

Integrated Water Mangement

Concepts of Rainfed Agriculture

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February,2007

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I. History of Rainfed Agriculture

A. *Pre-Independence period*

From time immemorial, the chief form of agriculture in the dryland tracts of India was cultivation of drought resistant crops *viz.*, millets for food and fodder. It used to be a gamble with rainfall. During good rainfall years, the hardships of farmers seem to have been mitigated, as surplus grain and fodder were available. But, as water is the most important single factor of crop production, the inadequacy (200-800 mm/year) and extremely uncertainty (cv: 60-70%) of rainfall often caused partial or complete failure of crops leading to periodic food scarcities and famines. Drought was a frequent phenomenon. These factors made the economic life of the dryland cultivator extremely difficult and insecure. To address these issues, the Government of India appointed the First Famine Commission in 1880. The Commission recommended creation of protective irrigation projects in the dry tracts. However, irrigation in scarcity tracts of Madras, Bombay, Mysore and Hyderabad provinces was possible only to a limited extent. Thus, most of the scarcity tracts of south and some in north India had to depend on rainfall for crop production (Kanitkar *et al.*, 1968).

The first systematic and scientific approach to the problem of dry farming was attempted only in 1923 to eradicate drought related problems. Dr H.H.Mann, the then Director of Agriculture, in consultation with Shri C.V.Mehta, the then Minister for Agriculture, Bombay Province, initiated research on dry farming on a small plot at Manjari Farm, near Pune, under the leadership of Shri V.A.Tamhane, the then Soil Physicist to the Government of Bombay. After the transfer of Shri Tamhane in 1926, Dr N.V.Kanitkar took up the responsibility.

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The Government of India constituted Royal Commission on Agriculture in 1928. The Commission revived the Department of Agriculture of the Government of India, and simultaneously founded the Departments of Agriculture in all the provinces. The Departments concentrated more on the best performing crops, but neglected millets and other crops of the rainfed areas. A few years of study at Manjari Farm led to the conclusion that the problem of cultivation of dryland crops was vast in extent and complex in nature. It required simultaneous in-depth research on different aspects such as conservation/collection of excess rainwater, soil characteristics and water requirements of crop plant. Dr Kanitkar during his visit to the United States of America in 1930-31, studied the methods and progress of their research on dryland farming. Based on his impressions, he proposed a comprehensive programme to find out solution to the dryland problems. Drs H.H.Mann and W. Burns, the then Directors of Agriculture, Government of Bombay, recommended the scheme to the Imperial (now Indian) Council of Agricultural Research (ICAR) for financial support. Convinced of the recommendation, the ICAR approved the Bombay Scheme of Research on Dry Farming and sanctioned the necessary funds. Later, the ICAR extended financial support to similar such schemes for Madras, Hyderabad and Punjab provinces. The Bombay Scheme was started in 1933 at Sholapur and Bijapur - the centers of famine tract. The work was started in 1934 in Madras at Hagari (near Bellary) and in Hyderabad State at Raichur. The Punjab Scheme was carried out from 1935 at Rohtak (Kanitkar, *et al.*, 1968).

Systematic work was planned on crop production aspects under dryland conditions. Detailed analysis of climate, mainly rainfall, was done to get information on relationship of rainfall with crop production. Long-term record of rainfall for 50-80 years showed that all the scheme centers received below normal rainfall fifty per cent of the normal. It was also realized that rainfall was not only scanty but, was erratic too. The dry spells extended from 3 to more than 8 weeks during the rainy seasons. It was thus felt that for good crop production, conservation of soil moisture and minimization of surface evaporation comprised the most suitable interventions.

Soil Loss and Moisture Conservation

In the Deccan Plateau, under normal cultivation, soil slope, low rate of infiltration and high intensity rainfall causes runoff. It was between 12 and 20 per cent with a concurrent upper soil loss of 10-14 t/ha/year due to erosion. During the rainy season, in the cropped fields, about 10 per cent of the rainfall was lost as runoff from black, and about 25 per cent from red soils. It was realized that the land needed some kind of vegetal cover to minimize the runoff and soil loss. *Kharif* (rainy season) crops such as pearl millet (*Pennisetum glaucum*) and pigeonpea (*Cajanus cajan*) provided cover to the soil, thus resulting in considerable reduction in runoff and soil loss. Deep ploughing, soil stirring and mulching helped to conserve soil moisture. Fallowing was also useful. Good yields were realized from sowing in wider rows with low seed rates of selected crop varieties (Umrani, 1999).

Development of Dry Farming Principles / Practices

A committee of experts while in coordinating and documenting the progress of all the five schemes between 1933 and 1943, summarized useful recommendations on different cultural and manurial methods for preventing runoff and erosion, efficient utilization of

soil moisture for better crop production. The practices, thus developed were given for different dry tracts in the form of principles of dry farming applicable to Indian conditions and suggestions were made for future line of research and extension. The packages of practices were popularly known as Bombay, Madras and Hyderabad Dry Farming Practices. The recommended practices constituted the following:

- constructing contour bunds as the basic and essential treatment,
- occasional deep ploughing of lands, once in 3 years,
- repeated shallow cultivation of soils (4 to 5 inter-cultivations) to remove weed and conserve moisture during the rainy season, particularly for *rabi* (post-rainy) season sorghum (*Sorghum bicolor*),
- adding moderate quantities of Farm Yard Manure to maintain the fertility and physical conditions of eroded soil,
- sowing in wider rows (45 cm row spacing for sorghum) with lower seed rate,
- adopting mixed cropping / crop rotations wherever possible,
- fallowing a part of the holding every year.

Unfortunately, the returns from the adoption of these technologies resulted in lower yields (40 to 100 kg grain/ha) probably due to: discouragement to use inputs and non-availability of proper biological material. Thus up to independence, the dryland agricultural research and development made no significant progress.

B. Post-Independence period

Even after independence, vulnerability of dryland agriculture to droughts continued to haunt the country with ever increasing food shortages. During the 1950s, the cropping systems were need-based mostly for subsistence level. The dryland research was also confined to long duration crops. Hence efforts were intensified to improve productivity and stability from rainfed areas. The ICAR focussed its attention in dryland regions on soil conservation measures by establishing the Central Soil and Water Conservation Research and Training Institute at Dehra Dun in 1954. Simultaneously, eight Soil Conservation Centres were also set up at Dehra Dun, Chandigarh, Agra, Kota, Bellary, Hyderabad, Vasad and Ootacamund. Another programme on 'Soil Conservation in the Catchments of River Valley Projects' was launched in 1962. It was later realized that this project focussed more on prevention of siltation of reservoirs and controlling floods, and gave secondary importance to agronomic aspects (Randhawa, 1983).

In spite of development of major and minor irrigation projects and so also improvement in the availability of inputs like seeds, fertilizers, electricity and the like since India's independence, food shortages continued, and gradually food grain imports reached 10 million tonnes by 1966. At this juncture, with international collaboration, Indian agricultural scientists developed high yielding varieties / hybrids of major crops like wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum typhoides*) were introduced to the farmers during the period from early to late sixties.

C. Green Revolution

The HYVs programme within a short span of time brought a break-through in productivity and production, mainly of wheat (wheat Revolution, 1968). The growth rate

in food production was above the growth rate of population and this era was termed as Green Revolution (Katyal, 1995; Paul, 1997; Vishnumurthy, 1999).

In the mid sixties, the Green Revolution acted as a boon. However, this brought an alarming disparity between productivity of irrigated and rainfed agriculture. The socio-economic imbalance led to a serious thinking on inducting an in-depth research programme to stabilize the performance of the recently introduced short duration hybrids of sorghum (CSH-1) and pearl millet (HB-1) in rainfed areas, and to moderate the adverse effects of drought on their productivity. The droughts of 1965 and 1966 further aggravated the problems of dryland research.

Keeping in view these continuing problems, the ICAR formulated an exhaustive programme on dryland agricultural research. Thus, the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) was launched in 1970 with the support from Canadian International Development Agency through an instrument of bilateral collaboration signed between the Governments of India and Canada. This cooperation lasted till 1987. The unique feature of this project, was its reliance on multi-disciplinary approach in identifying and analyzing the constraints limiting crop yields in vast semi-arid areas and seasonally dry areas. AICRPDA activities were spread over 23 Cooperating Centres (now 25) across contrasting soil and climatic conditions of the country. The research efforts made it possible to double the dryland crop productivity through adoption of soil and water conservation practices, improved varieties, good sowing methods, weed control and fertilizer use. The Consultative Group on International Agricultural Research had established the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad in 1972. The Krishi Vigyana Kendras (KVKs) were initiated in 1977 to demonstrate proven technologies in farmers' fields in most of the districts. The dryland agricultural research was further strengthened with the establishment of the All India Coordinated Research Project on Agro-meteorology (AICRPAM) in 1983 at Hyderabad with 12 Cooperating Centres (now 25). The modest beginning of AICRPDA resulted into establishment of a full-fledged research organization – the Central Research Institute for Dryland Agriculture (CRIDA) at Hyderabad in 1985. The main purpose of this institute was to focus on lead research in dryland agriculture, leaving location specific problems and their solutions to AICRPDA and AICRPAM. The present mandate of CRIDA is (Anon., 2005a):

- to undertake basic and applied research that will contribute to the development of strategies for sustainable farming systems in the rainfed areas,
- to act as a repository of information on rainfed agriculture in the country,
- to provide leadership and co-ordinate network research with state agricultural universities for generating location-specific technologies for rainfed areas,
- to act as a center for training in research methodologies in the fields basic to management of rainfed-farming systems,
- to collaborate with relevant national and international agencies in achieving the above objectives, and
- to provide consultancy.

In order to reduce the regional imbalances in agriculture, the ICAR set up the National Agricultural Research Project in 1987 to build up infrastructure and to strengthen the zonal research stations under SAUs for conducting location specific research.

The impact of accelerated growth rate in agricultural production did not last very long. Almost since the 1990s, there has been a stagnation or decline in the productivity and production of many crops in the country. In order to address them, the Government of India has been initiating several programmes to reverse the declining trend in agricultural production. However, Indian agriculture has taken the food grain production from 51 million in the early fifties to 206 million tonnes in 2000 AD (Anon., 2005b).

While differentiating between Rainfed and Dryland farming, it has been resolved that Rainfed farming generally refers to agriculture which is solely dependent on rainwater and does not receive any additional water at any stage of the crop through irrigation. In other words, rainfed agriculture is synonymous to non-irrigated agriculture. It includes rainfed wetlands (N.E. status) as well as rainfed/drylands. Drylands are therefore part of rainfed lands. Drylands are defined as the areas where the minimum annual and average rainfall for producing a crop is estimated to be as low as 500 mm. This range of rainfall is not sufficient for the crop plants to grow and very often they show moisture-stress symptoms as most of the growing period evapo-transpiration exceeds moisture absorption in dryland areas. Such areas are called dryland areas and cultivation of field crops in such areas is called Dryland farming. Drylands are scattered throughout the country except high rainfall states.

II. Magnitude of problems of rainfed agriculture

The land degradation in rainfed areas has resulted from climatic variations and unplanned over-exploitation of natural resources by human activities, and increasing pressure of human and livestock population. It has become unavoidable to cultivate even the marginal lands. The pasturelands are degraded due to overgrazing caused by both increase in livestock population and decrease in area under grazing due to encroachment for cultivation and urbanization. As a result more and more forests are being used for grazing purpose. At present nearly 70% of rainfed area is affected by wind erosion and sand deposition.

Out of an estimated 142 million ha net cultivated area, about 86 million ha (60%) is rainfed. Even after reaching the full irrigation potential, nearly 50% of the cultivated area will remain rainfed (Paroda, 1997). At present about 60% of India's population as also 60% of livestock depends on agriculture. By 2025 AD, it is likely to reduce to 40% due to continued migration of rural people to semi urban/urban areas out of the projected population of 1.5 billion. The average land holding is likely to be 0.08 ha from the present 0.15 ha, which would be uneconomical for farming. Rainfed farmers are economically weak with little ability to withstand risk. Out of the 97 million farm holdings, 76 per cent are small (<2 ha) and marginal, cultivating only 29 per cent of the total arable land. The holdings are unconsolidated and scattered (Sharma and Singh, 2006).

Rainfed area covers 218 districts in the states of Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. Physiographically the rainfed region encompasses the desert terrain of Rajasthan in the northwest, the plateau region of central India, the alluvial plains of the Ganga-Yamuna river basin, the central highlands of Gujarat, Maharashtra, Madhya Pradesh and Chhattisgarh, the rain shadow region of Deccan in Maharashtra, the

Deccan plateau in Andhra Pradesh and the Tamil Nadu highlands (Singh *et al.*, 2000). In this belt, cultivation of coarse cereals (91%), pulses (91%), oilseeds (80%) and cotton (65%) predominate (Sharma and Singh, 2006). Besides, farmers' dependence is very high on livestock as an alternative source of income, apart from arable cropping. Thus, rainfed agriculture would continue to play a crucial role in the Indian economy and food security for a long period.

III. Delineating Criteria of Rainfed farming

United Nations Economic and Social Commission for Asia and the Pacific distinguished dryland agriculture mainly into two categories, dryland farming and rainfed farming based on the criteria given in Table 1.

Table1. Dryland vs Rainfed Farming

Constituent	Dryland Farming	Rainfed Farming
Rainfall (mm)	< 800	> 800
Moisture availability to the crops	Shortage	Enough
Growing season (days)	< 200	> 200
Growing regions	Arid and semi arid, uplands of sub humid and humid regions	Humid and sub humid regions
Cropping system	Single crop or Intercropping	Intercropping or double cropping
Constraints	Wind and water erosion	Water erosion

Rainfed areas can broadly be classified into the following rainfall zones (Table 2).

Table 2. Classification of rainfall zones in India

Rainfall (mm)	Zone	Net sown area (%)	Rainfall
<500	Arid	16	Very low
500-750	Semi-arid	17	Low
750-1100	Dry sub-humid	35	Medium
1100-1400	Moist sub-humid	24	High
>1400	Humid mountains	8	Very high

Source: Ramakrishna, 1997; Paul, 1997.

IV. Assessment of Natural Resources

A. Soils

Rainfed soils are generally of poor quality (low fertility, high erodibility, fragile, shallow and susceptible to loss of physical integrity). These have very weak buffering and resilience capacity. The soils suffer from excess of salts (saline-alkali soils) in arid and semi-arid areas and acids (acid soils) in sub-humid and humid areas. Micronutrients and ameliorants (mainly lime) are deficient and need supplementation periodically. The soils are mostly coarse textured, highly degraded with low water retentive capacity, multiple nutrient deficiencies, and thus are not conducive for intensive cropping.

Major soil types

The principal factors of soil formation are nature of parent material, climate, vegetation, soil organisms and topography, which are the same both in dry as well as in humid regions. However, in arid regions, physical weathering predominates soil formation. Erosion and re-deposition are the most important soil forming processes in arid regions. Rainfall is an important factor which affects the type and predominant properties of soils. Soils developed in the semi-arid areas of Deccan Plateau are mainly Vertisols (black soils) and Alfisols (red and related soils), while in the arid zone of Rajasthan, they are Arid soils and Entisols. Inceptisols and Mollisols occur in humid and sub-humid regions (Srinivas *et al.*, 1999).

A variety of soils occur in our country as detailed in Table 3.

Table 3. Major soil orders in India and their area

Soil order	Region/State	Area	
		Actual (m.ha)	(%)
Entisols	Rajasthan, Gujarat, Haryana	80.1	24.4
Inceptisols	Uttar Pradesh	95.8	29.1
Vertisols	Kovilpatti (T.N.), Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh	26.3	8.02
Aridisols	Haryana, West Rajasthan, Gujarat, Anantapur (A.P.)	14.6	4.45
Alfisols	Andhra Pradesh, Jhansi (U.P.), Tamil Nadu, Karnataka	79.7	24.3
Oxisols	Ranchi (Jharkhand), Bhubaneswar (Orissa)	0.3	0.1
Mollisols		8.0	2.4
Ultisols		0.8	0.2
Non-classified soils		23.1	7.0
Total		328.7	100.0

Source: Prasad and Biswas (1999); Srinivas *et al.*, (1999).

In dryland regions, nearly 30 per cent of soils are covered by Alfisols and associated soils, 35% by Vertisols and associated soils (having vertic properties) and 10 per cent by Entisols of the alluvial areas. Most of the Alfisols are sandy loams with a sub-soil alluvial layer of clay, less water retentive and prone to drought. The Vertisols are deep (15-240 cm) with a clay content of 30-70% and rich in bases. The clay types are smectite, montmorillonite and beidellite. The soils have high water holding capacity, frequently fertile and less drought prone.

Characteristics of Dryland soils

Dryland soils are generally low in organic matter and alkaline to slightly acidic in reaction in the surface have calcium carbonate (CaCO₃) accumulation in the upper 150 cm

soil layer, weak to moderate profile development, coarse to medium texture and having low biological activity. Nearly two-thirds of India's land mass has more than 3% slope and is highly undulating. The top soil shows many textural groups like loamy sand, sandy loam, loam, silt loam to clay loam. The soils are predominantly coarse textured and hence retain less water and nutrients. Crops grown on them are prone to drought and nutrient deficiencies. The low organic matter content is due to sparse vegetation producing little residues. The top soil when eroded, is devoid of organic matter, thus resulting in deficiencies of several nutrients. Removal of vegetation, intensive agriculture, uncontrolled and excessive grazing, and large unprotected fields devoid of protective vegetation are known to cause wind erosion.

The inherent properties of dryland soils lead to degradative processes in rainfed semi-arid tropics, impose the following constraints for successful crop production (Virmani *et al.*, 1991) :

- much reduced permeability,
- poor or restricted root development,
- tillage and seeding problems,
- poor seedling establishment,
- uneven soil wetting,
- salinity and shallow water table and
- poor soil fertility.

B. Climatic classification

Climate is one of the major factors influencing crop growth. Favourable weather is essential for good harvests. Weather abnormalities like cyclones, droughts, hailstorms, frost, high winds, extreme temperature and insufficient photosynthetic radiation etc., may generally lead to very low or even no yields. Hence, characterization of agro climates is a pre-requisite to know the potential of a region, especially under dryland conditions for improving and stabilizing the productivity (Rao *et al.*, 1999).

i) Rainfall

The India Meteorological Department has recognized four rainfall seasons (Victor *et al.*, 1992) as:

South-west Monsoon (June to September)

Rainfall received during this season is the most important one as our agricultural production is mainly dependent upon its amount and distribution.

Though the advancement of monsoon from the Kerala coast to Jammu and Kashmir region is a regular phenomenon. However, great annual variability is observed in its onset, withdrawal and distribution in all parts of the country. The onset generally occurs on the 1st of June over Kerala coast and advances steadily further into the whole country by the end of June, except in extreme parts of western Rajasthan where it enters by mid July. Barring Kashmir in the extreme north and parts of Tamil Nadu, most of the annual rainfall occurs during the south-west monsoon season. The withdrawal of monsoon begins by 1st of September from west Rajasthan, by 1st October from western India upto

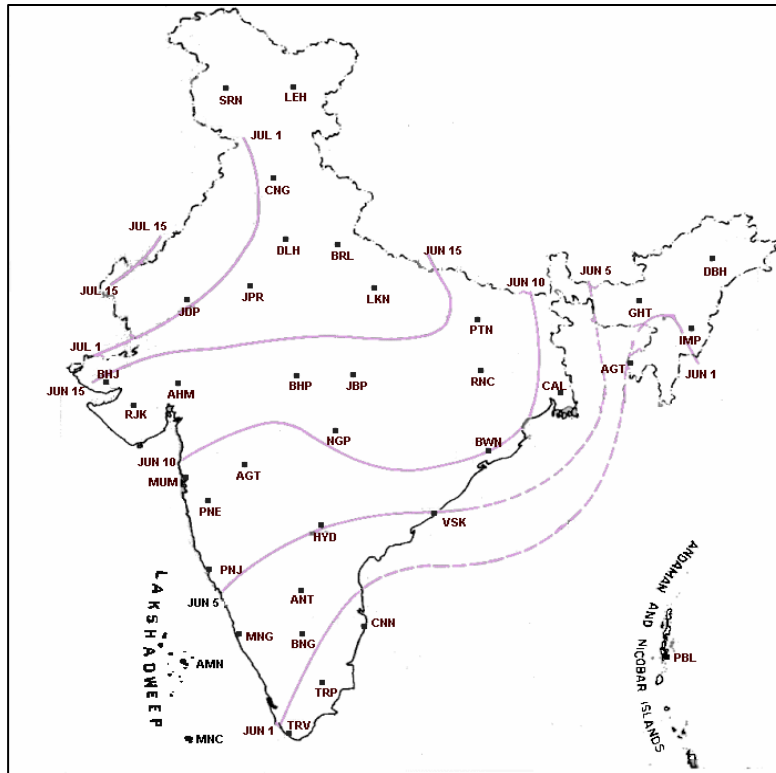
west U.P., West M.P. and Gujarat and finally by middle of October from the country (Rao *et al.*, 1972, Fig.1 & Fig. 2).

The average rainfall during monsoon for the whole country is about 850 ± 90 mm (80-90% of the annual average of 1200 mm) amounting to 400 M.ha meters of water over its geographical area. Orissa, east M.P., West Bengal and north-eastern states, west coast and ghats, and sub-montane region extending from north Bihar to Jammu receive more than average annual 1000 mm rainfall. In some areas of eastern India, higher rainfall occurs due to frequent occurrence of depressions and cyclones. The peninsular India, south of 15° N, receives less than 500 mm while western and north western India (Saurashtra and Kutchch to Delhi, Punjab, Haryana and Himachal Pradesh) receive 650 mm of rainfall. The extreme parts of western Rajasthan receive less than 100 mm.

Retracting south west monsoon (September 15-November)

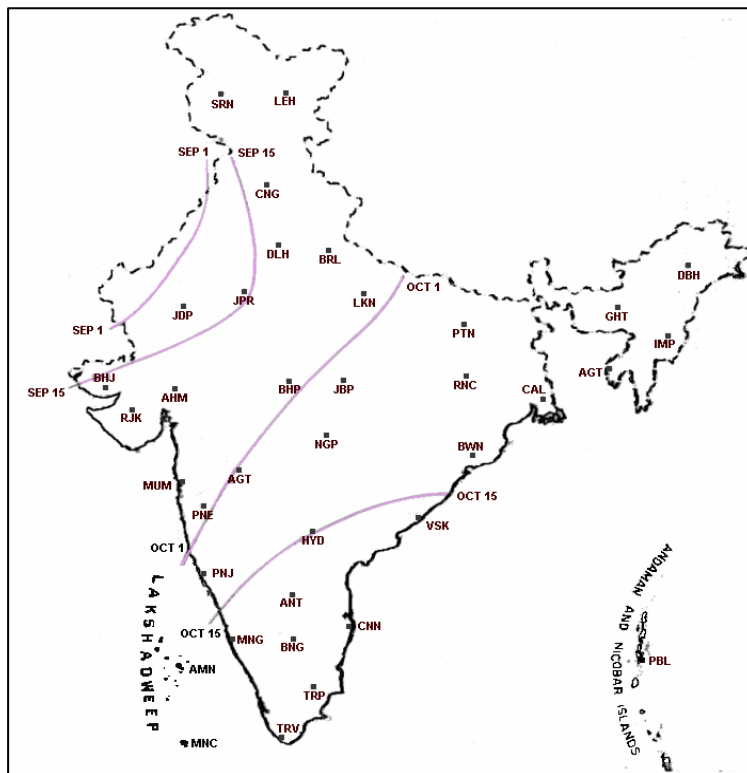
While the withdrawal of south-west monsoon happens in the middle of October, the north-east monsoon strikes the Tamil Nadu coast in the 3rd week of October. The rainfall during the season decreases from coast to interior places. While during October, storms occur in the Bay of Bengal, traveling towards north-east, in November they strike southern Tamil Nadu coast with more rainfall than that in October.

Fig.1: Onset of Monsoon



Source: India Meteorological Department, New Delhi - 2007

Fig.2: Withdrawal of Monsoon



Source: India Meteorological Department, New Delhi - 2007

North-east Monsoon / western disturbances (December -February)

Over most parts of the country, this season is almost rainless excepting north-west India and south-east portion of the peninsula. In the former, the passage of western disturbance causes the rains while in the latter it is due to retreating southwest monsoon. Western disturbances provide good supplemental moisture to the *rabi* crops grown on conserved soil moisture in north west India resulting in their higher productivity. Cyclonic storms occur occasionally along the coastal districts to the south of Chennai resulting in heavy rains. The north-east monsoon also shows significant variability in the onset and withdrawal.

Summer season (March-May)

In the early part of the season, western disturbances continue to give rain (pre-monsoon showers) in parts of north west India and progress east wards to Gangetic plain and north-east India. Some times in West Bengal and Assam, thunder storms known as 'Norwesters' occur and become more frequent mainly in the month of May, often accompanied by hail storms. On the other hand, in north west parts of the country dust storms replace thunder storms.

ii) Temperature

Thermal regime is the second important factor for active growth of the plants. Factors determining the temperature at a place are: altitude of the sun, latitude of the place, elevation, proximity to sea, character of prevailing winds, amount of cloudiness and rainfall.

Monsoon period: With the onset of south west monsoon, the temperature decreases sharply (5°C to 10°C) in June. The hot region shifts towards north west India. The southern peninsula (Tamil Nadu) also records high temperature during July-August due to low monsoon activity. With the withdrawal of monsoon, there is a $1\text{-}2^{\circ}\text{C}$ rise in temperature in most of the regions.

Winter season: The winter season begins by early December. The minimum temperatures during the cool period vary from -8°C to -6°C in Jammu & Kashmir, 3° to 10°C in Indo-gangetic plains and northern M.P., 10° to 15°C in central parts of the Deccan plateau, 15° to 20°C in southern coastal region and above 20°C in Bay Islands. Sometimes the minimum temperature falls below freezing point bringing cool air through western disturbances and damages crops.

Summer season: From early March, temperature starts rising and the month of May becomes the hottest. As summer advances, the hottest areas are slowly transferred from south India and central Deccan plateau, to north west India. The mean maximum temperature during summer varies from 30° to 40°C over most of the country with a range of 28°C in Jammu, to 48° to 50°C in extreme arid parts of western Rajasthan.

iii) Sunshine

In most parts of the country, sunshine is not a limiting factor in spite of cloudy conditions during monsoon. The actual sunshine duration in the peak monsoon (July and August) varies from 20 to 48% of the possible sunshine hours in NE, Gangetic West Bengal and Konkan regions. This is also true in NE region in winter season with only 52% of sunshine hours. The availability of sunshine in the rest of the country is 70-90% during winter period, giving scope for intercropping. Thus, sunshine is not a limiting factor for any kind of vegetation in rainfed areas.

iv) Wind speed

Wind regime influences the evaporative demand of crops to a great extent. Stronger winds may lead to plant injury and desiccation. The mean wind speeds are the lowest during the winter months (3-6 kmph), building up with the beginning of summer and reach peak (6-10

kmph) during the pre- monsoon period (April to June). Stronger wind regimes are observed in west Rajasthan, Gujarat and parts of Tamil Nadu. These can be extremely high for shorter periods during intense cyclonic activity, resulting in atmospheric pressure gradients, thus damaging standing crops and vegetation.

v) Humidity

Relative humidity indicates the level of atmospheric saturation and evaporative demand of the air and plays a crucial role in determining the water requirements of various crops. High humidity coupled with favourable temperature provides a congenial environment for the development of pests and diseases. As the monsoon starts, the relative humidity ranges from 30 to 60% in June in most of the regions. However, high RH values (greater than 85%) are observed along the coastal districts and in the NE region. With the advancement and further progress of monsoon over the entire country (July), the RH increases almost throughout, ranging from 50 to 80%.

vi) Potential evapo-transpiration

The concept of potential evapo-transpiration (PET) was first put forward by Thornthwaite (1948) and Penman (1948). PET has become the most important and fundamental factor for characterization of agro-climates for water balance, irrigation assessment and scheduling, and hydrology etc. Annual PET varies from 1400 to 1800 mm over most parts of the country. Parts of Deccan Plateau, western Rajasthan and parts of Gujarat round PET of >1800 mm, mainly in summer. During south west monsoon, the values range between 400 and 600 mm in most of the areas. During the north east monsoon and winter, PET is generally low except along the west coast and the peninsula (Rao, *et al.* 1999).

Agro-climatic characterization

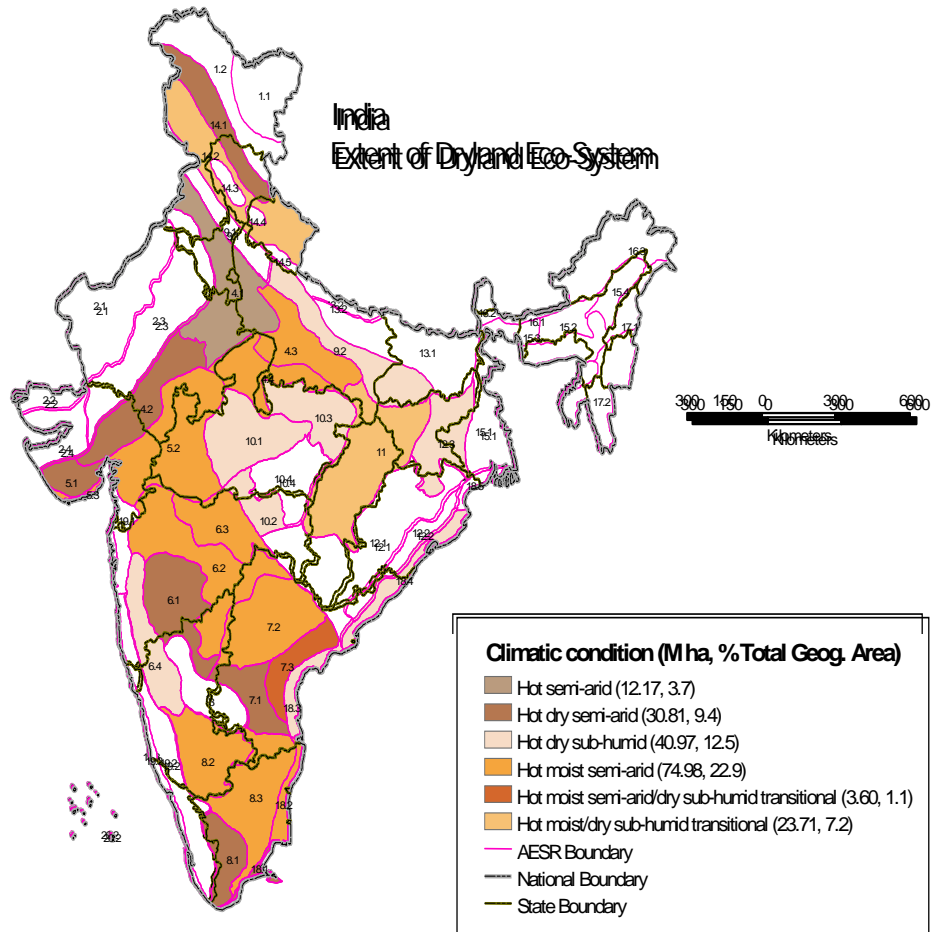
Several attempts were made to classify climates. Thornthwaite (1948) was the first to utilize the concepts of PET and water balance for a rational classification of climates into six types viz., per-humid, humid, moist sub-humid, dry sub-humid, semi-arid, and arid. Rao *et al.* (1972) classified the climates of India (following the revised method of Thornthwaite and Mather, 1955) utilizing PET and available water capacity of the soil on the basis of soil type and crop (Table 4, Fig.3).

Table 4: Types of climate in different regions of India

Region	Climate type
Saurashtra, Kutchch, western Rajasthan, Bellary (Karnataka), Anantapur (A.P.) & Tirunelveli (T.N.)	Arid
The area from Kanyakumari in the south to Punjab in the north, covering practically the whole of the Peninsula, east of western ghats and Gaya-Jumai area in Bihar	Semi-arid
Northern parts of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Orissa, Madhya Pradesh, Vidarbha and northern parts of A.P., and from Chennai to Nagapattanam (T.N.).	Sub-humid (moist or dry)
NE region, west coast and adjoining hills	Per-humid & humid zones

Source: Rao *et al.* (1999).

Fig 3: Extent of dryland eco system areas in India



GIS Lab, CRIDA

The Planning Commission of Government of India (Anon.,1987) had demarcated 15 agroclimatic zones based on climatic parameters, soils and physiography. The National Agricultural Research Project (NARP) of ICAR, based on physiography, rainfall, soils, cropping patterns and administrative boundaries, sub-divided the country into 127 Agro-Ecological Zones [(AEZ) (Ghosh, 1991)]. These AEZ were regrouped into 60 homogeneous Agro-climatic zones based on similar soil, climate, physiographical and cropping patterns for efficient agricultural planning (Venkateswarlu, *et al.*, 1994).

V. Droughts and Drought Management

Drought is a climatic anomaly, characterized by deficient supply of moisture resulting either from sub-normal rainfall, its erratic distribution, higher water requirement or a combination of all these factors. Understanding mechanisms of plant adaptation under severe water stress is very essential. Adaptation of rainfed crops to the changing environment is assessed on the basis of stability in yield over years. The factors contributing to the yield stability of any crop are root system, morphological characteristics, stomatal mechanisms, metabolic adaptation, canopy architecture and drymatter partitioning (Gangadhar Rao *et al.*, 1999). The National Commission on Agriculture (Anon., 1976) categorized droughts into three types, viz., meteorological, hydrological and agricultural drought.

- **Meteorological drought** is the negative departures of *kharif* rainfall in different parts of the country.
- **Hydrological drought** is the extended dry period leading to marked depletion of surface water and consequent drying up of reservoirs, lakes, streams, rivers, cessation of spring flows, and depletion of ground water levels.
- **Agricultural drought** refers to extended dry period in which the lack of rainfall results in insufficient moisture in the root zone, causing adverse effects on arable crops. The spatial and temporal variations in such droughts are of paramount importance particularly when it occurs at any critical phenological stage of a crop.

Agricultural drought is said to occur when the actual evaporation (AE)/ potential evaporation (PE) is <0.25 at the critical phenological stage of the crop. The critical stages in case of pearl millet are tillering, flowering and grain formation stages.

The studies on probabilities of meteorological droughts in different regions of the country were reviewed by Singh and Ramana Rao (1988) based on their occurrence from 1875 to 1987. They observed that about 70% of the geographical area was affected during the disastrous drought years, 1918 and 1899. Though the worst drought of 1987 had affected over 83% of area till the end of July, the good rainfall received in the following month (August) had saved the crops. Thus the impact of droughts on our food production could be minimized through later rains together with improved *khariif* and *rabi* crop management strategies.

Drought management

The risk involved in successful cultivation of crops depends on the nature of drought (chronic and contingent), its probable duration, and periodicity of occurrence within the season. In the arid region where mean annual rainfall is less than 500 mm, drought is almost an inevitable phenomenon in most of the years (Ramakrishna, 1997). In semi-arid region (mean annual rainfall 500-750 mm), droughts occur in 40 to 60% of the years due to deficit seasonal rainfall or inadequate soil moisture availability between two successive rainfall events. Even in dry sub-humid regions (annual rainfall 750-1200 mm), contingent drought situations occur due to break in monsoon conditions. Therefore, drought management strategies need to be identified separately for each climatic region and for each major crop.

Types of agricultural droughts

Crop production in rainfed areas is generally affected by five distinct categories of drought, viz., early season, mid-season, late season, chronic and apparent drought (Rao, *et al.*, 1999).

- **Early season drought** generally occurs either due to delayed onset of monsoon or due to prolonged dry spell soon after the onset, resulting in seedling mortality, need for re-sowing or poor crop stand and seedling growth. The early withdrawal of monsoon results in reduced water availability period for crop growth. Thus, the crops suffer from acute shortage of water during reproductive stage.
- **Mid-season drought** occurs due to inadequate soil moisture availability between two successive rainfall events during crop growth. Its impact depends on crop growth stage, duration and intensity of the drought spell.
- **Late season or terminal drought** occurs as a result of early cessation of monsoon, mainly during the years with late commencement or weak monsoon activity. Terminal droughts are more critical as the crop yield is strongly related to water availability during the reproductive stage. Rainfed rice in dry sub-humid regions is often subjected to terminal droughts due to failure of September rains with 40 to 50% of dry spells of over 5 days during that month.
- **Chronic drought** is common in arid areas where rainfall and stored soil moisture are inadequate to meet crop water requirement during most of the years. Here, the assured growing period is hardly 6 to 7 weeks. These are characterized as chronic drought or highly drought prone areas.
- **Apparent drought** conditions are observed in low to medium rainfall regions due to mis-matching of the cropping pattern in relation to rainfall / moisture availability.

Water balance studies

A balance between PET and rainfall considering the maximum water holding capacity of the soil, provides information on the status of water at a given period either as deficit or surplus. The concept of water balance has been extensively used in agro-climatological studies to

work out the water availability periods, length of growing period (LGP), agricultural drought, and irrigation scheduling.

The increased rainwater use efficiency can be achieved through (Singh, 1998); retaining maximum precipitation by minimizing runoff, reducing evaporation and use of drought resistant / tolerant crops and varieties fitting the rainfall pattern, selection of varieties having deep root system, off-season tillage for improving infiltration and reducing runoff, weed control also improves water use efficiency.

Crop Improvement for efficient water use

Studies on breeding for drought tolerance and increased water use efficiency (WUE) did not receive desired attention so far. Hence, breeding for higher WUE continues to be relevant for achieving higher productivity per unit of water consumed. Multi-disciplinary approaches involving breeders, physiologists and agronomists might provide useful results in this direction. Biodiversity could offer a potential gene pool in identifying water efficient crops for breeding both through conventional and biotechnological tools.

VI. Watershed management programmes

The concept of watershed development, integrating arable and non-arable areas was launched in 1983 with 47 model watersheds in the country. Such a project for the Hills was implemented in the states of Punjab, Haryana, Himachal Pradesh and Jammu & Kashmir with an objective to reverse the environmental degradation of the Himalayan foothills through appropriate soil and water conservation technologies thereby improving the production of crops, fruits, fodder, fuel wood and animal products (Jain, 1997).

Another project on integrated watershed development for the Plains was implemented in Gujarat, Orissa and Rajasthan to introduce sustainable land management practices in selected watersheds through cost effective and replicable conservation technologies (vegetative, soil and moisture conservation measures), to encourage land use as per peoples' needs and land capability to facilitate inter-agency coordination, and to ensure full participation of watershed-users in the development and management of common properties. The implementation was successful in achieving the physical targets like establishment of orchards, forestry, nurseries, and *gullies* and *nalas*. In this project some of the issues raised were:

- need for financial and manpower support by the states,
- use of measurable indicators in monitoring and evaluation to assess the benefits,
- improving quality in the execution of technology models,
- use of identified local flora for establishing vegetative barriers, and
- to place more emphasis on sustainability and replicability by village community involvement in the management of common property resources developed under the project.

The pilot projects for watershed development in rainfed areas were implemented in Andhra Pradesh, Karnataka, Maharashtra and Madhya Pradesh from 1983 to 1993 with the following objectives:

- to develop suitable technologies for increasing and stabilizing crop and forage yields, fuel wood and timber in selected rainfed farming areas,
- to define technical criteria, administrative procedures and investment limits useful in replicating the activities in other areas.

The approach adopted was through mitigation of the effects of variation in rainfall by: (a) introducing stable farming systems, (b) retaining more water in the soil profile, and (c) controlling erosion by providing safe disposal of runoff and drainage.

Outcome of R&D efforts on watersheds

- Over the years, to reverse the process of land degradation, technologies were evolved and extensively implemented through various core activities viz., land development and soil conservation, afforestation, sand dune stabilization, water resources development, integrated watershed development, rainwater harvesting/conservation, fuel wood plantations, recovery of degraded forests, pasture development and roadside plantations (Sharma and Singh, 2001).
- The cost benefit analysis of these interventions showed a positive net present value, annuity and internal rate of return in a comparable system prevalent in the region.
- In addition to the tangible monetary benefits, a large number of intangible benefits accrued such as amelioration of environment, protection of crop land and communication lines from sand dunes, reduction in human drudgery in fetching water from distances.
- Improved technologies such as off-season tillage and contour cultivation to enhance *in situ* rainwater conservation, improved biotypes of crops, soil fertility management and weed control helped in getting optimum production.
- The productivity of traditional mixed cropping systems was upgraded by adjusting row ratios of components of intercropping systems to minimize competition. To bring in stability and improvement in rainfed agriculture, techniques of rainwater conservation and agronomic practices have to be integrated.
- Two to several fold increase in crop productivity resulted over the base year.
- Shift in the area in favour of more cash yielding oilseed crops from less remunerative coarse cereals.
- Rise in income through profits.
- Improvement in cropped area and cropping intensity and a concomitant rise in number of working days.
- The participatory technology development needs active involvement of farmers in programme planning and implementation for combating land degradation, enhancing the productivity on a sustainable basis and to improve the quality of life of rural population.

Lessons Learnt

Several organizations studied the impact of watershed programmes in the country. The highlights are given here below (Jain, 1997):

- the size of the project should be manageable,
- project design should ensure flexibility to tune the prescriptions to cover a wide range of rainfall, slope and physical conditions involving the farmer,
- participation of beneficiaries, right from identification to implementation of the projects is of paramount importance in watershed management efforts,
- clear demarcation and management of common property resources (such as forest areas or grazing lands) is important as it involves changes in legal and policy rules and regulations,

- the sustainability of programmes was questionable since no one owned the responsibility to maintain continuity after the project was completed,
- the successful replicability of results of pilot projects in any watershed was difficult without any Government / external support,
- the desired support from Government of India and the States and the related departments was lacking. It is for the benefit of the programme to maintain the continuity of staff involved,
- the whole watershed programme was largely implemented as a departmental activity with staff on deputation, and
- several programmes on watershed management were simultaneously running in the states with little coordination and linkages. Besides, the criteria and systems followed different for the same activity in the same state in different projects.

Thus, it was concluded that judicious use of natural resources on the watershed basis is the only long term sustainable and practical approach for the improvement of rainfed agriculture. The present approach is cost prohibitive. Therefore, the future strategy for rainfed farming has to be an area based approach designed from watershed programmes.

Watershed based productivity and income enhancement with emphasis on rainfall and land capability - based farming (a mix of conventional as well as alternate land uses) including water efficient crops through multiple and diverse farming systems need to be implemented in all their aspects across various agro-ecological zones of the country. The interventions on watershed-based systems would not only help conserving soil, water and biotic resources but also provide insights into issues related to developing land use plans and equitable sharing of harvested water. Watershed framework helps in recharging ground water resources on a landscape basis. The operational scale watershed should be large enough to represent real life situation of farmers' fields.

VII. Choice of crops and cropping systems

In any given region, the amount and distribution of rainfall influences the choice of crops and cropping patterns. Venkateswarlu (1985) estimated effective cropping season based on mean monthly rainfall and PET. The Length of Growth Period (LGP) depends on the rainfall distribution, soil type, depth and water holding capacity. The National Bureau of Soil Survey and Land Use Planning estimated the LGP and superimposed these values on the soil map for delineation of 60 agro-ecological regions (Sehgal, *et al.*, 1995). The LGP as reported by Velayutham (1999) varies from 90 days in North West (NW) India to about 300 days in North East (NE) region. In the semi-arid region, the LGP varies between 120 and 150 days, while in dry sub-humid areas it is 150-180 days.

Hargreaves (1971) considered the ratio of dependable rainfall (75% probability) to the PET and defined it as Moisture Availability Index (MAI). Accordingly, the LGP is calculated as the period when MAI is more than 0.33. Based on the MAI values, the periods of water availability are classified (Ramana Rao *et al.*, 1994).

The choice of crops in rainfed conditions depends on length of the humid period during the crop growing season. The choice of cropping system (Ramana Rao, 1997) is mostly governed by the LGP as given in Table 5.

Table 5. Suggested cropping systems based on Length of Growth Period

LGP	Cropping system that can be adopted
<75 days	Perennial vegetation, monocropping of short duration, drought resistant pulses (mungbean, cowpea, mothbean and millets)
75-140 days	Monocropping (in soils with capacity to hold 150 mm of water)
140-180 days	Intercropping (in soils with capacity to hold 200 mm of water)
>180 days	Double cropping (mainly rice - based)

The choice of base and intercrop depends on the distribution of rainfall and farmers' needs. If the rainfall pattern is unimodal or also in shallow soils, short duration base crop and a long duration companion crop should be preferred. In medium to deep soils, the base crop should be of longer duration. In bi-modal rainfall distribution, the peak growth period of the base and companion crops should coincide with prominent rainfall peaks (Rao and Khan, 2003; Rao *et al.*, 2003).

It has been observed that climate variability can influence the agricultural productivity by as much as 20%. Thus, an efficient management of climate can help bridge this gap and achieve sustainability in rainfed agricultural productivity. The programmes of AICRPAM of ICAR are linked to those of India Meteorological Department and the National Centre for Medium Range Weather Forecasting in developing appropriate operational agro-meteorological models. These models, along with the improved production technologies from CRIDA and AICRPDA will enable the farmers to take weather - based decisions for efficient utilization of the weather resources, to minimize their adverse effects on crop productivity and to go for contingency crop planning against droughts or floods.

Crop Diversification in Rainfed Regions of India

A region is termed rainfed if it has less than 40% net irrigated area. In such regions, crop diversification through technologically feasible and economically viable enterprise seems to be the only option to achieve poverty alleviation through food security by overcoming the problems of land degradation and climatic aberrations. Diversification of agriculture (Fig. 4) has shown several important benefits besides ecological advantages (Vittal, *et al.*, 2006).

The cropping intensity was studied from the district-wise crop and season database for the period 1990-95 in different states covering arid, semi-arid, and dry sub-humid regions with <1500 mm rainfall. The study revealed that the crop diversification was higher under rainfed situations over irrigated areas. The cotton crop showed more diversification followed by coarse cereals, pulses and oilseeds. The rainfed rice also showed the impact of more diversification compared to irrigated crops. To be relevant, crop diversification in rainfed regions must address the following issues:

- Efficient cropping systems
- Risk and cost minimization
- High income and employment generation
- Upgradation of natural resources viz., land and water
- Food, nutritional, economical and ecological security
- Poverty alleviation viz-a-vis small and marginal holdings
- Competing with comparative advantage in new trade regime.

The benefits of crop diversification are likely to be :

- Availability of wide range of crops / products
- Enhanced profitability through alternative crops
- Reduced pest problems through diversified rotations
- Even distribution of labour through out the year
- Reduced risks from weather aberrations by different planting & harvesting times
- Renewable resources of high value products by introducing new crops.

The approaches must be linked with other enterprises like sericulture, agri-horticulture / horti-pasture, agroforestry, livestock, poultry, beekeeping and the like to be more effective, efficient and sustainable (Rao and Sujatha, 2006).

Crop diversification opportunities in crop - based production systems

Rice is the most important cereal crop of India. Though there is very limited scope for increasing the acreage under this crop (presently over 50%), scope exists for increasing its productivity. Double or triple cropping with irrigated rice, though possible should be discouraged because with the same amount of irrigation water, we can produce more of other crops efficiently. For instance, 3 acres of groundnut can be successfully cultivated in place of one acre of irrigated rice (Fig. 5).

Fig . 4: Recommended land uses in rainfed agro-eco regions (Anon., 1997b;

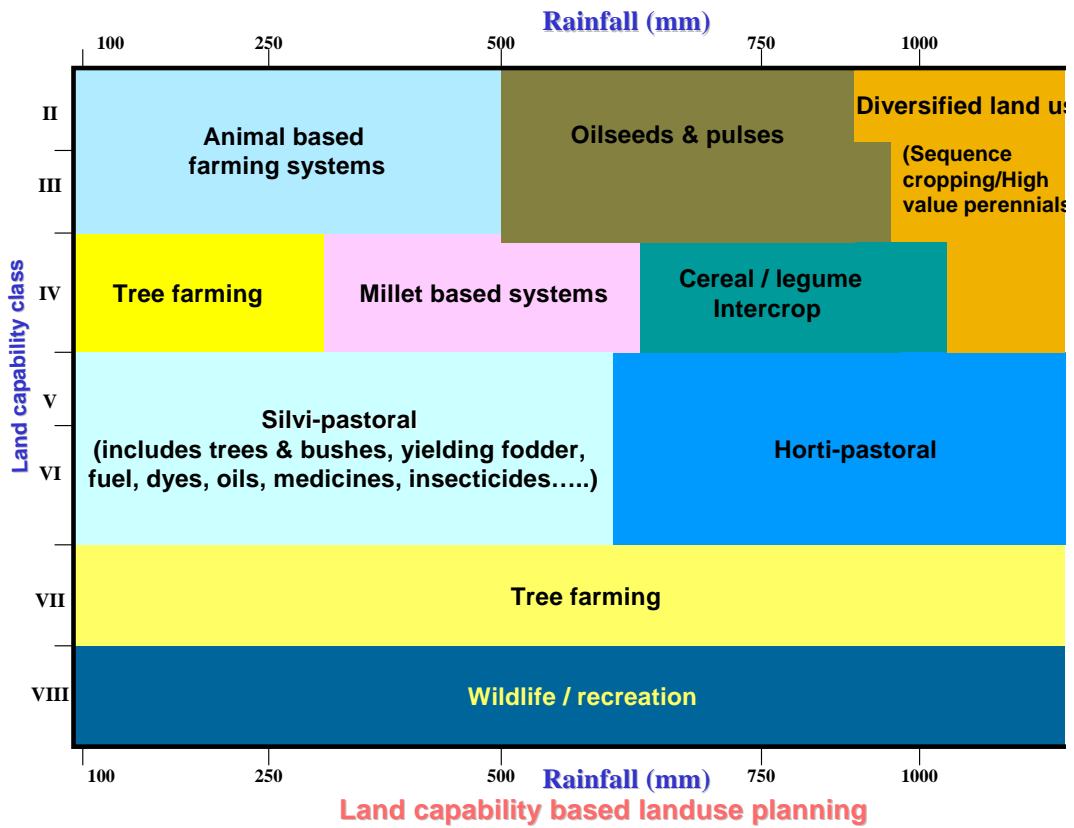
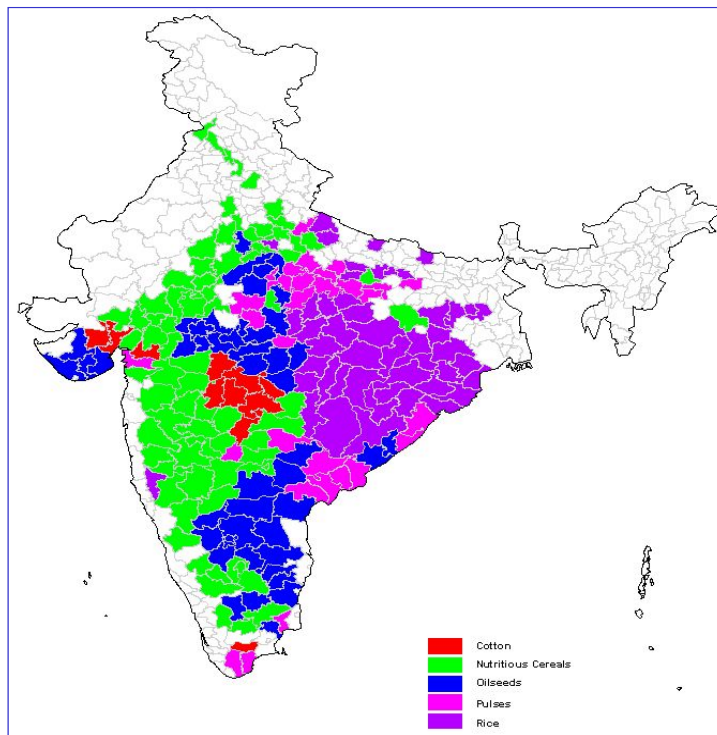


Fig.5: Rainfed Production Systems of India (Anon., 1997b)



The most efficient sorghum region is in the peninsular India (central and south Indian states). The common crops which are rotated with sorghum are: cotton, groundnut, pigeonpea and other pulses. Some sorghum is also grown in paddy areas. In cotton growing tract of Tamil Nadu, hybrid sorghum and its ratoon crop could be easily fitted in rotation with cotton. The area under hybrid sorghum steadily increased and the production maintained in spite of decline in its total area to about 6 million hectares before 1970. All the same, the production increased by about 2 million tonnes. The higher crop productivity mainly assigned to effective control of insect-pests through cultural practices and incorporation of disease resistance genotypes. However, losses due to late rains at harvest need to be reduced.

Until early 1980s coarse cereals (sorghum, pearl millet, several small millets) formed a part of the subsistence agriculture characterized by low and uncertain yields on about 40 million hectares area held by small and marginal farmers (Rao and Rana 1999). With the availability of wheat and rice at subsidized prices through the public distribution system, the consumption of coarse cereals declined in rural as well as urban areas. The coarse cereals have low productivity, adapt to poor habitats and resource base, produced and consumed by poor people. Consequently, the area under coarse cereals decreased sharply from mid 80s onward. The other important dryland crops, the oilseeds and pulses, had an edge due to their higher price. Irrigated hybrid maize (Deccan 1, High Starch, Ganga Safed 2 and Ganga 5) during *rabi* is becoming popular due to its multiple advantages. Development of early maturing cultivars is a boon for vast rainfed area under maize. Currently, the demand for coarse cereals is again picking up for feed, fodder and other industrial uses at a low pace. Hence, there is a need to relook into the ups and downs in the progress of coarse cereals.

National Agriculture Policy

The declining or slow pace of growth rate in Indian agriculture particularly during nineties could be assigned to continued migration of farm families to towns and cities, uneconomical cultivation, uneven development of agro-eco-regions and farming communities, degradation of natural resources, poor marketing infrastructure etc. Therefore, the Government of India formulated the National Agriculture Policy (Anon., 2001) with the main aim of efficient use and conservation of natural resources, for at-least 4% growth rate per annum across regions and farmers, demand driven growth both for domestic needs and exports to meet economic liberalization and globalization challenges and to aim at technologically, environmentally, socially and economically sustainable development of agriculture.

VIII. Towards Sustainable Rainfed Agriculture

Presently, with the rapid growth of population, the pressure on land increased and the size of holdings considerably decreased in spite of extending the cultivation to marginal and sub-marginal lands. Due to continuous erosion, the productivity of all lands decreased, while the demand for agricultural produce increased. As a result of all these factors, the practice of storing surplus grain and fodder in villages is gradually disappearing. This calls for a serious review of our research and developmental strategies in rainfed areas for making them sustainable.

Since the productivity in irrigated areas is continuously plateauing, bulk of rising food demand is met by rainfed areas. Lack of food security in resource poor rural areas makes it difficult for growing population to stay in villages. The human population in rainfed areas is likely to reach 600 million by 2020 AD from the present 410 million. Such a kind of increase in population will shrink the per capita availability of land from 0.15 hectares to about 0.08 hectares (Anonymous, 1997b). Thus, the operational holding is likely to be uneconomical to

cultivate the conventional cereal crops or to leave fallow. Similarly, the livestock population is likely to cross 650 million by 2020 AD (from the present 509 million heads). This leads to greater demand for fodder. During 1991, the gap between the availability and requirement of fodder was 67 and 137 million tonnes, respectively in terms of dry and green fodder. By 2020, this demand-supply scenario may be around 69 and 145 million tonnes, respectively in spite of raising the area exclusively under fodder cultivation, from the present 4% to at least 10%. Further, over-exploitation of natural resources is likely to worsen social disparity and create a host of socio-economic problems, such as unemployment and food and livelihood insecurity. With the enormous growth of towns and cities and changing rainfall patterns, the rainfed area is likely to decrease drastically. Therefore, from the significantly reduced area, the productivity needs to be doubled from the present 0.8 -1.0 t/ha by 2020 (Paroda, 1997). The quality of produce also must be improved. The cost of production needs to be reduced in order to improve farmers' income and also to remain globally competitive.

Thus, maintaining food security in future is a challenging task demanding intensive and extensive Research and Development efforts to meet the targets and to make rainfed agriculture viable (Sharma and Singh, 2006). The question currently being asked is “can we meet the new challenges on sustainable rainfed farming which raises the quality of life and is pro-nature”? The recent past trends in Indian agriculture suggest that it can be achieved, provided we adopt land use diversification with multidisciplinary and holistic approach. This must include interactions among climate, soil, water, vegetation, livestock, human and socio-economic dimensions in devising most productive, remunerative, eco-friendly and environmentally sustainable land use.

Strategies

A few key strategies suggested to achieve these goals are:

- characterization of bio-physical and socio-economic resources utilizing GIS and remote sensing,
- integrated watershed management,
- improving rain water use efficiency through appropriate mechanisms in terms of rain water storage, delivery and application,
- contingency crop planning to minimize loss of production during drought or flood years,
- diversification of agriculture by growing high value crops such as medicinal, aromatic and dye yielding plants,
- sericulture and livestock farming to minimize climatic risks,
- alternate land uses such as agri-horticulture, horti-pasture, agroforestry, silvipasture to maximize returns,
- integrated nutrient-water-crop-pest management,
- building soil organic matter and soil quality enhancement, and
- designing appropriate farm implements for timeliness of agricultural operations.

Extension of crop insurance schemes to rainfed crops, improving credit availability, timely input supply systems and launching of pilot projects in farmers' participatory mode integrating with Non-Government Organizations (NGOs) and others, will ensure long-term sustainability of rainfed agriculture. Rural agro-industry development is most essential to support farm mechanization and value addition besides off-season employment generation to ensure honourable livelihoods for small and marginal farmers and land-less herders and also to check migration (Samra and Pratap Narain, 1997 and Anon., 1997a).

The continued destruction of natural vegetation and over use of marginal lands is likely to affect upto 9% more land by wind erosion by 2020 (Anonymous, 1997a). Areas affected by water erosion and gully formation are increasing at the rate of (@) 0.71% per year since 1958. Due to over-exploitation of ground water, water table is receding @ 0.2-0.4 m/year in about 75% of the area.

Likewise currently, over 50% of ground water resource has already been utilized, and by 2020, a major part of the arid and semi-arid zones will be devoid of economically viable groundwater thus, adversely affecting small and marginal farmers. The imbalance between the rain water input and the drawal from surface and groundwater sources is likely to widen further needing an estimated 24 million hectare meters water, equal to estimated harvestable runoff.

Future options

- Improved crop production technology aimed at individual farms and crops has made a definite impact in rainfed regions. However, their adoption rate is still low.
- Many of the soil and water management practices need be implemented in watersheds ensuring community participation.
- Limited farm mechanization is necessary to reduce the gap between draft power available and the need for maintaining timeliness in farm operations.
- Location specific cropping systems approach must be adopted based on the feed back received on the draw backs, keeping in view the food and fodder requirements.
- The rate of adoption of improved technologies is directly linked to the net income on a sustainable basis. With the availability of timely resources and their efficient management, semi-arid areas are likely to generate more food, fodder and other products.
- A holistic approach with multi-disciplinary, multi-commodity and multi-institutional involvement is needed. The existing declining trend in area of crops like sorghum and soybean would continue due to changes in eating habits. A greater shift is expected from food crops to commercial crops in the next decade, but equilibrium may be achieved with the economics of different commodities determining the choice of a cropping enterprise. Processing of food/fruit products, animal husbandry and dairying are likely to emerge as important sources of income and employment. The plants/products having comparative advantage of growing in rainfed areas need to be identified for global trade.

Future research should be centered around water as the nucleus and watershed as the unit of activity in a participatory mode. Effective rainwater harvesting and management is essential for sustainability in food grain production. The feedback from the farmers revealed their reluctance to partition the land to accommodate conservation structures. Hence, simple, affordable and effective mechanical or vegetative structures need be promoted along field boundaries. Contour vegetative barriers (preferably native species) offer effective alternative against soil erosion and encourage *in situ* rainwater conservation. Their acceptance and multiplicity is likely to be faster if these offer some kind of visible economic benefit.

Promotion of more of small dug-outs in a given watershed is better than investing on a large farm pond. The rainwater harvested and stored either on the surface or below the ground will have to be judiciously utilized through efficient irrigation methods and less water demanding crops. Provision of extensive life saving and supplemental irrigation have demonstrated its impact on stabilizing crop production.

Essential strategies on rainwater recycling include water saving methods of irrigation, water efficient crops, emphasis on moisture stress management at critical stages of growth and preferential irrigation of high value crops.

Indigenous alternative crops like *henna*, Jaffra and others are grown well under rainfed conditions for natural dyes. Neem exhibits immense potential to yield oil, manure, bio-medicine and bio-pesticides. These help to earn valuable foreign exchange besides avoiding harmful effects of synthetic dyes. Insecticidal properties of custard apple and *Jatropha* seeds, bio-diesel from *Jatropha* and *Pongamia* seeds, other tree borne oil seeds like *simarouba*, *mahua*, *jojoba* etc. have great potential for rehabilitation of degraded and wastelands besides checking environmental pollution and generating livelihood opportunities. The off-season and off-farm occupations like poultry, dairying, horticulture, sericulture, bee-keeping are likely to support the income of rainfed farmers to an extent of nearly 40%. However, these activities need increased and continuous availability of fodder, feed, water, nutrients, human work force and similar other inputs.

Water efficient dual-purpose millets and top feed species, need be identified for cultivation on marginal lands to meet fodder needs. Integrated nutrient management including organic and inorganic sources should receive more attention to avoid nutrient imbalances. This requires generation of green leaf manure/ green manure crops, leguminous crops on key lines, contour bunds, farm road-side and wasteland segments within the farms.

Timely credit availability, appropriate marketing, price support system and transport will help in improving the input use and in turn, the profitability from gray areas. Active participation of NGOs and farmers' associations is likely to improve the rate of technology transfer in rainfed areas. Technology generation, assessment, refinement, transfer and effective adoption will have to be strengthened actively involving scientists, extension agencies, NGOs and the farmers.

Future Strategies

Depending upon the rainfall availability, crop production technologies are to be mounted as suggested here under (Osman and Rao,1999; Rao *et al.*, 2003; Sharma and Singh, 2006).

For areas receiving <500 mm rainfall

- Linking arable cropping with animal husbandry.
- Adoption of arable cropping (limited to millet and pulses), arid-horticulture agroforestry, horti-pasture and silvi-pasture systems.
- Growing drought-tolerant perennial tree species for fodder, fruit and fuel.
- Adopting efficient methods of irrigation for higher productivity.
- Efficient management of rangelands and common grazing lands, with improved grasses, reseeding techniques and creating fodder banks.
- Small farm mechanization.

For areas receiving 500-750 mm rainfall

- Energy rich crops like oilseeds and pulses in intercropping systems.
- Emphasis on high value crops (fruits, medicinal, aromatic, dyes, pesticide yielding) and high tech-agriculture (drip irrigation, processing, extraction, value addition).
- Stressing *in situ* moisture conservation, rainwater harvesting and effective recycling and off-season tillage in a watershed approach.
- Mounting efficient alternate land use systems with agriculture-forest-pasture-livestock, based on land capability criteria.
- Afforestation in highly degraded / wastelands.
- Adoption of seed village concept for self-sufficiency in seeds of improved varieties.
- Small farm mechanization.

For areas receiving 750-1050 mm rainfall

- Developing aquaculture in high rainfall, double cropped regions with rationalization of area under rice.
- Use of improved crop varieties of maize, soybean, groundnut, sorghum, pigeonpea, cotton and other crops in intercropping and double cropping wherever possible to increase cropping intensity.
- Rainwater harvesting / conservation including ground water recharge.
- Improving sustainability of rice-wheat cropping system in the Gangetic plains.
- Rehabilitation of degraded lands through perennial vegetation.

With the support of World Bank, the Government of India launched a major R&D project in agriculture through ICAR - called the National Agricultural Technology Project in the year 1998 to address the specific issues like regional imbalances and disparity in the resources. Major attention was paid to the development of implementable farmer friendly production technologies in arid and semi-arid regions. As a result, several sustainable technologies were identified for their large scale adoption in different agro-eco-regions of the country. Their appropriate implementation together with matching, timely supply of inputs is likely to boost the productivity from rainfed areas besides appreciating the natural resources.

Currently, the Government of India is aiming at finding permanent solutions to the agrarian crisis by framing the National Policy for Farmers with the main aim “to stimulate attitudes and action which will result in assessing agricultural progress in terms of the net income of farm families rather than just on production of farm commodities (Anon., 2006)”. The draft National Policy for Farmers envisages 10 major goals. Likewise, the proposed National Rainfed Areas Authority is also to address specific issues for the over all development of rainfed areas.

Summary

To sum up, the future R&D programmes need to be centered on the following for overall growth and development of rainfed agriculture in India.

Soil related

- Focus on efficient use of off-farm and on-farm generated organic materials in a participatory approach.
- Monitoring carbon sequestration.

Water related

- Revival of the traditional water storage systems (tank) and the utilization of defunct open wells as recharging wells for augmenting the ground water resources for life-saving irrigation, particularly during *rabi* season.
- Application of most appropriate and efficient agricultural practices on multiple uses of water.

Vegetation related

- Participatory plant breeding and varietal selection for genetic enhancement and using molecular biological tools to develop biotic and abiotic stress tolerance in rainfed crops.
- Development of location specific land capability-based land use systems stressing equitable and sustainable use of surface and ground water.
- Conservation of bio-diversity and arresting future loss and extinction from dryland regions needs specific attention.
- Production systems research instead of component or disciplinary considerations.

Livestock related

- Improvement of indigenous livestock breeds and their disease control.

Rainfall domain (mm)	Interventions
500-700	Cropping - livestock farming system
700-1100	Cropping-horticulture - livestock, poultry
>1100	Multiple cropping - horticulture, aquatic plants, in - land fisheries

Personal communication from Dr J.C.Katy, 2006.

- Utilization of CPRs for fodder production, increasing nutritive value of feeds and fodders.
- Integrated programmes on sustainable development of wastelands to support landless poor and their animals.

Development related

- Economic, social and environmental response to various developmental interventions.
- Suitable policy incentives for production and incorporation of biomass, management of natural resources and integrated nutrient and pest management.
- Promotion of minimal use of chemical fertilizers, including micronutrients.
- The National Academy of Agricultural Sciences has suggested that the rainfed eco-regions of the country, mainly the North East, tribal and hilly areas, are the most suited for organic farming as their fertilizer use is meagre. In this direction, public-private partnership needs to be encouraged to reap maximum benefit.
- Designing, developing and popularizing implements for small and marginal farmers is necessary. Custom hiring centers for mechanization at village level are likely to ensure availability of implements at low cost.
- Market intelligence, information flow on prices, consumer preferences, weather advisories and contingent crop planning for efficient management of resources and using ICTs, need our urgent attention.
- Establish seed, grain, fodder, credit, self-help groups and other common interest groups.
- Defining and implementing user rights over common property resources.

Training and Education related

Although rainfed agricultural technologies are available, they have not properly percolated down to the farmers. The poor adoption rate is due to vagaries of monsoon, changing needs of farmers, land tenancy laws, credit constraints, poor market links, and similar factors. Inadequate and inappropriate transfer of technology methods and ignorance of farmers on new knowledge also lead to instability in production.

Active participation of farmers in identifying suitable technologies, farmers' education and training are essential to reduce the dependence on agriculture. For this purpose encouragement of off-farm activities for livelihood and to reduce poverty is essential. Strengthening of KVKs is needed to provide vocational training to the farmers.

Acknowledgements

The authors are grateful to the Director, CRIDA and all the scientists of CRIDA and other Institutes whose contributions have been cited in this chapter.

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