solar still (Thanvi and Pande, 1988) and the development of following devices.

#### **Solar cooker cum dryer**

A solar cooker cum dryer can cook food for 4-5 persons without sun tracking and in this dual purpose device fruit and vegetable can also be dehydrated. The design has been chosen after considering the performance of collector -booster geometry for different width to length ratio (Pande and Thanvi, 1988a). The device cost is Rs.1200/-. About 240 kWh can be saved through this device and 30 kg fruits and vegetables can be dehydrated for their use in off season when fresh vegetables are not available.

#### **Solar water heater cum dryer**

A solar water heater cum dryer can dehydrate 10-15 kg fruits and vegetables as a solar dryer and can provide 80 L hot water of 55-60°C in winter afternoons (Pande and Thanvi, 1991). The main feature of the device is that during dehydration the water also gets heated and the dehydration process continues even in night and simultaneously the temperature of the product is regulated in between 60-65°C, optimum for dehydration of fruit and vegetables. The cost of this device is Rs. 4000/-. It can save 480 kWh energy for water heating and in addition 500 kg fruits and vegetables can be dried in a year.

A compact prototype with improved design has also been developed in which air circulation is better and the insects can not enter inside the device. The improved model has been tested successfully for dehydrating tomatoes, grapes, celery, carrot, etc. Since the drying process continues even during night, the quality of the dried product is better (Pande, 1997a).

#### **Solar cooker cum water heater**

A solar cooker cum water heater has been developed for isolated canteens (Pande and Thanvi, 1988b). The device can cook food for 22-25 persons in the forenoon and subsequently hot water can be obtained to clean the utensils. The device can be used as a solar water heater exclusively for providing 80 L hot water of 55-60°C. In this device the removable trays which are insulated at the base and sides work as cooking chamber as well as insulation cover for water heater. The system cost about Rs. 6000/-. Solar water heater cum cooker of different design for domestic applications was also developed (Nahar, 1988a).

### **Solar cooker cum still**

A solar cooker cum still has also been developed which can cook food in stationary mode and can be used for getting distilled water or making rose water (Pande, 1997b). In this device the two glazings are fixed on separate wooden frames and thus it enables to use the same device for cooking as well as for distillation. It also makes it convenient to clean the dust which enters in between the two glazings. It is worth mentioning that the falling of dust in between the two glass covers requires maintenance by skilled worker from time to time.

### **Multipurpose solar device**

The three- in-one multipurpose device can produce hot water and distilled water year-round and the same device can be used for drying of fruits and vegetables (Pande *et al.*, 1981). From this unit, 100 L hot water of 55-60°C and 2-3 L day<sup>-1</sup> distilled water can be obtained. 10-15 kg fruits and vegetables can also be dehydrated when required. The cost of the device is Rs. 5000/-. The year round use of the device saves 480 kWh energy for water heating and provide distilled water of Rs.1000/-. In addition 120 kg fruits and vegetables can be dehydrated.

### **Passive Cooling**

The studies on the development of passive structures revealed that the building should be oriented in east-west direction and roof should preferably be inclined towards north. The roof should be painted white during summer. Low cost thermal insulation e.g. embedded air pockets in earthen bowls in the roof has helped in appreciably lowering the inside room temperature. For better comfort, the door and window should be used to button up the house during the day and open up during night. Advantage of low sub-soil temperature should be taken for designing underground structures with proper ventilation (Gupta *et al.*, 1988). Two excellent solar passive houses have been constructed at the MBM engineering College Jodhpur. The passive house is a two storied building consisting of two eight rooms flats. The building is partially sunk in the ground. The exposed roof has an insulation of inverted earthen pots. A wind tower with built in evaporative cooling has been designed for bringing air to the rooms. Each living unit has provisions to facilitate suction of air. The buildings are reported to be working satisfactorily to provide better human comforts inside the building (Mathur, 1985). Efforts are now underway at CAZRI, Jodhpur for developing low cost technique for cooling animal sheds with evaporative cooling.

### **Solar Photovoltaic Applications**

Photovoltaic cells are considered very useful for generating electricity in remote rural areas where the possibility of extending the electric grid is bleak in near future. It does not require any long transmission lines, can be installed right at the place of utility and have no moving part. Solar lantern based on available solar cells panels and compact fluorescent lamps (CFL) of 5 to 11W

are available in market and provided through Nodal agencies at a subsidised rate. The life cycle cost in Rs./kilo lumen hours comes to 1.02 for this solar lantern compared to 1.46 for kerosene lamp giving only 70 lumen and requiring 1 L kerosene oil per week. (Bhargava and Shastri, 1992). In arid region solar lanterns find more utility in illuminating isolated cluster of houses known as Dhanis which are devoid of electricity. Solar PV system for street lighting are also very useful in remote rural areas. Several SPV street lighting systems have been installed in remote border villages and Panchayat Samitis of arid region. Solar PV pumps have good potential for irrigation (Ramana Rao and Pande, 1982). Power packs of 10 kW have been provided by REDA in villages for lighting the houses, street lighting, running of television in community centre and pumping of water for drinking purposes. A 10.6 kW<sub>p</sub> power pack has been installed in Sam of Jaisalmer district for providing electricity to 166 house holds. In this district, power packs ranging from 3.92 kW<sub>p</sub> to 8.0 kW<sub>p</sub> have also been provided in various villages viz., Meghwalonki-dhani, Kathoch, Devikot, etc. and arid village like Neembali (Agarwal, 1994). Jodhpur Division has taken a lead in Northern Railways by using PV systems for electrification and illuminated record number of 17 railway stations like Khedisalva, Jajiwal, Marwar khara, Udaniya chacha, Dehlana, Hanumant, Pharsin, Gole, Chilo, Pirwa, Bhimarlai, etc. The places have no source of electricity in near vicinity up to 2 km. The gang huts have also been provided with electricity generated by photovoltaic modules (Pandey, 1997). PV operated refrigerator for keeping vaccines has also been installed by WHO and tested at Baleshwar near Jodhpur. Now small PV refrigerators are also manufactured in India. Solar PV sprayer, PV duster and PV pump operated drip irrigation system have been developed at CAZRI, Jodhpur. Attempts were made to actuate a random oscillator through varying PV output for scaring birds (Pande, 1990a). Recently successful attempts have been made by Defence Laboratory, Jodhpur to desalinise water by using PV operated electro dialysis plant at remote places in arid region where potable water is not available.

Although the PV systems are useful for arid region, the dust laden atmosphere and higher ambient temperatures are the two such factors which affect the performance of the system adversely. Therefore a systematic study was carried out at CAZRI and attempts were made to develop suitable systems.

### **Performance Evaluation of PV Modules**

The effect of dust on the performance of the PV panel was evaluated and it was found significant to reducing the current values. It reduced from 5 to 17 per cent in 3 to 7 days in winter when tilt was 41 degree from horizontal. In contrast during summer when tilt of the panel was 16 to 25 degree from horizontal, the reduction in current varied from 2 to 10 per cent and the time that reduced the maximum values of current varied from 7 to 10 days. In a separate experiment, when the panel was not cleaned for two months in winter, the current output reduced to 30 per cent of the values obtained from the cleaned panel. The maximum reduction was as high as 47

per cent. It was concluded from seven years data that out of these, except for one year, the effect of dust on reducing the current output of PV panel was more during winter months than in summer although there are prevalent dust storms during summer months. This was attributed to the blowing of the settled dust by the south west wind during summer (Pande, 1992a). There was no discernible pattern on the time that reduces the PV output due to dust and therefore the cleaning needs to be done on regular basis according to requirements.

### **Solar PV Sprayer and Duster**

Considering the importance of small solar PV systems for combating insect and pest manifestations, a solar PV insecticide sprayer was earlier developed for spraying fluid insecticides after considering three sets of combinations including different storage system (Pande *et al.*, 1990). The solar PV sprayer is essentially an ULV sprayer connected to solar cell panel through battery. The PV panel is carried over the head of the worker with the help of an especially designed carrier that comprises a head gear, back support, belt and slings. Thus the PV panel, on one hand converts solar energy to electricity and on the other hand provides shade to the worker. In this connection of plant protection the need of a handy and convenient piece of equipment for dusting powder was felt due to prevalent practice of using insecticide powder. A solar PV duster (SD-1) was designed and developed to dust insecticide powder on agricultural crop (Pande, 1990b). The duster has three components: duster, PV panel carrier and storage battery. The duster comprises of a vertical cylindrical chamber made of aluminium sheet. This unit has three compartments from inside. The top one is the hopper which holds powder, the middle portion provides inlet to air and regulates the flow of powder towards the impeller. The fast moving impeller disc provides the required centrifugal action to dust the powder. The duster is attached to a wooden handle through iron clips so that it can easily be carried and comfortably operated. A switch is provided on the side of the handle to operate the device.

Although, this first model (SD-1) works satisfactorily, the unit is semi-automatic in the sense that one has to agitate the powder mechanically while impeller is run by PV output. In order to make the unit completely automatic and more practical, another model SD-2 was developed with an agitator (Pande, 1992b).

With a view to using the unit in late evenings or early mornings or during cloudy days, a storage battery [6 V, 14 Ah] has also been provided. In Model SD1 the battery is carried separately with the help of slings. Some problems were faced due to spilling of fluid. In the subsequent model (SD-2) a bracket is fixed *in situ* to the PV panel carrier. The PV output keeps on charging the battery and can be used to run the duster as and when required. Performance studies have revealed that with this device one can dust insecticide powder at a rate of  $30\text{g min}^{-1}$  on crop covering about 0.75 ha in 1 hour when wind speed is about  $5\text{ km h}^{-1}$ . During operation of the device, the weight of panel carrier was found to be more for practical purposes. Therefore, the PV panel carrier was completely redesigned and fabricated. The weight of the new model is half

of that developed earlier (Pande and Hill, 1995; Pande, 1997c). This improved design PV panel carrier enables the worker to carry the system with convenience. Further, arrangements have been made to use the device for lighting through out the year and for plant protection as and when required. Such a system makes the device more practical.

### **Solar Photovoltaic Based Drip Irrigation System**

The importance of growing orchards in the arid region is getting more with the availability of water for irrigation from IGNP canal. However, the overuse of water has caused the problems of waterlogging and salinity in phase I of IGNP canal command area. In view of this, it is important to adopt better irrigation technique for the sustainable development of arid region by optimally using valuable water and avoiding losses by evaporation and infiltration simultaneously. In this context, the method of drip irrigation is of great significance. A careful study was carried out considering various design and operational aspects to match the changing output of the PV modules during different hours of the day with the energy requirements of the drippers for providing uniform distribution of water in the field. Different drippers viz. threaded type (TD), low pressure compensating (LPC) and openable low pressure compensating (OLPC) were tested in the laboratory as well as in the field to identify their suitability in the system. Results have indicated that the OLPC drippers provided the least coefficient of manufacturing variation (6.3%) and highest field emission uniformity of 92 per cent at 90 kPa operating pressure (Pande *et al.*, 1997). Further, diurnal performance of solar PV pump using 900 Wp PV panels revealed that it can provide the operating pressure of 70-100 kPa for more than 7-8 hours which was sufficient to run OLPC drippers. Considering the maximum requirement of water to about 20 L per plant a day the system was extended to 1 ha area with three drippers on each plant, a microfilter and *in situ* facilities for fertigation and insecticides applications. It was found that the PV pump could provide a discharge of 3.2 to 3.8 l/h through each of the drippers during the day in this extended area. These observations confirm that the system can cover some 5 ha area of orchard. The cost benefit ratio of PV pump operated drip system for pomegranate has been evaluated to be 1.96 (Singh and Pande, 1996) even with costly single crystal silicon solar cells. With futuristic low cost solar cells, such a system would prove to be a boon.

### **Allied Aspects**

While developing the solar gadgets, concerted efforts were made to carry out some basic studies on the material and design aspects which were used subsequently in improving the device. The air gap between absorber and cover glazing was optimised (Nahar and Garg, 1981). It was found that a gap of 40-50 mm should be kept for minimum shading and convective losses. The length to width ratio for collector booster geometry was optimised for using such system in stationary mode (Pande and Thanvi, 1988a). Further, studies on weatherability of glazing materials e.g. glass, PVC and acrylic has been carried out. The annual average reduction in

transmittance for a weekly cleaning cycle was 15.06 per cent, 9.88 per cent, 3.28 per cent, for glass; 17.10 per cent, 11.08 per cent, 6.47 per cent for acrylic, having a tilt of 0, 45 and 90, respectively. The reduction in transmittance for PVC samples having a tilt of 45 and 90 was 12.78 per cent and 8.38 per cent respectively (Nahar and Gupta, 1990). A feasibility study has been carried out for establishment of 30 MW solar Thermal Power Station at Mathania near Jodhpur (Gupta and Nahar, 1988). In this connection, considering the average frequency of 10 dust storms at Jodhpur (Mann and Ramakrishna, 1980) and the concentration of dust in Thar desert to be 300 microgram per cum (Brysan, 1971), a study was taken to quantify the effect of dust on the deterioration in spectral reflectance of mirror materials. On the basis of weekly cleaning at Mathania, dust fall was found to range from 1.1 to 3.4 g and from 0.2 to 2.1 g at exposure angle of 0 and 60 respectively. Corresponding deterioration in reflectance was found to range from 24 to 50 per cent and from 14 to 28 per cent at an angle of 45 (Gupta *et al.*, 1994).

The storage of solar energy was also given some considerations (Pande and Garg, 1979). Attempts were made to store energy in pebble beds in air heating systems. Paraffin wax was used in solar water heating systems but found to create practical difficulties. Investigations on flat-plate collector with TIM having different design configurations have been carried out and its utility in solar cookers and candle device are now investigated at CAZRI, Jodhpur.

The material aspects include the studies on different absorber, glazing, casing, insulation, etc. Selective surface of coloured aluminium ( $Al_2O_3-Co$ ), having solar absorptance 0.93 and thermal emittance 0.20 and stable upto 400°C were developed on aluminium substrate (Nahar *et al.*, 1986, 1989). Black nickel on galvanised steel substrate prepared by chemical conversion process was found to have solar absorptance 0.962 and thermal emittance 0.43 while a selective surface on stainless steel has solar absorptance 0.91 and thermal emittance 0.33 (Nahar, 1988b). The coating is of low cost and very hard (Nahar, 1992b). Some paints were selected to reduce the corrosion problem in solar still (Thanvi and Pande, 1990b). The aluminium sheet was considered as a better casing material compared to mild steel sheet and pearl millet stalk as a convenient insulation material for inclined solar dryer (Thanvi and Pande, 1989a). The locally available wood scrap may be used as insulation in the solar water heaters fabricated at village level. However, it would require replacement in 2 years (Chaurasia, 1988b).

To develop low cost solar cells, attempts were made to prepare electrophoretically deposited CdS-CdTe thin film devices, using polar organic solvents as dispersion media. Apparatus for deposition and rig for optoelectronic characterisation were developed. Parameters like choice of media, applied voltage, current through sol, period of deposition, drying time, thermal annealing and recrystallization were considered to produce these devices with this novel non vacuum process having potential to produce low cost solar cells in scaled up production (Pande, 1990c; Pande, 1992c; Pande, 1994; Pande *et al.*, 1996).

## Energy Production/Saving Through Other Sources

Biogas can also be used for supplementing a great amount of energy requirements through the use of several models like KVIC type, Pragati model, fixed dome Janta and Deen bandhu design. Some R&D activities were carried out earlier in CAZRI and as a result an underground biogas plant using locally available stone slabs was developed (Garg *et al.*, 1980b), however, leakages of gas through the roof beset the progress. It is estimated that there is high potential of biogas in Rajasthan (Thanvi *et al.*, 1987). Power can also be generated with the excess biogas for carrying out post harvest work like chaff cutting, etc. However, there have been only 35,273 biogas plants in Rajasthan which were installed under NDBP programme compared to 208869 in U.P. and 102093 in Gujarat (Ramana, 1991). Efforts are needed to look into the operational problems.

Smokeless stoves (*chulhas*) are appropriate devices to save conventional fuel. It has a fire base, a tunnel, a baffel and a chimney. The design makes it possible to enhance the efficiency of fuel burning to 20-25 per cent from 5-10 per cent of conventional *chulhas* implicating an yearly saving of some 700 kg fuelwood for a family. Moreover, the health hazard through smoke are also minimised. By 1992, 12 million *chulhas* were installed in India while in Rajasthan the number was only 1273549 (Annual Report, MNES 1993). Installation of these *chullahs* will amount to decrease in the trees felling .

Wind power can be suitably used in certain locations where it is available at a speed of about 15 km/h throughout the year. In India wind farms are successfully operating along coastal areas in Gujarat and Tamil Nadu providing some 900 MW electricity. Wind pumps are also suitable devices for isolated places for providing drinking water. At CAZRI, Jodhpur a sail wing windmill was developed earlier (Chowdhry and Krishnan, 1978) and subsequently its performance was studied in detail (Chowdhry *et al.*, 1980). Another vertical axis wind mill (Savonius rotor) was also developed in CAZRI and A PU 12 type wind mill was also installed. 12 PU 500 type and 19 Deep wind mills have been installed in Rajasthan. These are distributed in Churu and Jodhpur district (Mehta, 1994). In places like Phalodi and Jaisalmer of Rajasthan, average wind speed at 20 meter height is about 28 km/hr. These are good location for exploiting wind power. R&D activities in this field require more efforts. Emphasis is now given by REDA to find the actual potential of wind power at varying heights in different locations to ascertain the suitability of wind power utilisation for pumping and electricity generation.

The energy management is a difficult problem in general and more intricate in arid region. Alternative sources like solar, biogas and wind power are available which can be used to supplement the energy needs. Extensive work has been done in the field of solar energy utilisation. Suitable solar devices are available for cooking, water heating, drying, distillation and candle making. Solar photovoltaic sprayer, duster, PV pump operated drip irrigation system are a few PV devices which can be used for agricultural purposes. There is a need for disseminating the technology to the rural hinterland. An integrated package is required with a proper assessment of



resources and requirements of isolated locations while simultaneously continuing the efforts for the development of low cost, durable and economical systems.

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## STATUS OF FARM MECHANISATION IN RAJASTHAN

Harpal Singh, D. Mishra and M.A. Khan

The Indian desert occupies over 0.32 million square kilometres of hot desert located in Rajasthan (western Rajasthan), Haryana and Gujarat, besides small pockets in peninsular India. An area of about 70,000 square kilometres of cold desert in Ladakh in Jammu & Kashmir, presents deserts conditions entirely different from the hot desert.

Rajasthan is the second largest state (area basis) of India. The state has an area of 342239 km<sup>2</sup> which is about 11 per cent of the total geographical area of the country. The total human population of the state is 44 million and density 130 (year 1991). About 70 per cent of the state population are engaged in agriculture. The total area under cultivation is 18.4 million ha of which 3.3 million ha are irrigated (17.9% of the cultivated area). The average annual rainfall is 600 mm mostly received between the middle of June and end of September. Major summer crops are millet, sorghum, maize, pulses, cotton, rice, vegetable, etc. while winter crops are wheat, gram, pulses, oilseeds, vegetable, etc. (Anonymous, 1982, 1989-90, 1991). Many spices and condiments like chillies, *kasuri methi*, cumin, ginger, etc. are also grown in pockets in western Rajasthan. The situation in arid zone is changing fast. More and more land is being put under crop production. The animal population in the region is already high. There is more emphasis on fodder/grass production. Varieties of various locally grown fruits such as pomegranate, ber, aonla, etc. have been developed and popularised. Due to introduction of highly efficient irrigation system (drip, sprinkler, etc.) more and more area is being brought under horticultural crops. As a result the intensity of cultivation has improved (Anonymous, 1984).

### ***Farm Mechanisation***

Farm mechanisation has positive relation with farm productivity, firstly through timeliness of operation and, secondly, through good quality work. In Rajasthan where farming is predominantly rainfed and climatological resources are unfavourable, farmers are left with less time for field operations. Also, since farmers' fields are widely scattered, much time and energy are being lost in movement. Mechanisation, therefore, has a high place in such area.

Farm mechanisation in Rajasthan started in the 1940s when some progressive farmers moved little forward to test improved agricultural machines and the results were very encouraging. Since then continuous efforts are being made to mechanise agriculture thus reducing human drudgery. In the last five decades, particularly in the post green revolution period, tractors and other farm

machines have multiplied many times over-testifying there by a progressive trend towards farm mechanisation.

## **Tractors**

Tractorisation in Rajasthan is mostly oriented to intensification of agriculture and to break the labour peak arising from development in technology in dynamic context. The tractor population in 1945 and 1951 was 15 and 506 units, respectively (Anonymous, 1951). The increase in tractor population was faster since 1966-67 when the green revolution campaign was launched. In 1966 about 4000 tractors were on farms which increased to about 12000 in 1972, 25000 in 1977, 55000 in 1983 and 87000 in 1988. The number of tractors rose to about 1.5 lakh in the year 1992. The number of tractors from 1966 to 1992 (26 years), therefore, has increased about 37 times. With the increase in tractors, the number of draft animals since 1966 experienced a decreasing trend except during 1977, when there was slight increase over the 1972 (Anonymous, 1956-88).

There was no tractor in western Rajasthan till 1951. However, 698 tractors were introduced in the region in 1956. The increase in number of tractor was faster since 1972. In 1972 about 7000 tractors were on farms which increased to about 15000 in 1977, 33000 in 1983 and 45000 in 1988 and 76000 in the year 1992. The tractors from 1966 to 1992 (26 years), therefore, has increased about 25 times (NCAER, 1992).

Contrary to the common belief that tractors are only suitable for big farmers it is quite interesting to observe that a large number of tractors are being used (on hire basis) by the marginal and small farmers. This is due to the fact that many of the marginal and small farmers are unable to maintain draft animals since cropping is limited to 3-4 months in a year.

## **Ploughs, Harrows and Cultivators**

Tilling the field is essential for creating favourable soil condition for seed germination and plant growth. The age old wooden plough gives low and poor quality work output. With the introduction of tractors in farming, improved matching tillage implements such as plough, harrow, cultivators etc. were brought in use. In 1988, over 41000 ploughs (mould board and disc), 37000 disc harrows and 57000 cultivators were in use in the state. Many manufacturers are engaged in producing these implements locally (Anonymous, 1994).

## **Seeders**

With the introduction of high yielding seed varieties and inorganic fertiliser, the value of mechanical seeder has increased. Mechanical drills offer advantage by way of ensuring desired application rate, uniform distribution and correct placement of seed and fertiliser, beside having relatively higher work output thus increasing farm productivity. In 1972, only about 900 units of power operated drills were on farms which increased to about 37000 units in 1988. In addition, there are about 475000 units of animal operated drills on farm at the present time.



Seed planters are still not popular and their use is limited to some big private farms or Government farms only.

### **Pump Sets**

The dependence of agriculture on monsoon and its consequent vulnerability has been recognised from the earliest time. Pump sets were introduced during the British rule in India to lift water from dug wells and surface reservoirs for irrigation. Thereafter, there has been continuous increase in its population. Oil engines and electrical pumps have multiplied 10 times and 7 times respectively, in just 20 years (1972-1992) resulting in increased cropping intensity and higher grain production.

With the proposed plan to introduce electricity to all the remaining villages by the end of the century the choice will shift in favour of electrical pump sets. The large use of electrical pump sets may bring revolution in irrigation in the state.

### **Sprayers and Dusters**

With the application of new technology plant protection measures have become inescapable. There are three types of sprayers and dusters in use; (i) hand operated, (ii) foot operated, and (iii) power operated. In 1988, about 36500 units of sprayers and dusters (all type) were on farms compared with only 2500 units in 1966.

### **Threshers and Harvesters**

Power thresher being highly efficient and with higher work output have gained wide acceptance among local farmers. Threshers are driven either by gasoline engine or electric motor, mostly in the range of 3 to 7.5 hp. Tractors are also used as prime mover. In 1988, over 28000 threshers were owned by local farmers which was more than 25 times higher compared with the 1972 figure. Besides some big manufacturers, small scale industries and some trained village artisans are engaged in manufacturing threshers locally.

Combine harvesters were introduced during the 1970s for testing purpose only. Soon after they were adopted by State Government farms and some big private farms. In 1988, about 47000 combine harvesters were on farms. Though the combine harvester has added advantage of harvesting and threshing, its scope is limited to big farms only. Small farmers do not accept the machine due to its high initial cost and requirement of large-sized plots for operation (Anonymous, 1994).

### **Improved Agricultural Implements and Machinery for Arid Western Plan**

The power source wise implement/tools and machinery recommended for the region for carrying out various field operations are presented in Table 1. Few agricultural implements and tools have been developed and tested at CAZRI, Jodhpur.

Table 1. Improved agricultural implements and machinery for arid western plain

Area under this region	:	Rajasthan and Gujarat
climate	:	Arid with extremes of temperature
Annual rainfall		10-65 cm
Important soil types	:	Alluvial, grey brown alluvial, black, desert and saline and alkaline.
Important crops	:	In desertic tract pearl millet and sorghum are important. Other crops are wheat, pulses, maize, cotton, millets, rice, groundnut, sugarcane and oilseeds.

Operation	Agricultural implement and machinery
<b>Seedbed preparation</b>	
Manual	Pick-axe, Spade, Trenching hoe, Garden rake
Animal drawn	Mould board plough 15 cm, Disc harrow 6 disc, Harrow <i>patela</i> , Bund former, Buck scraper, Clod crusher
Power tiller operated	Rotovator, Mould board plough, Cage wheel
Tractor drawn	Rotovator, Mould board plough, Cage wheel
<b>Sowing</b>	
Manual	Dibbler, Push type seed-cum-fertiliser drill
Animal drawn	Seed-cum-fertiliser drill 2-3 row, Seeding attachment over <i>deshi</i> plough, Maize planter, Groundnut planter, Cotton planter, Sugarcane planter (in lighter soil)
Tractor drawn	Seed-cum-fertiliser drill, Maize planter, Groundnut planter, Cotton planter, Sugarcane planter
Others	Power operated sugarcane set cutting machine
<b>Inter-culture weeding earthing</b>	
Manual	Wheel hoe V-blade 3 tined hoe, <i>kudali</i>
Animal drawn	3-5 tined cultivator, ridger, improved <i>bakhar</i>
Power tiller operated	5-7 tined cultivated
Tractor drawn	11 tined cultivator with duck foot shovel
<b>Irrigation</b>	
Manual	Diaphragm type low lift pump
Animal drawn	Persian wheel, Duplex pump
Power tiller operated	Irrigation pump attachment
Others	Centrifugal pump, Deep well turbine or submersible pump, Sprinkler irrigation

**Plant protection equipment**

Manual	Hand compression sprayer, Backpack sprayer, Foot sprayer, Duster, Wide swath spray boom for tall crops
Power tiller operated	Sprayer attachment
Tractor drawn	Tractor operated sprayer
Others	Motorised knapsack sprayer-cum-duster

**Harvesting**

Manual	Improved sickle, Sugarcane stripper
Animal drawn	Groundnut digger
Tractor drawn	Reaper binder, Tractor drawn combine, Groundnut digger
Others	Self propelled combine on custom basis

**Threshing**

Manual	Pedal type paddy thresher, Groundnut stripper, Tubular maize sheller, Burr type maize sheller, Pedal operated maize dehusker sheller, Winnowing fan
Power tiller operated	Multi crop thresher
Tractor drawn	Multi crop thresher 15-20 hp
Others	Spike tooth type thresher, Raspbar type thresher 3-5 hp, Power operated groundnut sheller, Maize dehusker sheller, Cotton delinter, Winnowing fan

**Post harvest operation**

• Cleaning	Precleaner
• Decorticating	Groundnut decorticator, Power operated groundnut decorticator
• Moisture indicator/meter	Moisture indicator, Moisture meter at market level
• Drying	Solar cabinet dryer, Solar batch and bin dryer
• Storage	Metallic storage bin 1.5 to 10 q capacity, 'Chittor' storage bin

**Processing**

• Chaff cutting	Hand chaff cutter, Bullock drawn chaff cutter, Power operated chaff cutter
• Sugarcane crushing	Sugarcane crusher, Power operated sugarcane crusher, improved <i>gur</i> furnace
• Milling	Mini rise mill 1 q/hr capacity
• Oil extraction	Power <i>ghani</i> , oil expeller

**Transport**

Manual	Hand cart with solid rubber wheel
Animal drawn	Improved bullock cart
Power tiller operated	Trailer
Tractor drawn	Tractor trailer

**Horticultural operations**

Manual	Secateur, Pruning knife, Budding knife, Bark scrapper, Hedge shear, Hand saw, Garden ladder, Watering can
Others	Tree duster, High pressure stationary sprayer

**Ratooning**

Tractor drawn	Stubble shaver
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(Source : Srivastava and Pandya, 1980).

**Seed-cum-fertiliser drill**

A bullock drawn seed-cum-fertiliser drill (CIAE design) was tested in the field under arid conditions. It was observed that the seed distribution was not proper, thus, wooden rollers for seed metering were fabricated for sowing seeds of mung bean, moth bean, guar etc. A suitable hitching arrangement was also fabricated to suit to camel.

**Two-row-planter**

A two row tractor drawn planter was developed in collaboration with ICRISAT, Hyderabad. It consists of a tubular steel frame, small ridger type furrow openers for removing dry soil, ground wheels, chain and sprocket assembly, device type furrow openers for placement of seed, seed covering discs, press wheels and cone type seed metering device. Two different varieties of seeds can also be sown in two different rows. The press wheel provides compaction to the soil above the seed so as to made use of available soil moisture for germination (Mishra *et al.*, 1997).

**Weeders**

Four different weeding tools, viz., wheel hoe, rotary peg weeder, rotary weeder and three tyne (Grubber) were evaluated in moth bean crop. The wheel hoe type rotary weeder was found most effective followed by rotary peg weeder, rotary weeder and three tyne hoe.

Beside, there are few agricultural implements, equipment and tools developed and evaluated at CIAE Bhopal which can be used in arid region. These includes improved *bakhar*, harrow, animal drawn seed-cum-fertiliser drill, rice transplanter, weeders of different designs, improved serrated sickle, tractor and power tiller operated harvester, multicrop thresher, tubular maize sheller, hand operated groundnut decorticator and manually operated cleaner and grader (Ojha, 1984).

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Harpal Singh and P.K. Malaviya

The greatest challenge for the technologist, engineer or scientist for next century lies in the area of Post Harvest Engineering and Technology. It is a powerful instrument for bringing around socio-economic and technological changes in arid region. It can be a starting point to introduce rural industrialisation and has potentialities for increasing farmer income and employment opportunities in villages. Multidisciplinary approach is needed to develop appropriate post harvest technologies which are technologically superior and economically viable as well as simple enough to be managed at rural level. Such technologies have to be made popular and acceptable to the farmer, so that he is not only a producer but also a processor. This will generate additional income and employment in rural areas and will also check the migration of rural people to cities in search of job.

### Current Status

The major crops of Rajasthan are bajra, wheat, mustard, gram, coriander, cumin, chillies, garlic, ginger and turmeric. The status of post harvest activities in arid region is almost non-existent at producer's level except small oil *ghanis*, flour mill etc. Mostly processing units are located in cities and towns. The details of such agro-based units are as under (Table 1).

Table 1. Agro-based industries in Jodhpur District.

S.No	Particulars	Number (%)	
1.	<i>Dal</i> Mill	24	(4.70)
2.*	Oil Mill	164	(32.09)
3.	Grain Crushing and Grinding	233	(45.60)
4.**	Guar Gum	52	(10.18)
5.***	Masala Grinding	27	(5.28)
6.****	Others	11	(2.15)
	Total	511	(100.00)

Source : Zila Udyog Kendra, Jodhpur

\* Including edible oil, non-edible oil with some grain crushing

\*\* Including *Churi* + *Korma*, guar split

\*\*\* All types of spices and Ayurvedic products

\*\*\*\* Milk, *ghee* and other dairy product, cattle feed, cotton ginning and processing(s) etc.

## **Post Harvest Losses**

To harness full benefit of green revolution responsive support from post harvest sector is necessary. In arid region technological and managerial innovations in post harvest sector have not kept pace with the development in agricultural production resulting in high order of losses to the farm produce from the stage of harvesting of the crops till their consumption. There are glut situations during harvesting at several places and then shortages follow soon after. It is estimated that 5-10 per cent of farm produce get lost in harvest and post harvest phase.

Post harvest losses could be substantially reduced by adopting improved post harvest equipment and processes. Organised research and development activities on post harvest engineering and technology in arid region is of recent origin. All India Co-ordinated Research Project on Harvest and Post Harvest Technology started in the year 1972 and different centres developed location and crop specific technology and equipment which could also be applicable in this region. Such details are given unit operation wise.

## **Cleaning and Grading**

The agricultural produce like grain etc. containing foreign matter will force farmer to sell his produce at a lower price in the market. Small scale manual or power operated cleaner can be adopted by the farmer. Pedal-cum-power operated air-screen cleaner developed at CIAE, Bhopal is made of mild steel with two screens, capacity 300-900 kg hr<sup>-1</sup>. Separation of food grains takes place on the basis of difference in size and weight. Light material is first carried away by air stream, then separation is achieved by two sieves by difference in size. The machine can be manually operated by two persons or with 0.5 hp electric motor.

Manually operated two screen Ber Grader was designed and developed at CAZRI, Jodhpur for grading mixed lots of ber into three sizes. The sieves are provided with rubber sheet to avoid bruising of bers. There is a provision for change in angle of screens, top screen 0-15 degree, middle 0-20 degree and stationary sieve with 5 degree slope. The oscillation motion is provided to the screens through single step V-belt arrangement. The complete unit is mounted on iron frame.

## **Drying and Dehydration**

The moisture content of various agricultural products are usually high and unmanageable for their safe storage at the time of harvest. However, harvesting of these products at high moisture content is desirable to minimise shattering losses and to produce good quality product. Consequently all such products have to be dried prior to their storage and further processing to produce value added product. Solar cabinet dryer developed at CAZRI, Jodhpur is essentially a solar hot box having capacity of 20-30 kg of fruits and vegetables which can be dehydrated in about 4-5 days. The maximum stagnation air temperature in this dryer varies from 55 to 96°C. Successful trials of drying chillies, dates, ber and converting grapes into resins have been



conducted. In these dryers all type of fruits and vegetable (high moisture products) can be easily dehydrated. Under forced circulation an estimated energy saving of 4500 Kwh can be achieved for drying of fruits and vegetables using mixed mode solar dryer having batch capacity of 100 kg (2 days drying period). There are other solar dryer developed at CIAE Bhopal, CPCRI Kasargod, CIFT Cochin, CRRRI Cuttack and IIT Kharagpur for drying chillies, coconut, black pepper, arecanut, cardamom, fish, paddy and other perishables, semi-perishables and wet processed food materials. Batch type re-circulating grain drier suitable for wheat, shelled maize, jowar, pearl millet and pulses having capacity of 1.25 tonnes/batch and power requirement of 4.0 kw has been developed at IIT, Kharagpur. Portable batch dryer for drying cereals, pulses and oilseeds has also been developed at PAU, Ludhiana.

### **Milling of Cereals**

In the estimated total production of 181 million tonnes of food grains during 1993-94, the coarse cereals accounted for 33.7 million tonnes or 18 per cent. In India, production of coarse cereals like sorghum, pearl millet, maize, ragi, small millets and barley varied between 4.64-7.78 million tonnes in the past five years. Rajasthan accounts for nearly 40 per cent of total production of pearl millet in the country. Coarse cereals like pearl millet form staple food of poorer sections of population in villages particularly in arid regions. Studies have shown the possibility of broadening consumer acceptance of coarse grains substantially.

A number of grain mills are available for making flour, suji, maida, besan, spice powder, etc. Mini grain mill, grain pearler developed by CIAE Bhopal and mini-grain mill ( $100 \text{ kg h}^{-1}$ ) developed by CFTRI can be used for making flour, maida and suji in small scale.

### **Milling of Pulses**

Pulses are major protein source in Indian diet. The traditional stone mill do not produce good quality of dal. The recovery of dal is also low in these traditional mills. Processes and equipment have been developed for making good quality dal which are superior to traditional methods. The dal mill ( $100 \text{ kg h}^{-1}$  capacity) and processing technology developed at CIAE Bhopal and manually operated Dal Mill developed by CFTRI, Mysore can be adopted at rural level for making dal. Dal mill-cum-wet grinder for wet grinding, splitting of pulses into dal and dry grinding of cereals and pulses at the rate of  $30 \text{ kg h}^{-1}$  has been developed by TNAU, Coimbatore. Pearler for removal of hard coat of millets, coarse cereals and pulses has also been developed by TNAU, Coimbatore and CIAE Bhopal.

### **Processing of Oilseeds**

Oilseeds are the major source of oil (40%) and protein (20%). Out of total oilseed production in the country 7 per cent is used for seed purposes, 8 per cent for food, and 85 per cent for oil extraction. Oil expellers have been developed for giving good recovery of oil with lesser residual

oil in the cake. The mini solvent extraction plant for 10 tonnes day<sup>-1</sup> capacity is manufactured in the country which can be adopted by rural level industries.

### **Processing of Fruits and Vegetables**

Due to extreme weather conditions, spoilage of fruits and vegetable is maximum in all other agricultural produce. Fruits and vegetables being perishable in nature their shelf life is very short. An industry based on fruit and vegetable product has good potential in rural areas. Products like jam, jelly, pickle, sauce, dehydrated vegetables and potato chips can be prepared successfully in rural areas. Punchkuta - a mixture of arid fruits and vegetables containing kair (*Capparis aphylla*), Sangri (*Prosopis cineraria*), Lasoda (*Cordia myxa*), kumat (*Acacia senegal*) and Kaachra (*Cucumis melo* var. *momordica*) is one of the traditional recipe relished as vegetable by all sections of people in Rajasthan and even exported to many countries. In traditional processing the product loses its colour, aesthetics and taste. Studies are already undertaken at CTAE, Udaipur to develop improved process for this valued item.

A rural level industry can be set up in the area where fruit/vegetables are available in plenty. Mechanical dehydrator developed by CIAE, Bhopal can be used for dehydration of fruits and vegetables. This dehydrated product can be sold in the local market for its consumption in off-season. Continuous type power operated, chillies seed extractor capacity 4q day<sup>-1</sup> (8 hrs), has been developed at TNAU, Coimbatore for extraction of seeds from dried chillies. Tomato seed extractor has been developed at IARI, New Delhi and TNAU, Coimbatore for extracting seeds from the ripe tomato, capacity 60 kg ha<sup>-1</sup>.

### **Processing of Spices and Condiments**

Rajasthan is producing a variety of spices which include chillies, ginger, turmeric, garlic consumed locally and also exported. These spices are used in various forms viz., raw/green, dried powder, pickles, oleoresins, etc. The unit operations such as cleaning, grading, drying/curing, polishing could be carried out at rural level using small scale processing equipment for value additions and income and employment generation. Peeling machine, solar dryer, polisher and pulveriser were developed by Sukhadia University, Udaipur for small scale processing of ginger.

### **Guar-Gum Industries**

Clusterbean (guar) is one of the major crop of arid zone. Guar gum industry in the State of Rajasthan has come up in a big way for processing guar for gum extraction. The straw of clusterbean is one of the main source of animal feed.

### **Gur/khandsari Industries**

Gur/khandsari Udyog is being run as cottage industry on small scale in the State. About fifty five thousand people are working in this industry.

**Sugar Mills:** There are three sugar mills in the State. Bhopalgarh sugar mill is in private sector, Keshoraipatan sugar mill is in co-operative sector and Shri Ganganagar sugar mill in public sector. The total production of sugar in the state was recorded as 9000 tonnes in the year 1988.

### **Milk and Milk Product Processing**

There are ten dairy plants operating under Rajasthan Co-operative Dairy Federation (RCDF). The plants are located at different parts of state. The total capacity for milk handling and processing is 9 lakh lit day<sup>-1</sup>. Milk production in arid districts of Rajasthan was estimated at 1.50 mts in 1995 and by 2000 it is expected to 1.61 mts. There are numerous types of dairy products processed at home level in traditional way but there is a great scope to adopt improved equipment and technology for processing the milk products at rural or co-operative level. Some work on small scale processing of dairy products has been carried out like solar milk pasteuriser developed at IIT, Kharagpur. The pasteuriser is driven by solar energy and electric pump (0.25 hp) and has capacity of 20 litre h<sup>-1</sup>. UHT type low cost milk processing equipment has been developed at the NDRI, Karnal. Its capacity is 120 litre h<sup>-1</sup>. The shelf life of the milk processed by this plant has been estimated to be 60 days.

**Continuous Ghee Making Machine:** Ghee is prepared traditionally in villages. NDRI, Karnal has developed a simple machine having capacity of 150-200 kg h<sup>-1</sup> and is operated with electric motor. NDRI has also developed continuous *Chana* making equipment, mechanised khoa pan for rural application and semi-automatic ghee filling and seaming machine for processing of milk and milk products at rural level.

### **Livestock Feed, Fodder and Seed Pelleting**

**Animal Feed Plant:** Rajasthan state has five animal feed plants under Rajasthan Co-operative Marketing Federation (RAJFED) making feed pellets and urea-molasses blocks. The plants are located at Jhotwara (Jaipur), Nadvai (Bharatpur), Tabiji (Ajmer), Bikaner and Jodhpur with total capacity of 440 tonnes day<sup>-1</sup>. About 83, 420 tonnes of animal feed was produced in the year 1987-88.

**Forage Densifying Machine:** Indian Grassland and Fodder Research Institute, Jhansi has developed Forage Densifying Machine. The machine was installed and tested for its functional performance on wheat bhusa and dry grasses with and without berseem. Wheat bhusa at 15-36 per cent moisture content (wet basis), adding 10-15 per cent molasses, can be densified to the extent of 350 to 400 kg m<sup>-3</sup>. The densified fodder is 6-7 times less in volume and can be easily and economically transported at places of its consumption.

**Pelleting of Cattle Feed:** A animal feed pelleting machine was developed at IGFRI, Jhansi. The machine is useful in pelletising wheat bhusa and chaffed grasses mixed with concentrates in 7:3 and 1:1 proportion with subabool leaves/berseem. The bulk density of these pellets varied from 350 to 358 kg m<sup>-3</sup>.

**Feed Briquetting Machine:** The feed briquetting machine also developed at IGFRI, Jhansi has been tested in briquetting wheat bhusa and chaffed grasses mixed with subabool leaves and berseem. The briquettes were 22-24 mm in diameter. The average bulk density of these briquettes was 358 to 370 kg m<sup>-3</sup>. The capacity of the machine is 60-80 kg h<sup>-1</sup>.

**Straw Baling Machine:** An electric motor (2 hp) operated straw baling machine was developed at CIAE, Bhopal. The machine consists of baling chamber, compression unit, electric motor, transmission mechanism and unloading system. On an average 60 bales can be prepared in one day (8 hours each). A bhusa making machine was developed at IARI, New Delhi. The machine can be used for making feed grade chaff from straw. This is a cylinder concave hammer mill type machine operated with 5 hp electric motor having capacity 10 q h<sup>-1</sup> (wheat straw).

**Fodder Storage Structure:** Fodder storage structure for silage making and storage was developed at CAZRI, Jodhpur. The capacity of structure is 250-300 kg of fodder at 70 per cent moisture and 30 per cent dry matter. M.S. bars and spiral hard drawn steel bars were used for reinforcing the storage structure. Circular cages and longitudinal reinforcement, are placed symmetrically with respect to thickness of the unit. Inside surface of silo wall is kept smooth to ensure that cavities do not form along the walls to avoid spoilage of silage.

Dry fodder generally stored in arid region are pearl millet (*kuttar*), wheat straw (*Bhusa/khakla*), moth bean (*Panna*), clusterbean (*phalgati*), sorghum, and *ber* leaves. The fodder is stored above ground in temporary structure, made up of pearl millet stalk and wheat straw. These structure are called as *Karai*. The *karai* is round in shape at bottom with conical top having fodder storage capacity 600-800 kg. About 10-20 per cent of stored fodder is lost during the storage period, usually one year. Improved *karai* having capacity 2500 kg was developed at CAZRI Jodhpur for storage of dry fodder. Locally available stone slabs were used for construction of the *karai*.

**Seed Pelleting:** Seed pelleting machine for making pellets of small/light weight seeds for sowing purposes was developed at IGFRI, Jhansi. The machine is power operated having capacity 100 kg hr<sup>-1</sup> (seed pellet). Pelleting of seeds of range grasses, pasture legumes and tree is recommended for ease in sowing and planting operation and better establishment of these seed on grazing/pasture/eroded lands. This technique has also been found useful in reclaiming the inaccessible land through reseeding by aerial seeding. In tyre type seed pelleting unit unserviceable tyre is mounted vertically on a shaft supported on angle iron frame with the help of two ball bearings and crank handle to revolve the tyre and set of sieve for grading the pellet. About 60 kg dry pellets can be prepared in an hour by use of the device.

**Storage Structure for Food Grain:** In Rajasthan, traditionally *Banda* is used for storage of farm produce. This is an underground structure. Outdoor structures, dug at an elevated place, have storage capacity of 100-200 quintals of grain. The extent of loss due to grain getting mixed with soil varies from 15-20 per cent. Other commonly used storage structures are

*Thekka* primarily made up of the hessian cloth supported by metal and or bamboo. The CTAE, Udaipur has developed storage bin which is made out of used coal tar drums. About 1.30 quintal of wheat, maize and other food grains can be stored in this bin for short duration. This technology has already been adopted by small and marginal farmers of the region. Stone bin made of locally available 40 mm thick stone slab with dimensions of 680x680x1200 mm with square cross section has a capacity to store 3.8 quintal of grain. There are other storage structures like PKV bin, Pusa bin which are basically modified/improved version of ordinary mud storage structure commonly used in villages. An improved storage structures was developed at Indian Grain Storage Institute (IGSI), Hapur. The Hapur bin is a metallic cylindrical shaped indoor grain storage structure. The bin is suitable for storage of all types of food grains and has capacity upto 1 tonne (for wheat). The bin is made of corrugated GI sheet with flat bottom cylindrical shape provided with elevated plinth. Large size outdoor storage structures capacity of 50-60 tonnes (wheat) have also been developed. Large size RCC storage structures are also developed for outdoor storage of foodgrains and seeds. IGSI conical bottom bin is a hopper bottom, metallic outdoor bin for storing wheat, other cereals and pulses upto 60 quintals. CBRI, Roorkee has developed different silos, single cavity brick silo (capacity 10 q), concrete silo with cavity (capacity 1 tonne), underground concrete ring bin (capacity 1 tonne and 3 tonnes) for safe storage of food grains. CIAE outdoor metal bin developed at CIAE Bhopal is a metallic outdoor inclined bottom bin suitable for storage of cereals, pulses and oilseeds, capacity upto 5.0 tonnes.

Small and marginal farmers generally store about 60-65 per cent of their farm produce for their own consumption in storage structures such as *Mud Kothi*, *Bukhara*, improved metallic and store bin. Transportation of farm produce from farmer's field to nearby *mandi* and other local market is mostly done by bullock carts and camel carts.

**Bullock Carts for Transportation:** Two wheel multipurpose spoked wheel cart having load carrying capacity 12 q. on loose field terrain has been developed at CIAE, Bhopal. One pair of bullock (draft 125 kg) can pull the cart. Farm produce in bags/bulk can be transported easily from fields to house/*mandi*/market. A punctureless rubber type bullock cart was also developed at the CIAE Bhopal. The used tyre is stuffed with coconut fibres to provide cushioning effect.

Balwan bullock cart developed at the school of Applied Research, Sanghi is an animal drawn cart having steel frame with braking system. To minimise friction tapered bearings are provided. The cart has a load carrying capacity of 3 tonnes on tar road. One pair bullock can easily transport 3 tonnes of food grains (draft 125 kg) in this cart. Yatra bullock cart developed at IIM, Bangalore is an animal drawn (one pair of bullock, draft 124 kg), spring loaded cushion type steel frame passenger cart. The carrying capacity of the bullock cart is 10 adult passengers or 20 school children or fragile goods upto 5.5 q.

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The socio-economic researches, of late, have assumed a great significance in the transitional phase of socio-economic development. Over the last many years lot of technologies have been evolved for the development of the desert dwellers although the acceptance of various technologies remained poor. The general problem of Indian arid zone is essentially one of human ecology since arid lands in this country are not virgin but have fairly high densities of human population. The economy of the region is primarily based on agriculture and animal husbandry. The way of life of the people in this region and their sources of livelihood have chiefly been conditioned by disturbances in ecological balance due to the severity of the arid climate.

The research on social and economic aspects in the Indian hot desert was initiated as early as 1960 with the establishment of Human Factor Studies Division at Central Arid Zone Research Institute, Jodhpur. The erstwhile division of human factor studies and presently the division of social and information sciences has been carrying out various studies on human ecological problems among the settled, nomadic and semi-nomadic population in arid and semi-arid regions of the country. During the last three and half decades a good number of studies have been carried out in various dimensions like demographic, social and economic structure, socio-cultural factors impeding development process, group dynamics, factionalism, leadership pattern, nomads and nomadism, socio-cultural and economic factors influencing the desertification processes, impact of major and minor irrigation, environmental perception, socio-economic factors of sustainable development, diffusion and adoption of agricultural innovations and its constraints etc. Studies on agricultural production system, marketing, livestock forestry, evaluation of various technologies, etc., have also been carried out.

### **Population**

The population in this region can be divided into two broad groups viz., sedentary and semi-nomadic or nomadic. The heterogeneous caste composition and the inter-dependence of various caste/communities are quite dominant. Caste stratification is strictly followed and all socio-economic activities are controlled by the institution of caste. The functional specialisation of various castes, exchange relationship, water harvesting and water use, practice of mixed farming and mixed cropping, fallowing of land, crop rotation, etc., are some of the adjustment mechanisms of desert dwellers. A sizeable part of rural population live in *dhanis* (dispersed dwellings), usually away from village nucleus formed mainly on kinship and caste basis, apart from compact settlement.

Spread over an area of 208 thousand km<sup>2</sup> the arid areas of western Rajasthan is so far the thickly populated desert with 90 persons km<sup>2</sup> compared to 3-5 persons in other desert of the world. India, despite its massive family welfare programme initiated in 1952, could not arrest its population at a desired level having differential growth pattern. The hot desert region of India has relatively higher growth rate of population compared to other regions (Bose, 1962, 1966; Malhotra, 1977; Malhotra and Saha, 1987; Saha, 1993). A good number of studies were also carried out in this region on various socio-demographic and economic structure discussing the composition of population, family type and family size, intra-family relationship, ownership of land holding and settlement pattern, other sources of livelihood, resource use and their conservation, etc. (Bose and Malhotra, 1965; Malhotra, 1964; Malhotra and Sen, 1964, 1966, 1974; Malhotra and Gupta, 1980; Bharara *et al.*, 1970, 1984). With the increasing population more and more marginal and sub-marginal lands have been brought under cultivation, disturbing the ecosystem. It is estimated that at the current rate of population growth the availability of land per household by the turn of century in the arid region of Rajasthan will be only 6.03 ha (Malhotra, 1977) compared to 17.77 ha in 1951. Malhotra (1977) reported that the coefficient of correlation between the rainfall and the density of population in the arid zone of Rajasthan was positively significant (+0.6079) whereas the values of 'r' exhibited a negative correlation between the population density and average annual rainfall in the plains ( $r = -0.2923$ ) as well as in the hilly regions ( $r = -0.0172$ ) of Rajasthan. The density of population in Sri Ganganagar district is higher owing to the availability of surface water through canal irrigation. Similarly, the districts such as Jhunjhunu, Nagaur, Jodhpur, Sikar and Pali having greater facilities of well and tank irrigation show a higher density of population. The age and sex composition of population of the arid zone of Rajasthan revealed a broad based pyramid with preponderance of young population. Empirical studies conducted in this region also revealed that more than 40 per cent population falls in the age group of 0-14 years which would substantially enhance the population in near future.

Data on decennial growth rate of population (1901-1991) in arid zone of Rajasthan, Rajasthan state as a whole and India revealed an increasing trend of population. It is evident that starting with a base of roughly 3.40 million in 1901, the population in the arid region of western Rajasthan had increased by more than five times by 1991. The percentage increase of population during each decade had been higher in arid Rajasthan. The factors responsible for higher growth rate of population are the early marriage, traditional beliefs and customs, illiteracy, especially the female illiteracy, gap between the birth and death, inadequate family welfare measures etc.

The mean age of marriage for boys and girls of Rajasthan is low compared to all India average. There are very few unmarried persons over 35 years of age, showing an universal nature of marriage. Early marriage is widely prevalent with little variation. Even in recent times marriages take place at the death feast called *Mosar* and in some cases it was found that the age of bride and bridegroom was even less than a year. Early marriages and begetting of children are



important parts of the social ethos of these people. Any deviation from the established norms being not only looked down upon as wholly aberrant but also incompatible with the social fabric of the community. Divorce is a rarity, if not altogether unknown and widowhood soon culminates in remarriage. This region, moreover, had developed high fertility norms over the centuries due to high mortality. Although with the advancement in medical sciences the mortality rate has been checked, high fertility still continues.

The limited use of birth control measures in this region has aggravated the situation. Very few studies have been reported on family planning measures (FPMs) in this region. Saha and Bhandari (1997) reported that 14.0 per cent either of the spouse in the age group of (15-46 years) adopted some or other family planning measures in sixteen villages of Sikar district which is quite less looking to the average fertility rate of 3.51 children. Patel (1990) reported the various problems encountered by villagers in adoption of family planning measures. Malhotra (1977) reported the declining trend of joint family which is posing a paradox, just at the time when new longevity conditions are generating the necessity for the care of aged in the joint family.

Migration has not played any significant role in the growth of population in the rural arid Rajasthan as immigration from other states remained almost negligible due to the paucity of productive lands and dearth of large scale industries. Similarly, out migration from this region is significantly low because of backwardness, conservative traditional caste system, joint family system, early marriage, illiteracy, etc.

Bose and Malhotra (1964) and Malhotra and Gupta (1980) reported the socio-demographic and economic characteristics of child population in two arid districts of western Rajasthan. The child population (0-14 years) constituted more than 40.0 per cent of the total population while 60.0 per cent in the age group of (10-14 years) were involved in household activities. The per cent literacy in the age group (4-14 years) especially for girls were almost negligible. Saha (1993) reported the population dynamics of four micro-climatic zone of arid Rajasthan and the Kachchh district of Gujarat. The increase of population in Kachchh district was less compared to various arid regions of Rajasthan. The sex ratio is one of the vital components in demographic structure of population. The sex ratio of four zones and Kachchh district were analysed from 1901 to 1991. In zone-I there has been a dominance of masculine sex in all the decades than the Zone-II, III and IV. The prevalence of female infanticide was reported by Tod (1829). Conversely, in the Kachchh district the dominance of feminine sex was observed in all the decades. Patel (1971) reported the prevalence of female infanticide in eighteenth century among some clan of Rajput caste in Kachchh district.

From the foregoing discussion it is quite clear that the growth of population in the great Indian desert is quite alarming than the state and country as a whole. Among the four arid zones, zone-I, i.e. Jaisalmer district had the highest growth rate which clearly indicated that in the extreme arid condition the growth of population is extremely high which needs micro-level village studies involving the social scientists and other development agencies. However, attitudinal changes

were observed among the desert dwellers in favour of various cultural practices like the preference for small family and higher age at marriage of boys and girls. This has indicated the positive sign for disapproving the age old customary practices and willingness to limit the family size, which may help in stabilising the growth of population in the years to come.

## **Education**

Even after 50 years of independence the level of education is low in the state of Rajasthan especially in the arid region of western Rajasthan. The level of literacy is even lower than that in Sri Lanka and Maldives. However, in the new education policy government of India is trying for 100 per cent literacy between the ages of 15 and 35 and adult education moving parallel to that. Education has been made free for all upto the age of fourteen and girls education upto secondary level and in some states it is even upto university level. Mere literacy may not serve any fruitful purpose unless a certain level of education is attained for better understanding of day to day life.

The arid areas of Rajasthan are characterised by sparse population with scattered settlement. The villages are, by and large, scattered far and wide and devoid of many community facilities. More than eight out of every ten persons still live in the rural areas with their problems and daily life saturated with customs. Not even three out of every ten persons are literate. A very few indepth studies have been carried out on socio cultural and economic aspects of literacy in this arid region. Saha (1993) and Malhotra (1977) reported the poor level of literacy in arid region of Rajasthan and compared with Kachchh district of Gujarat. The per cent literacy was, by and large, poor in arid Rajasthan compared to Rajasthan state as a whole and India. Within the arid zone, zonal variation was observed and the per cent literacy was quite poor in zone-I. The female literacy percentage is even more in Kachchh than the state of Rajasthan as whole. The poor literacy rate in various arid regions is associated with the prevalence of early marriage, traditional ideas and age old beliefs, lack of occupational diversities, poor infrastructure facilities, scattered settlements, etc. Due to early marriage and poor economic conditions farmers are unable to employ outside labours which force entire family labour to work in various agricultural operations irrespective of their age and sex. The female children usually look after the livestock and help in domestic activities.

Saha (1993) studied the extent of literacy, factors affecting education and people's aspiration for children education in six villages of Jalor district. The study revealed that the extent of education was very meagre. The socio-economic factors did not vary significantly with the level of literacy. The socio-economic factors bound with tradition and custom, distantly placed schools, lack of motivation and reluctance of parents were some of the factors causing poor level of literacy. The physical characteristics of the region is also one of the important factors causing poor level of literacy. The actual standard of education differed significantly with aspiration level. The female education was viewed only with the understanding of day to day activities.

## Nomads and Nomadism

Nomadism is one of the oldest form of adaptation to an arid environment although the exact population of nomads is not known. 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 it is culturally degenerated. Nomads have a stable social and economic organisation which has been influenced by the exigencies of nomadic existence. 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.

In the early sixties a good number of studies were carried out in this region on various nomadic groups - their social and economic organisation, rehabilitation measures of various nomadic groups, etc. (Bose *et al.*, 1964, 1968; Malhotra and Bose, 1963; Malhotra *et al.*, 1966; Mishra, 1965; Malhotra, 1971, 1977). Malhotra (1977) has synthesised the various studies reported on nomadic population as mentioned here. The resource use being the decisive factor of the pattern of their living, the nomadic groups of the arid zone may be broadly grouped into four categories, viz., (a) the pastoral nomads (*raikas, sindhis, parihars, billochs*, etc.), (b) the trading nomads (*banjaras, ghattiwala jogis and gawarieas*), (c) artisan nomads (*gadoliya lohars, sansis and sattias*), and (d) miscellaneous types of nomads (*nats, kalbeliya jogis*).

### Pastoral Nomads

The pastoral people inhabiting the Rajasthan desert have been carrying on livestock-breeding for generations and have contributed to the economy of the region by way of providing milk, cattle, ghee, wool, mutton, etc. A detailed survey (Malhotra *et al.*, 1966) conducted among the livestock-breeders of Anupgarh-Pugal region revealed that these nomads had been facing difficulties in grazing their livestock as there had been shrinkage in the extent of grazing lands owing to the extension of cultivation and also with the coming of the Indira Gandhi canal to this area. The inhabitants of the region are not completely nomadic, but have permanent homes and generally have parcels of land. Their nomadism is directly dependent on the necessities of their herds. The economy of these breeders largely dependent on the harvesting of the available water and the efficient use of extensive grazing lands available in the area, as the cultivated area is only 4 per cent of the total land surface.

Among the breeders, water-harvesting for livestock has been in vogue for generations. Having evolved a regional ecological association, the traditional livestock breeders of the region are maintaining it more profitably and effectively for raising livestock in the region. This old method, presently known as *toba*, provides water for the livestock.

It has been recommended (Malhotra *et al.*, 1966) that each household in the canal command area may be allotted 6.3 ha of land and a partial mechanisation of cultivation may be resorted to. Dairying may be introduced as an industry on scientific lines. Sheep rearing is the chief subsidiary

occupation in the region. At present, the sheep-owners have to travel long distances and their nomadism can be arrested by upgrading the short grass rangelands by reseeding these pastures with grasses, e.g., anjan (*Cenchrus ciliaris*) and dhaman (*Cenchrus setigerus*).

### Artisan Nomads

The second important category of nomads is constituted by those who specialise in certain trades, much-publicised *gadoliya lohars*, *sansis* and *sattias*. The *sattias* and the *sansis* carry on a limited trade in cattle and render veterinary services to the livestock of the villages on their routes.

The nomadic blacksmiths are locally called *gadoliya lohars*. They are one of the artisan nomads in the States of Rajasthan, Punjab and Madhya Pradesh. The traditional occupation of the *gadoliya lohars* is black-smithy and trade in cattle. They have developed symbiotic relationship with the sedentary farmers for supplying them with agricultural tools and implements.

The nomads move about in small kinship bands in their bullock-carts with their families. The nature of movement of different bands of these artisan nomads follow a regular cycle on regular monthly intervals (Malhotra *et al.*, 1966). They owe their allegiance to a definite demarcated area. In one band, the number varies from one to twelve families. During movements, they split themselves into smaller constituents which group and regroup at different places, depending upon their social and economic needs. Their movements are limited only to those places which are connected by roads or tracks on which their bullock-carts can go. Owing to the recent changes in economic and political set-up and the increasing means of communication, the *gadoliya lohars* are not as welcome in the villages now as 15 years ago. About one-fourth of them stated that there has been a definite decrease in their getting work as blacksmiths and in cattle trade in recent years. Ninety five per cent of the household surveys, therefore, desired to abandon nomadic life and lead a sedentary or semi-sedentary life, leading finally to sedentarization. Efforts made by the State Government of Rajasthan to sedentarize *gadoliya lohars* in colonies consisting of many households at one place, has achieved only a partial success. Most of them desired to sedentarize in small kinship groups consisting mostly of agnatic (related on the fathers side) and matrimonial relations. They desired sedentarization in a scattered fashion at a central place within the present area of their movement, locally called by them Chokla (Malhotra *et al.*, 1966).

### Trading Nomads

The third important category of nomads-designated as the trading nomads consist of the *banjaras*, *ghattiwala jogis* and *gawariyas*. The *gawariyas* mainly cater for the village women, selling beads, bangles and trinkets, and use the donkey as the transporting animal for a fixed area of movements. Like that of the *gawariyas*, the area of the *ghattiwala jogis* who manufacture and trade in grinding-wheels and earthen smoking pipes is also fixed. While some of these trading nomads are on the move perpetually, others lead a restricted settled life, taking to cultivation or working as daily-wage agricultural labourers during cultivation season. After the season, they start peddling their age-old wares again.

The *banjaras* are one of the most publicised trading group of nomads. They are organised into a distinct class in different territories (Malhotra and Bose, 1963). Each clan is divided into smaller groups called *tandas*. In each *tanda* there are six to twenty families. The doctrine of collective responsibility operates among the members of *tanda* (Malhotra and Bose, 1963). The families within the *tanda* are bound by the ties of kinship which give security to the members. The rights, obligations and expectancies towards one another are well established. The structure of family is patriarchal. Early marriage is very common among them. Every *tanda* has a headman who commands respect from other members. The main occupation of the *banjaras* is trading in salt.

With the onset of monsoon, the *banjaras* move towards saline basins where salt is manufactured. After rains, grass and water are available enroute for their animals. In addition to the salt trade, they sell Fuller's earth and onions in the remote villages of the desert tracts. These *banjaras* move towards the Gujarat state during the post-monsoon period. There, they get ready employment in the form of hauling of commodities, e.g., building materials and grains, by their bullocks.

The *banjaras* are economically backward and their standard of living is very poor. As a result of improved means of communication and the opening up to hitherto inaccessible areas to road transport, their traditional relationship of mutual dependence on the sedentary population has broken down. Their earnings have sufficiently declined and several of them are in perpetual debt. For sedentarizing *banjaras*, the *tanda* should be taken as one unit for settlement purposes in different villages.

The fourth class consists of miscellaneous nomads, e.g., the *nats* and *kalbeliya jogi* who earn their livelihood by showing acrobatics, jugglery and snake-charming at village fairs and to roadside gatherings. The technological, economic and political changes of the recent times have influenced the lives of population in this region. The sedentarisation of the nomadic way of life is a gradual and slow process. Though all-round development of the region may result in a spontaneous sedentarisation of the nomads, there is a possibility of social as well as cultural annihilation of the nomads. The question that haunts the ecologists and sociologists today is how to absorb these people within the framework of modern living and make them useful members of society by exploiting their natural aptitudes.

Government efforts made in the past have proved to be of limited success because of the short-sighted policies and unscientific approaches, which completely overlooked the social structures and existing institutions that could have gone a long way in keeping the nomads together. The experimental attempts of the state Government to rehabilitate the *gadoliya lohars* in Sojat, Khanpur, Barmer, Shiv, Beawar and Kishangarh are classic examples of random allotment of land and unfulfilled promises.

In the recent years, however, no studies have been carried out among the nomadic population and their problem of sedentarisation. After the availability of irrigation and various infra-

structural facilities there has been an enormous change in the socio-economic structure of desert dwellers which has also severely affected the resource use of nomadic population. It was also observed that the nomadic population are no longer interested in practising nomadic life, especially the pastoral nomads like *raikas* who want to leave their migratory life as they face lot of problems, while moving with livestock from one place to another. They now prefer to do agriculture with animal husbandry. In some villages efforts had also been made to settle down some miscellaneous nomadic groups and the huts were made at the outskirts of the village for their sedentarisation.

There is thus an urgent need to study the socio-economic and cultural organisation of various nomadic groups in the transitional phase of development with the advent of communication facilities even in the remote areas.

### **Agricultural Production**

The land-use pattern studies indicated that arid-region has traditionally been guided by conservation motives (Kalla, 1997) and in last 37 years (1956-94) there has been consistent increase in forest area, non-agricultural uses, and net area sown. On the other hand culturable waste, current and old fallows and barren and uncultivated area has registered a considerable decline. The depleted and degenerated landform, when used to cropped area would inevitably result in low and highly unstable production of crops.

In order to quantify the changes in cropping pattern over time in all 11 districts of arid zone of Rajasthan, 27 years (1956-82) data were used and analysed by employing rank correlation and concordance analysis. The value of concordance 'W' varied from 0.8239 (Jaisalmer) to 0.9429 (Nagaur district) which is highly significant at 1 per cent level. It indicates that there has been no major shift in area allocation to different crops (cropping pattern). Similarly, production data of six districts were also examined for any shift. The results revealed that concordance coefficient 'W' for different crops in arid districts ranged from 0.5994 (Jaisalmer) to 0.8632 (Churu) and was highly significant implying that there has not been any significant change in production of different crops.

The pattern of different crops in western Rajasthan was examined by measuring the growth trends in the last 24 years (1954-77). The 24 years data were divided into two phases - Phase I (1954-70) and Phase II (1970-77). Mruthunjaya *et al.* (1983) reported that pearl millet has registered a positive and significant growth rate of 1.22 per cent in Phase I while the growth rate declined by 2.32 per cent per annum in Phase II. Sorghum showed highly significant negative growth rates in the area during both the periods. Kharif pulses registered positive and significant growth rates of 0.51 per cent and 1.52 per cent during Phase I and Phase II, respectively. The study of cropping pattern changes showed that the joint share of pearl millet and sorghum which was about 54 per cent in Phase I has dropped to 37 per cent in Phase II. Kharif pulses marginally increased from 19 per cent in Phase I to 23 per cent in Phase II. There were significant gains in

mean yields of only coarse grain in Phase II. The average yields of pearl millet ( $240 \text{ kg ha}^{-1}$ ) and sorghum ( $165 \text{ kg ha}^{-1}$ ) in Phase II were significantly higher than those of Phase I ( $181$  and  $110 \text{ kg ha}^{-1}$ , respectively). Also the coefficient of variation of yields of all the crops were higher in Phase II as compared to Phase I. In case of pearl millet, the coefficient of variation increased from 38 per cent in Phase I to 57 per cent in Phase II and from 21 to 40 per cent in case of kharif pulses.

Crop yield and weather parameters were also studied. Multiple regression equations were worked out between pearl millet yield as dependent variable and weather parameters as independent variables in the three stages of pearl millet crop (i) vegetative, (ii) panicle development, and (iii) grain filling phase of Jodhpur district. The study revealed that 38 per cent variation in yield were explained at vegetative growth, 27 per cent at the stage of panicle development and 79 per cent at the time of grain filling stage of pearl millet crop. Coefficient of determination was found to be significant only in case of grain filling. In grain filling stage the estimated yield by the regression method is in close agreement of actual value. The weather elements such as rainfall and maximum humidity were found useful for forecasting the yield of pearl millet crop in grain filling phase. Similarly, study was also conducted for clusterbean, moth bean and mung bean crops at pre-flowering, flowering and post-flowering stages in Jodhpur district. The study revealed that forecasting of these crops is possible only at the time of flowering stage.

Anantha Ram and Dave (1988) analysed the trend of sesame crop in arid zone of Rajasthan and found that area and production of sesame in the triennium ending 1983-84 stood at 2.09 lakh hectare and 0.16 lakh tonnes, respectively. Because of extremely low yield of sesame (around  $80 \text{ kg ha}^{-1}$ ) since 1968-69, both area and production has registered a declining trend of the order of 23 and 30 per cent, respectively.

Vyas (1989) studied the farm size, resource productivity and allocation on dryland farms in Nagaur district of western Rajasthan by collecting primary data from 146 small (0-4 ha), 107 medium (4-8 ha) and 120 large ( $>8$  ha) farmers for a period of 4 years (1976-80). The results revealed that in all four years pearl millet, sesame and gram were considered to be relatively less risky crops. They could thus be considered in crop-plan in arid zone. The groundnut, mung bean and clusterbean form another group of crop-mix, characterised by high value response as well as high instability. The result of farm-level production functions revealed that in short-run input-output relationship of almost all the farm crop activities followed by log-linear specification and generated constant returns to scale in dryland agriculture. Labour and tractor use were conspicuous by their positive and significant effect on all farm size groups. The contribution to fixed capital assets was positive but significant for large farmers. Marginal value productivity analysis led to inescapable conclusion that all the components of input-mix excepting labour need additive adjustment for enhancement of value productivity of crop output-mix on dryland farms.

Vyas (1988) reported that "best-fit" production functions conforming to log-linear in milk production process. The variances explained in milk production function included fodder, feeds,

human labour, fixed costs. It is also revealed that in a given good year with assured fodder supply, the milk production will not be affected by seasonality.

Impact of irrigation has been found in many activities in rural sector. Before the introduction of irrigation in arid zone, the animal husbandry was the main occupation and crop cultivation was always given a secondary importance. But the change has been observed after introduction of irrigation system in the region. Farmers are now cultivating a number of crops like pearl millet, sesame, pulses, wheat, mustard, chillies, cumin, etc.

Vyas, and Kalla (1972) studied the economics of commercial crops in Borunda, tubewell command area in arid zone of Rajasthan. The study revealed that due to the availability of water, cropping pattern has changed from pearl millet monoculture programme to multi-activity crop programme where commercial crops like cumin, chillies and rapeseed have been adopted by the farmers. The cost structure revealed that cost per hectare was higher for chillies and hybrid pearl millet; it was lower in cumin and rapeseed as compared to wheat. The value of output at current prices, by hybrid pearl millet (seed), chillies and cumin had higher returns ha<sup>-1</sup>.

Diwakar and Mruthyunjaya (1985) reported that difference in the power costs as a result of variation in the source of power was noticed under different water lifting devices, viz., electric-dug-cum bore well; diesel-dug-cum bore well, tubewell and open well. The open well was more important for bullock operated devices like *charas* and *rahat*. It was observed that bullock power charges varied from Rs. 325.00 under *charas* to only Rs. 47.00 under electric-dug-cum bore well to irrigate one hectare of land. The average annual running hours were lower for animal driven devices. However, due to more number of running hours in a year under modern devices, the working cost per hour of operation was higher in case of animal power operated devices.

Comparative economics of tractor and bullock power was carried out in Luni block of Jodhpur district. The study revealed that 51.8 per cent of farmers were keeping additional pair of bullock to supplement the field operations with the tractor. The percentage allocation of area to different crops to the tractor were pearl millet 46.34, sorghum 14.86, mung bean 5.94, moth bean 2.45, clusterbean 8.79 and sesame 21.62. Investment of capital on different size of holding has a negative correlation with livestock, building and bullock drawn implements.

Extent of agricultural mechanisation in arid Rajasthan with particular reference to tractors and pumps revealed that proportion of oil engine operated pumpsets declined from 88 per cent in 1961 to 48 per cent in 1977 due to electrification. Similarly, the proportion of Government owned tractors has declined from 13 per cent in 1961 to 3 per cent in 1977. At the same time private tractors increased from 22 per cent in 1961 to 173 per cent in 1977. The study inferred that the introduction of more tractors and pumps in agricultural system does not appear to substitute human resources.

Economic analysis of arable farming system from nine crop combinations, revealed that the mixed cropping, except castor did not give favourable results. The sole cropping yielded better



results. The average of total variable costs and returns of various crop components of four years (1990-91 to 1993-94) revealed that maximum return of Rs. 3048 over the variable cost, was obtained by cowpea followed by pearl millet (Rs. 1584), mung bean (Rs.1534) clusterbean (Rs. 1490). The returns obtained in these three crops are almost at par. The least return was obtained from moth bean crop (Rs. 83/ha). It was noted that mixed crop and the pure crop of castor gave negative returns.

Economic appraisal of pomegranate orchard of the institute revealed that high values of Net-Present-Value (Rs. 105331 ha<sup>-1</sup>), B-C ratio (2.74), internal rate of return (IRR) at 14 per cent discount rate and less pay back period (4 years) and annuity value Rs. 20193 ha<sup>-1</sup>, indicating thereby that pomegranate cultivation in western Rajasthan is an economically viable proposition if water is available for irrigation.

Long-term economic viability and employment generations potential of ber nursery, based on the data of five nurseries around Jodhpur, revealed that the benefit cost (B-C) ratio ranged from 1.88 in 1987 to 1.14 in 1991. The long term viability of ber nursery enterprise depends on extension of the technology to new areas and strong linkages in marketing, storage and processing of ber fruits. Further, raising of ber seedlings in nursery generated 164 mandays of employment in one season.

Economic evaluation of five integrated farming systems, viz., agroforestry, agro-horticulture, farm forestry, agri-pastoral and silvi-pastrol system yielded positive returns over viable cost to the tune of Rs. 3091 and Rs. 2146 ha<sup>-1</sup>, respectively. The remaining three system gave negative returns.

Anantha Ram (1985) reported that net income per house hold from livestock by using common property resources varied between Rs. 4202 to Rs. 5653 in different ecological zones. From the crop activities the variation was between Rs. 664 and Rs. 5822. The area receiving rainfall less than 400 mm are predominantly suited to livestock rather than crop farming. The results further revealed that net return per rupee value of home produced and purchased fodder and grass amounted to Rs. 3 in Zone-I, Rs. 2 in Zone-II and Rs. 1.50 in Zone-III. The margin of profit due to freely grazed grass worked out Rs. 2.70, Rs. 1.03 and Re. 0.66 in ecological Zone I, II, III, respectively. The household collected 66, 42 and 25 per cent of their fuel wood requirement from the village common property resources free of cost in zone I, II and III, respectively. It has been further revealed that the area under common property resources declined by 20 per cent in the whole zone and livestock population increased by 30 per cent leading to further degradation of this resource. The study further revealed that forage drawn from common grazing lands per household ranged between 36 to 44 t per annum for medium and big farms compared to small farms (8.6 t per annum). The cultivated fodder and crop residues supplied only 14.5 per cent of the total forage/fodder demands of livestock in selected household. The per hectare average yield of top feeds on private holdings was 30 kg with substantial yields from bordi (*Z. nummularia*, 53 kg ha<sup>-1</sup>). Widespread use of tractors for cultivation and indiscriminate

cutting of trees and shrubs from CPRs have resulted in lowered supply to top feeds from private holdings and CPRs. The average non-commercial fuel consumption per household was 4.8 per annum. Fuelwood (2.76 t) dung cake (1.34 t) and crop waste (0.076 t) accounted 58, 28 and 14 per cent, respectively was used in cooking food in the sample households. However, in terms of energy, the actual per capita energy from non-commercial fuel was short by 22 per cent as compared to requirement under country side conditions, indicating thereby the inefficient use of fuels leading to the diversion of valuable cowdung to hearths.

## Forestry

Kalla *et al.* (1975) measured the economical viability of tree species (*Acacia tortilis*, *Azadirachta indica*, *Prosopis juliflora* and *Albizia lebbek*) suitable for afforestation of degenerated lands. The cost and returns structure revealed that high benefit-cost ratio was observed in *Prosopis juliflora* (1071:1) and lowest in *Azadirachta indica* (0.11:1). Some of the xerophytic plants which commonly grow in arid zone have significant economic potential. The trees and plants like *Tumba*, *Matira*, *Niras*, *Rohira*, *Khejri*, *Sares Gugal*, *Kumat* and *Phog* can contribute significantly to fill the vacuum in production of agro-industrial goods. The comparison of net annual B-C ratio indicated the economic justification of growing *Tumba* (1.03:1) and *Matira* (4.42:1) for oil, *Niras* (3.76:1) for fibre, *Rohira* (0.35:1), *Khejri* (0.46:1) sares (0.65:1) for timber, *Gugal* (0.18:1) and *Kumat* (0.13:1) for gums and resin and *Phog* (0.37:1) for coal manufacturing on commercial lines.

Quantitative prediction of fuel yield potentiality of different tree species is *sine-qua-non* of any afforestation strategy in arid areas (Kalla, 1977). Following step-wise or (step) regression programme a fuel yield production model was run for five promising fuel species. The result conclusively revealed that all the usual morphological variates like collar diameter, diameter at breast height, length of clear bole and height of tree are not simultaneously and equally effective in generating efficient prediction. Kalla *et al.* (1978) studied the techno-economic felling cycles for selected energy plantation species, viz., *Acacia tortilis*, *Albizia lebbek*, *Acacia nilotica* and *Azadirachta indica* in the arid areas of western Rajasthan by employing regression techniques

Kalla *et al.* (1978) reported that most important manifestation of the resource depletion process in arid region use is the indiscriminate use of phytomass for fuel requirements. The study revealed that arid region on the whole has a potential of producing 19 million tonnes of dung annually from which substantial effective energy in multiple forms can be generated. The slurry as the by-product of such technology can add 3.5 million tonnes of organic matter and 0.02 million tonnes of the essential elements. The study also revealed that implementation of such a plan should involve over 3800 million rupees spread over 15 years span.

Gupta *et al.* (1974) established the order of relative importance of morphological variates for their contribution to forage yield performance of *Dichanthium annulatum* Forsk. (Stapf) grass.

The study revealed that number of tillers and basal diameter ranked first and last, respectively. There was difference of ordering for plant height and crown diameter, in the two approaches. The study shows that whenever coefficient of determination fails to bring out strong order of priority in establishing the relative contribution of independent variates, value of coefficient of 'B' proves to be useful criterion to find out the order of importance for attempting finally to predict forage yields on large scale.

Kalla and Bhati (1985) studied the productivity of pastures in terms of four alternative objectives, viz., seed production, sheep grazing, cattle grazing and mixed grazing on three alternative pasture management system, viz., natural pasture, with soil conservation practices sown pasture with improved grasses. The results revealed that sown pasture had high net present value (NPV) (Rs. 35821 ha<sup>-1</sup>), DC-BC (1.08), IRR (21%) and less pay back period (13 years) indicating its economic soundness. The results revealed that the lands put to pasture production irrespective of any system followed, are economically viable. The results also pointed out that improved technology of pasture raising in its present form is not cost-effective and it can generate comparable long returns only if the pasture are grown near economic fodder demand points. Alternatively managing pastures for seed collection will ensure high degree of economic viability.

## **Livestock**

The livestock sector is of considerable economic significance for the arid districts of western Rajasthan. However, the observed increase in livestock productivity over the years is mere reflection of the increased number of livestock.

Kalla and Gupta (1978) studied the impact of growth of sheep population. The quadratic equation was most efficient in describing the sheep population growth in the region. Further, the results in demand-supply imbalances revealed a fierce competition for forage from the other livestock population.

The study on impact of sheep husbandry programme in Operational Research Project (ORP), lab to land programme in selected villages and asset structure distribution revealed that capital investment in creating assets for beneficiaries was primarily concentrated (99 per cent) in the form of land, livestock and buildings. For non-beneficiaries the assets structure was more evenly distributed for land, implements, buildings, livestock and water resources accounting for over 81 per cent of the total per family capital. The study conclusively revealed that the impact of loan and subsidies provided by Govt. agencies for sheep raisers was significant in maintaining of herds, generating self employment and better utilisation of wastelands.

The economics of sheep production arid management in the three zones of arid Rajasthan revealed that sheep raising in the region was positively related to the size of holding. The study of costs and returns from sheep enterprise revealed that the enterprise was highly profitable in Zone

I, profitable in Zone II and unprofitable in Zone III. A flock of 100 sheep in Zones I and II was found to generate annual net income of Rs. 2319 and Rs. 1532, respectively. The employment opportunity generated from a flock of 100 sheep in Zones I, II and III was found to be 379, 399 and 503 mandays per year.

The performance of livestock productivity on arid pasture lands was studied based on the performance of livestock productivity on arid pasture lands. Data on costs and returns for a period of six year (1978-83) from a experiment at sewan grass pasture plot maintained with 20 cows of Tharparkar breed under deferred rotational grazing system in arid conditions of Jaisalmer district were analysed. The figures of net present value came out to be of order of Rs. 9163 at 14 per cent discount rates. Benefit cost ratio remained positive and profitable. Similarly, annuity value was Rs. 2356 per ha. Internal rate of return worked out to be 31 per cent.

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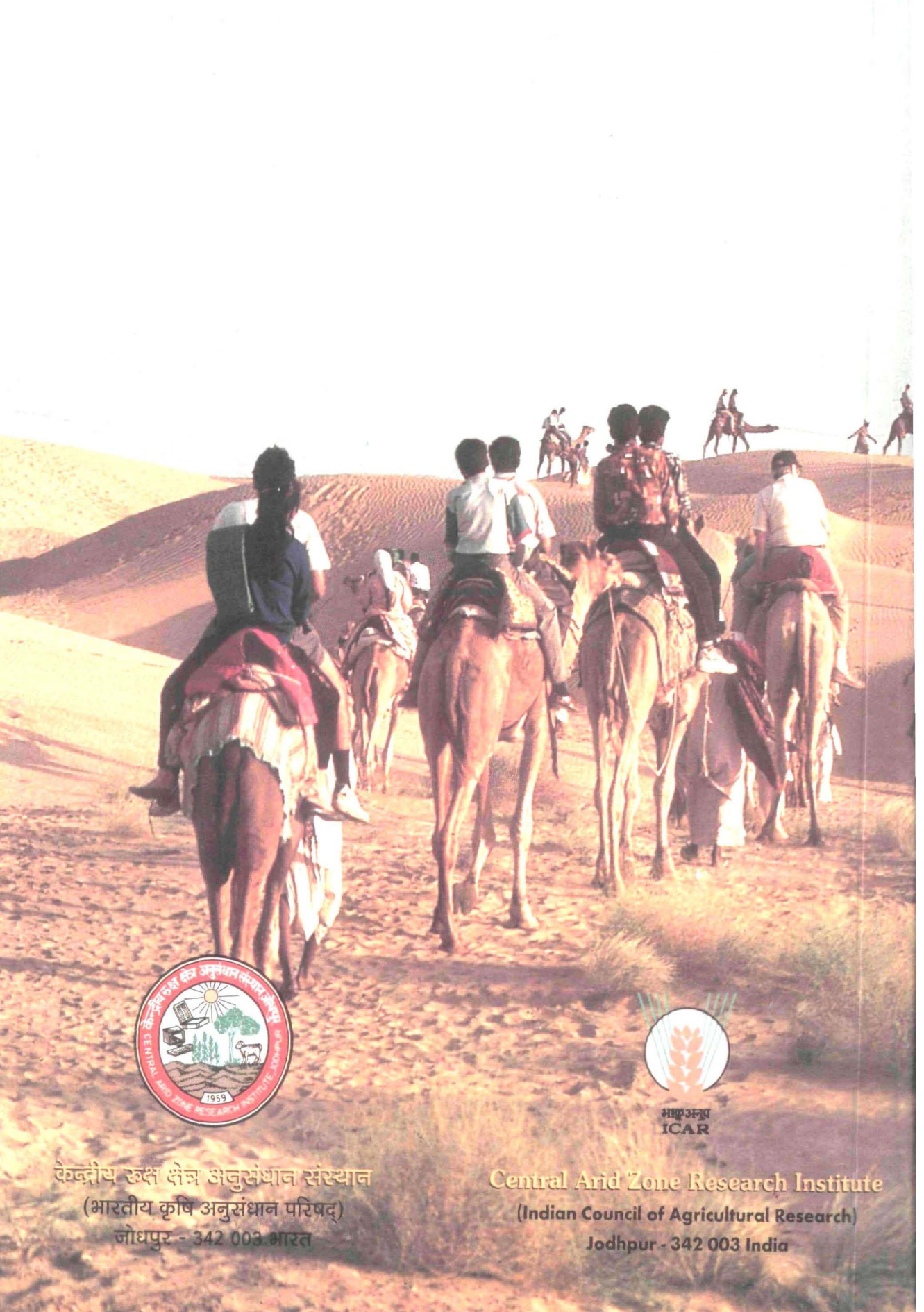
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