LECTURE NOTE ON
Agron 6.10
RAINFED AGRICULTURE AND WATERSHED MANAGEMENT

6TH SEMESTER
B.Sc. (Tech) Agri.

DR. K. D. MEVADA  
Associate Professor  
Department of Agronomy  
B.A. College of Agriculture  
Anand Agricultural University  
Anand

DR. T.C. POONIA  
Assistant Professor  
Department of Agronomy  
College of Agriculture  
Junagadh Agricultural University  
Amreli

PIYUSH SARAS  
Assistant Professor  
Department of Agronomy  
C.P. Patel College of Agriculture  
Sardarkrushinagar Dantiwada Agricultural University  
Sardarkrushinagar

S.P. DESHMUKH  
Assistant Professor  
Department of Agronomy  
College of Agriculture  
Navsari Agricultural University  
Bharuch
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**Credit**: $1+1 = 2$

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<td>-</td>
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**Glossary and Abbreviations**
1.1 Introduction

Even after the utilization of all our water resources for irrigation, about half of the cultivated area will remain rainfed. As there is hardly any scope for increasing the area under cultivation, it is really a colossal task for meeting the future food needs. It is against this background that the role of dryland agriculture gained importance. Agriculture is the single largest livelihood source in India with nearly two thirds of people depend on it. Rainfed agriculture is as old as agriculture itself. Growing of crops entirely under rainfed conditions is known as dryland agriculture.

Very often, the words dry farming, dryland agriculture and rainfed agriculture are used synonymously to indicate similar farming situation. Clearly, the two exclude irrigations. **Depending on the amount of rainfall received, it can be grouped into three categories: Types of Dryland/Rainfed Agriculture**

1.2 Definitions

a) **Dry farming**: is cultivation of crops in regions with annual rainfall less than 750 mm. Crop failures is most common due to prolonged dry spells during the crop period. These are arid regions with a growing season (period of adequate soil moisture) less than 75 days. Moisture conservation practices are necessary for crop production.

b) **Dryland farming**: is cultivation of crops in regions with annual rainfall more than 750 mm. In spite of prolonged dry spells crop failure is relatively less frequent. These are semi-arid tracts with a growing period between 75 and 120 days. Moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for vertisols or black soils.

C) **Rainfed farming**: is crop production in regions with annual rainfall more than 1150 mm. Crops are not subjected to soil moisture stress during the crop period. Emphasis is often on disposal of excess water. These are humid regions with growing period more than 120 days. In dry farming and dryland farming, emphasis is on soil and water conservation, sustainable crop yields and limited fertilizer use according to soil moisture availability. In rainfed agriculture, emphasis is on disposal of excess water, maximum crop yield, high levels of inputs and control of water erosion.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particular</th>
<th>Dry Farming</th>
<th>Dryland Farming</th>
<th>Rainfed farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rainfall/annum (mm)</td>
<td>&lt; 750</td>
<td>750 – 1150</td>
<td>&gt; 1150</td>
</tr>
<tr>
<td>2</td>
<td>Moisture availability</td>
<td>Acute shortage</td>
<td>Shortage</td>
<td>Enough</td>
</tr>
<tr>
<td>3</td>
<td>Crop growing season</td>
<td>&lt; 75 days</td>
<td>75 – 120 days</td>
<td>&gt; 120 days</td>
</tr>
<tr>
<td>4</td>
<td>Growing region</td>
<td>Arid</td>
<td>Semi-arid</td>
<td>Humid</td>
</tr>
<tr>
<td>5</td>
<td>Cropping systems</td>
<td>Single crop/ intercropping</td>
<td>Single crop/ intercropping</td>
<td>Inter/ Multi-cropping</td>
</tr>
</tbody>
</table>
United Nations Economic and Social Commission (UNESC) for Asia and the Pacific distinguished dryland agriculture mainly into two categories: dryland and rainfed farming. The distinguishing features of these two types of farming are given below

1.3 Dryland farming v/s Rainfed farming

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Dryland farming</th>
<th>Rainfed farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>&lt;750</td>
<td>&gt;750</td>
</tr>
<tr>
<td>Moisture availability to the crop</td>
<td>Shortage</td>
<td>Enough</td>
</tr>
<tr>
<td>Growing season (days)</td>
<td>&lt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Growing regions</td>
<td>Arid and semiarid as well as uplands of sub-humid and humid regions</td>
<td>Humid and sub-humid regions</td>
</tr>
<tr>
<td>Cropping system</td>
<td>Single crop or intercropping</td>
<td>Intercropping or double cropping</td>
</tr>
<tr>
<td>Constraints</td>
<td>Wind and water erosion</td>
<td>Water erosion</td>
</tr>
</tbody>
</table>

1.4 The Concept:

The concept of rainfed agriculture (farming) under which both dry farming and dryland farming (dryland agriculture) is included has changed. Dry farming was the earlier concept for which amount of rainfall (less than 500 mm annually) remained the deciding factor for more than 60 years.

In modern concept, dryland areas are those where the balance of moisture is always deficit side. In other words, annual evapotranspiration exceeds precipitation. In dryland agriculture, there is no consideration of amount of rainfall. It may appear quite strange to a layman that even those areas which receive 1100 mm or more rainfall annually fall in the category of dryland agriculture under this concept. To be more specific, the average annual rainfall of Varanasi is around 1100 mm and the annual potential evapotranspiration is 1500 mm. Thus the average moisture deficit so created comes to 400 mm. This deficit in moisture is bound to affect the crop production under dryland situation, ultimately resulting into total or partial failure of crops. Accordingly, production is either low or extremely uncertain and unstable which are the real problems of dryland in India.
Success of crop production in these areas depends on the amount and distribution of rainfall, as these influences the stored soil moisture and moisture used by crops. Amount of water used by crop and stored in soil is governed by water balance equation:

$$ET = P - (R + S)$$

When balance of the equation shifts towards right, precipitation (P) is higher than ET, so that there may be water logging or it may even lead to runoff (R) and flooding. On the other hand, if the balance shifts to left, ET becomes higher than precipitation, resulting in drought. Taking the country as a whole, as per meteorological report, severe drought in large area is experienced once in 50 years and partial drought once in five years while floods are expected every year in one or other part of the country, especially during rainy season. In fact, the balance of the equation is controlled by weather, season, crops and cropping pattern.

**Present Status**

- Growing of crops entirely under rainfed conditions is known as dryland agriculture.
- India has about 108 m ha as rainfed area/dryland agriculture of total 143 m ha (67 %)
- Dry farming contribute in total food grains production: 44 %
- Area under oilseeds (groundnut, rapeseed, mustard and soybean): 80 %
- Nearly 67 M ha of rainfed area falls in the mean annual precipitation range of 500 – 1500 mm.
- Average annual rainfall of the country is 1200 mm amounting to 400 M ha-m of rainwater over the country's geographical area (329 M ha).
- However, distribution across the country varies from less than 100 mm in extreme arid areas of western Rajasthan to more than 3600 mm in NE states and 1100 mm from East Coast to 2500-3000 mm in the West Coast.
- Broad area of summer monsoon activity extends from 30° N to 30° S and from 30° W to 16.5° E. Detailed information on rainfall and monsoonal pattern in India has been summarized below.

### Rainfall pattern in India

<table>
<thead>
<tr>
<th>Season/Period</th>
<th>M ha-m</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter (Jan-Feb)</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Pre-monsoon (March-May)</td>
<td>52</td>
<td>13</td>
</tr>
<tr>
<td>S – W monsoon (June – Sept.)</td>
<td>296</td>
<td>74</td>
</tr>
<tr>
<td>N – E monsoon (Oct-Dec)</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total for the Year</strong></td>
<td><strong>400</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
India ranks first in rainfed agriculture globally in both area (86 M ha) and the value of produce.

Rainfed regions in India contribute substantially toward food grain production including 44% of rice, 87% of coarse cereals (sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), maize (*Zea mays* L.), and 85% of food legumes, 72% of oilseeds, 65% of cotton, and 90% of minor millets (Table 1.2).

Rainfed agriculture, with nearly 58 per cent of the cultivated area, contributes 40 per cent of the country's food production.

Even after full irrigation potential of the country is realized, half of the cultivated area will continue to be under rainfed farming.

Hence, it is necessary to increase the productivity of major rainfed crops to meet the ever-increasing demand for food and fiber.

During the past 25 years, there occurred significant changes in the area and yield of important crops of rainfed areas.

Area under coarse cereals decreased by about 10.7 M ha and most of this was under sorghum.

Area under oilseeds increased by 9.2 M ha and most of this increase was due to irrigated rapeseed and mustard and soybean.

Total area under pulses and cotton remained constant but more of cotton became irrigated and shifts in the area occurred from one agro-ecological region to others. Area under chickpea in northern belt decreased but increase in central belt. This change occurred due to increase in area under rice-wheat cropping system which displaced chickpea and also pearl millet to a great extent and maize to a small extent.

### Table 1.2: Area sown under various rainfed crops and percentage of rainfed area

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area sown (M ha)</th>
<th>Rainfed area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>45.5</td>
<td>42</td>
</tr>
<tr>
<td>Coarse cereals</td>
<td>27.5</td>
<td>85</td>
</tr>
<tr>
<td>Sorghum</td>
<td>7.5</td>
<td>91</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>8.7</td>
<td>91</td>
</tr>
<tr>
<td>Maize</td>
<td>8.2</td>
<td>75</td>
</tr>
<tr>
<td>Pulses</td>
<td>22.1</td>
<td>83</td>
</tr>
<tr>
<td>Pigeonpea</td>
<td>3.4</td>
<td>96</td>
</tr>
<tr>
<td>Bengalgram (Chickpea)</td>
<td>7.9</td>
<td>67</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>27.6</td>
<td>70</td>
</tr>
<tr>
<td>Groundnut</td>
<td>6.2</td>
<td>79</td>
</tr>
<tr>
<td>Rapeseed and mustard</td>
<td>6.3</td>
<td>27</td>
</tr>
<tr>
<td>Soybean</td>
<td>9.5</td>
<td>99</td>
</tr>
<tr>
<td>Sunflower</td>
<td>1.8</td>
<td>69</td>
</tr>
<tr>
<td>Cotton</td>
<td>9.4</td>
<td>65</td>
</tr>
</tbody>
</table>

Of these 25 districts, covering 18 M ha of net area sown with 10 per cent of irrigation, receives 375-750 mm rainfall annually spread over central Rajasthan, Saurashtra region of Gujarat and rain shadow region of Western Ghats in Maharashtra and Karnataka.
Rainfed Agriculture: Introduction, Types and History of Rainfed Agriculture in India

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**Basic Facts:**

- India is home to 18% of world’s population, 15% of the world livestock, 4.2% of fresh water resources, 1% of forests, and 0.5% of pasture land, but only has 2.3% of the geographical area.
- India is home to 25% of the world’s hungry population of world. 1 billion along with an estimated 43% of children malnourished under the age of five.
- The net sown area in India has remained constant for several years at 141 M ha, but the human and livestock populations have been steadily increasing. Though the Indian population increased from 361 million in 1951 to 1360 million in 2019, the food-grain production has more than quadrupled, but the yield gains are largely from the irrigated agro-eco systems.
- Notwithstanding the increase in average productivity from 0.6 t/ha in the 1980s to 1.1 t/ha at the present time, large yield gaps exist for rainfed crops in the semiarid regions.
- Even after realizing the full irrigation potential, nearly 40% of the net sown area of 142 M ha will remain totally rainfed.
- The per capita availability of land has fallen drastically from 0.37 ha in 1951 to about 0.19 ha in 2001; and it is projected to decline further to 0.09 ha by 2050. According to the World Bank collection of development indicators arable land (hectares per person) in India was reported at 0.11813 in 2016.

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<table>
<thead>
<tr>
<th>Area Under Irrigated and rainfed conditions in India</th>
<th>Per Capita Land Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class</strong></td>
<td><strong>Area (m ha)</strong></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Total Arable</td>
<td>143.8</td>
</tr>
<tr>
<td>Dryland</td>
<td>34.5</td>
</tr>
<tr>
<td>Rainfed</td>
<td>65.5*</td>
</tr>
<tr>
<td>Irrigated</td>
<td>43.8</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Includes Flood-prone area of 15 m/ha

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**Principles of Agronomy, Reddy & Reddy, 2016**

- Increasing productivity of rainfed cropping systems is of critical importance to meet the food demands of an ever-increasing population in India.
- The potential productivity of maize (Z. mays) in high rainfall regions under rainfed condition are 8.0 t/ha vis-a-vis the national average yield of 2.1 t/ha, indicating an unabridged yield gap of 6 t/ha. Large yield gaps exist in other crops as well which are primarily grown under rainfed conditions.
- Recommended management practices (RMPs) such as improved cultivars, site specific nutrient management (precision agriculture), and water harvesting and recycling can potentially increase the yields in several crops up to 6 t/ha, indicating the large realizable potential under rainfed conditions.
- There are many districts in India where the actual yields are much lower than the national average, and there is enormous potential for improvement.

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**Food security and SRI, Pradhan et al., 2019**

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- There are many districts in India where the actual yields are much lower than the national average, and there is enormous potential for improvement.
According to the present concept, there are 128 districts in the country which face the problems of dryland.

Twelve districts have irrigation covering 30-50 per cent of the cropped area and do not pose serious problems.

Remaining 91 districts covering mainly Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Uttar Pradesh parts of Haryana, Tamil Nadu etc. represent typical dryland area. Total net sown area in these districts is estimated to be 42 M ha of which 5 M ha are irrigated. Rainfall in these districts varies from 375 to 1125 mm. Therefore, more and more efforts are to be made for enhanced and stable production in these areas so that the recurring droughts do not stand in the way of meeting the growing food demands.

**History of Dryland/Rainfed Agriculture:**

- First systematic scientific approach to tackle the problems of dry farming areas was initiated by Tamhane in 1923 on a small plot at Manjri Farm near Pune and the work passed on to Kanitkar in 1926.
- A comprehensive scheme of research was drawn up by Kanitkar with financial support from the ICAR. Realizing the importance, the ICAR launched a comprehensive project on dryland farming at five centers: Sholapur and Bijapur in 1933, Hagari and Raichur in 1934 and Rohtak in 1935.
- A decade of work up to 1943-44 mainly on rainfall analysis, physico-chemical properties of soils, physiological studies on millets and on agronomic aspects resulted in a series of dry farming practices commonly known as the Bombay dry farming practices, Hyderabad dry farming practices and Madras dry farming practices.
- These practices stressed the need for contour bunding, deep ploughing, and application of FYM, low seed rate with wide spacing, mixed cropping and crop rotation. These recommendations could not motivate the farmers to adopt them as the yield advantage was about 15-20 per cent over a base yield of 200-400 kg/ha.
- By the mid-1950s, importance of soil management (soil and moisture conservation) was realized for improving the productivity of dryland and the ICAR established eight Soil Conservation Research Centers in 1954. However, yield improvement was not more than 15-20 per cent over the basic yield of 200-400 kg/ha.
- Importance of short duration cultivars maturing within adequate soil moisture available period (crop growing period) was recognized during 1960s.
- The place of high yielding varieties and hybrids for yield advantage in dryland agriculture was realized in mid-1960s.
- With the establishment of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 1970, emphasis was shifted to multi-disciplinary approach to tackle the problem from several angles.
- Similar efforts were initiated at ICR1SAT, Hyderabad in 1972.
- The ICAR selected 25 dryland agricultural centers all over the country on the basis of the moisture deficit, soil type and rainfall characteristics as indicated below:
1. Agra (Uttar Pradesh)  
2. Akola (Maharashtra)  
3. Anantapur (Andhra Pradesh)  
4. Arjia (Rajasthan)  
5. Ballowal Saunkhri (Punjab)  
6. Bengaluru (Karnataka)  
7. Bijapur (Karnataka)  
8. Biswanath Chariali (Assam)  
9. Chianki (Jarkhand)  
10. Faizabad (Uttar Pradesh)  
11. Hisar (Haryana)  
12. Indore (Madhya Pradesh)  
13. Jagdalpur (Chattisgarh)  
14. Kovilpatti (Tamil Nadu)  
15. Parbhani (Maharashtra)  
16. Phulbani (Odisha)  
17. Rajkot (Gujarat)  
18. Rakhdhiansar (J & K)  
19. Rewa (Madhay Pradesh)  
20. Sardarkrushinagar (Gujarat)  
21. Solapur (Maharashtra)  
22. Varanasi (Uttar Pradesh)  
23. Bellary (Karnataka)  
24. Jhansi (Uttar Pradesh)  
25. Jodhpur (Rajasthan)

The chronology of major events in dryland agricultural research in India is as follows:

1880 The First Famine Commission was appointed by the then British Empire to suggest ways and means to offset the adverse effects of recurring droughts, which country faced from 1860 onwards. An important recommendation of the commission was to set up protective irrigation project.

1920 The Royal Commission on Agriculture stressed the need for scarcity tract development.

1923 Imperial Council of Agricultural Research sanctioned six schemes and established the first Dryland Research Station at Manjari (Pune) by Tamhane.

1933 Bombay Dry Farming Research Schemes at Bijapur and Sholapur the centers of famine tract.

1934 The Madras Dry Fanning Research Scheme at Hagari (near Bellary) and the Hyderabad Dry Farming Research Scheme at Raichur.

1935 The Punjab Dry Farming Research Scheme at Rohtak (Punjab).

1942 Bombay Land Development act passed.

1944 Monograph on dry fanning in India by NV Kanitkar (Bombay, Hyderabad and Madras Dry Farming Practices)

1953 Establishing Central Soil Conservation Board.

1954 The Central Soil and Water Conservation Research and Training Institute at Dehradun.

1954 Soil Conservation Research, Demonstration and Training Center, Ootacamund.

1954 Soil Conservation Research, Demonstration and Training Center, Bellary.

1954 Soil Conservation Research, Demonstration and Training Center, Kota.

1955 Soil Conservation Research, Demonstration and Training Center, Vasad.

1957 Soil Conservation Research, Demonstration and Training Center, Agra.

1957 Soil Conservation Research, Demonstration and Training Center, Chandigarh.

1959 Central Arid Zone Research Institute (CAZRI) was established at Jodhpur to tackle the problems of arid agro-ecosystem.


1962 Launching of Soil Conservation in the Catchments of River Valley Projects.
1970  All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 23 locations (now 25) with the support from Canadian International Development Agency through an instrument of bilateral collaboration signed between the Governments of India and Canada (up to 1987).
1972  The Consultative Group on International Agricultural Research (CGIAR) established the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad
1980  Integrated Watershed Management in the Catchment of Flood prone area
1983  Starting of 47 model watersheds under ICAR.
1984  Initiation of World Bank assisted Watershed Development Programs in four states
1985  The Central Research Institute for Dryland Agriculture (CRIDA) at Hyderabad
1986  Launching of NWDPRA programs by Government of India in 15 states
1989  Integrated Watershed Development Projects (IWDP) by National Watershed Development Board (NWDB)
2006  National Rainfed Area Authority (NRAA).

The ICAR collaborated with Canadian dryland research (Indo-Canadian Dryland Research, from 1970 to 1987. The 1CAR-1CR1SAT collaborative research programs are working in areas of biological nitrogen fixation, agro-forestry, soil and moisture conservation, economics of watershed technology and vegetative barriers in soil and water conservation. The Indo-US collaboration started in 1980. Currently, CRIDA-US collaborative research projects are working on fertilizer use efficiency, germplasm enhancement, evaluation of legumes for high nitrogen fixation, crop simulation modeling and implements for dryland agriculture.

Rainfed Agriculture Research in Gujarat
Agricultural Research Station, JAU, Targadia
Agricultural Research Station, AAU, Arnej

Major constraints and problems in these areas are:

1. Uncertain, erratic and uneven distribution of rainfall
2. Degradation of forests and natural tree cover
3. Low soil fertility and soil depth
4. Shortage of drinking water and assured irrigation for crops
5. Considerable area under wastelands
6. Cultivation of marginal lands due to population and animal pressure
7. Lack of infrastructure and facilities
8. Shortage of fuel wood and fodder
9. Continuance of traditional varieties and management practices
10. Improper management of community lands
2.1 Problems or constraints for crop production in dry farming regions

Most of the cropping in the arid and semi-arid regions continues to be under rainfed conditions. A majority of the farmers are small farmers with meager resources. The poor resource base permits only low input subsistence farming with low and unstable crop yields. The low productivity of agriculture in dry farming regions is due to the cumulative effect of many constraints for crop production.

The problems can be broadly grouped in to

a) Climatic constraints
b) Soil constraints
c) Lack of suitable varieties
d) Traditional cultivation practices
e) Heavy weed infestation
f) Resource constraints
g) Technological constraints
f) Socio economic constraints

2.1.1 Climatic constraints

A) Rainfall characteristics: Among the different climatic parameters, rainfall is an important factor influencing the crop production in dry regions

(i) Variable rainfall: Rainfall varies both in time and space dimension. Annual rainfall varies greatly from year to year and naturally, its coefficient of variation is very high. Generally, higher the rainfall less is the coefficient of variation. In other words, crop failures due to uncertain rains are more frequent in regions with lesser rainfall. The average annual rainfall of India is 1192 mm where as in Gujarat it is 816 mm. Based on the average annual rainfall, the India can be divided into four zones. More than one third of total geographical area in India receives rainfall less than 750 mm (Table. 2.1).

(ii) Intensity and distribution: In general, more than 50 per cent of total rainfall is usually received in 3 to 5 rainy days. Such intensive rainfall results in substantial loss of water due to surface runoff. This process also accelerates soil erosion. Distribution of rainfall during the crop growing season is more important than total rainfall in dryland agriculture.

(iii) Aberrations or variations in monsoon behavior

(a) Late onset of monsoon: If the onset of monsoon is delayed, crops/varieties recommended to the region cannot be sown in time. Delayed sowing lead to uneconomical crop yields.

(b) Early withdrawal of monsoon: This situation is equally or more dangerous than late onset of monsoon. Rainy season crops will be subjected to terminal stress leading to poor yields. Similarly, post-rainy season crops fail due to inadequate available soil moisture, especially during reproductive and maturity phases.

(c) Prolonged dry spells: Breaks of monsoon for 7-10 days may not be a serious concern. Break between two consecutive rainfalls for more than 15 days duration especially at critical stages for soil moisture stress, leads to reduction in yield. Drought due to break in monsoon may adversely affect the crops in shallow soils than in deep soils. It also has ill-effect on crop yield in tropical and sun-tropical regions.
High atmospheric temperature: Because of high atmospheric temperature, the atmospheric demand for moisture increases causing high evapotranspiration losses resulting in moisture stress.

B) Low relative humidity: Low relative humidity results in high ET losses causing moisture stress whenever moisture is limiting.

D) Hot dry winds: Hot dry winds causes desiccation of leaves resulting in moisture stress. High turbulent winds especially during summer months cause soil erosion resulting in dust, storms and loss of fertile soil.

E) High atmospheric water demand: Due to high atmospheric water demand the potential evapotranspiration (PET) exceed the precipitation during most part of the year.

2.1.2 Soil Constraints

The different soil groups encountered in dryland areas are black soils, red soils and alluvial soils. The constraints for crop production are different in different soil groups. The predominant soil group is alluvial where the problems for crop production are not so acute as in red and black soils. The different soil constraints for crop production are

a) Inadequate soil moisture availability: The moisture holding capacity of soils in dry regions is low due to shallow depth especially in alfisols (red soils), low rainfall and low organic matter content.

b) Poor organic matter content: The organic matter content in most of the soils under dryland conditions is very low (< 1 %) due to high temperature and low addition of organic manures. Poor organic matter content adversely affects soil physical properties related to moisture storage.

c) Poor soil fertility: Due to low accumulation of organic matter and loss of fertile top soil-by-soil erosion, the dry land soils are poor in fertility status. Most of the dry land soils are deficient in nitrogen and zinc.

d) Soil deterioration due to erosion (wind, water): In India nearly 175 m.ha of land is subjected to different land degradations, among them, the soil erosion is very predominant. The erosion causes loss of top fertile soil leaving poor sub soil for crop cultivation.

e) Soil crust problem: In case of red soils, the formation of hard surface. Soil layer hinders the emergence of seedlings, which ultimately affect the plant population. Crusting of soil

<table>
<thead>
<tr>
<th>Zone</th>
<th>Average annual rainfall (mm)</th>
<th>Per cent of geographical area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone I (very low rainfall area)</td>
<td>&lt; 350</td>
<td>13</td>
</tr>
<tr>
<td>Zone II (low rainfall area)</td>
<td>350 to 750</td>
<td>22</td>
</tr>
<tr>
<td>Zone III (Medium rainfall area)</td>
<td>750 to 1125</td>
<td>36</td>
</tr>
<tr>
<td>Zone IV (High rainfall area)</td>
<td>&gt; 1125</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 2.1 Classification of India into different zones based on rainfall
surface after rainfall reduces infiltration and storage of rainfall, resulting in high run off.

**f) Presence of hard layers and deep cracks:** Presence of hard layers (pans) in soil and deep cracks affect the crop production especially in case of black soils.

**2.1.3 Lack of suitable varieties:** Most of the crop varieties available for cultivation in dry lands are meant for irrigated agriculture. There are no any special varieties exclusively meant for dryland areas. Hence still more efforts are required to develop varieties in different crops exclusively meant for dryland agriculture.

**2.1.4 Traditional Cultivation practices**

The existing management practices adopted by the farmers are evolved based on long term experience by the farmers. The traditional management practices are still followed by farmers leading to low yields.

- Ploughing along the slope
- Broadcasting seeds/ sowing behind the country plough leading to poor as well as uneven plant stand
- Monsoon sowing
- Choice of crops based on rainfall
- Application FYM in limited quantity
- Untimely weeding
- Low productive cropping systems
- Inadequate nutrient supply
- Traditional storage system

**3.1.5 Heavy weed infestation:** This is the most serious problem in dryland areas. Unfortunately, the environment congenial for crop growth is also congenial for weed growth. Weed seeds germinate earlier than crop seeds and try to suppress the crop growth. The weed problem is high in rainfed areas because of continuous rains and acute shortage of labour. The weed suppression in the early stage of crop growth is required to reduce the decrease in crop yields.

- a) Less access to inputs, poor organizational structure for input supply
- b) Non availability of credit in time
- c) The risk bearing capacity of dryland farmer is very low

**3.1.6 Resource constraints**

1. Most of the resource for dry land are run under subsistence level of farming
2. There is less intention to adopt new technologies in dry lands among the farmers.
3. Occurrence of frequent drought for flood in dry farming areas
4. Uncertainty and is distributed rainfall and mid-season break in monsoon leading to crop failure
5. Difficulties in adoption of new cropping pattern for cropping systems to suit the monsoon and its behaviour
6. Absence of suitable varieties, non-availability of quality seeds, inadequate nutrient supply and problems of soil salinity and alkalinity aggravate the situation in dry farming areas
7. Resource poor dry land farmers are not able to practice soil conservation practices and other new technology
8. There is a limited recognition of indigenous methods of soil and water conservation
9. Poor land preparation and untimely ploughing, sowing, lack of labour and animal power during peak season
10. Lack of adequate linkages between crop and animal components in dry farming

3.1.7 Technological constraints
1. Lack of suitable Technologies for lesser rainfall areas
2. Lack of varieties capable of yielding higher in adverse condition. Improved varieties for high yielding varieties are found more vulnerable to moisture stress as compared to traditional variety
3. Non-availability of seeds of improved varieties and the demand supply is found to be 80% with groundnut, 50% with Sorghum, 25% with pearl millet and 90% with forest species
4. Problems with prediction of sowing rain
5. Laser utilization of improved machineries/ implement under dry lands leading to poor timeliness in feel operation and crop failure/ reduced yield
6. Poor pest and disease management practices, lack of resources for the purchase, ultimately untimely or delay control measures and lack of water for good quality water for spray in dryland
7. Lesser adoption of alternate land use system agroforestry, alley cropping and dry land horticulture in dry farming region
8. Inadequate extension activities reading to poor Technologies dissemination

3.1.8 Social economic constraints
1. Lack of capital, support prices for the produce, marketing facilities and credited proper time make the farmers hesitant to adopt the technology
2. Most of the dry land farmers are resource poor which tends them to avoid risk
3. Many dry land farmers engage only limited labor , mostly family labor for most of the farm activities
4. Prevailing social system in dry regions prevent the farmers in adopting the improved technology
5. Non-promotion of stakeholders concept in development of dry farming

FUTURE PROSPECTS FOR RAINFED FARMING

A. Research:
1. Proper agro-meteorological analysis of climate- soil- crop relationship for efficient crop planning and management
2. As water harvesting systems for crop production is uneconomic including cost of runoff and cost of storage; however, this technique is helpful to stabilize crop production in dry land areas. Therefore, there is a great deal of scope for stabilizing production in dry land areas by adopting water harvesting techniques on community basis.
3. Review of contingent crop planning for Major three current weather conditions and improvement in the contingent crop planning for different zone mainly to mitigate drought effects.
4. Importance the development and release of dual conditions high yielding varieties of food and vegetable crops for normal monsoon season and for dryland conditions.
Availability of seeds of these varieties along with the suitable agronomic practices will certainly improve and stabilize the production and productivity of rainfed areas.

5. Identification of improved soil and moisture conservation practices and turn off management suited to the conditions of individual farm holding as well as the watershed as a whole.

6. Emphasis to increase intensity of cropping by developing appropriate inter-cropping and double cropping systems with importance on pulses and oilseeds.

7. Agro-techniques on socially acceptable cropping systems (viz; laser leveling, application of organic manures, modified method of sowing i.e. Aqua-fertilizer drill and FIRB system of seed bed preparation) bases are to be developed with a view to increase the FUE/WUE, efficient weed management, tillage system and crop residue management including INM.

8. Emphasis on site-specific research mainly to optimise the use of resources available for conservation and utilisation of moisture under rainfed conditions.

9. Proper adoption of alternate land use system including Agro-forestry, Agro-horticulture and fodder based cropping system in terms of diversification in cropping system is required for saving water and for efficient water management.

10. Completion of incomplete major and minor projects and covering about 69 m ha. cultivated under micro irrigations by 2030 is to be exercised.

B. Policy:

1. Undertake significant shift in investment from irrigated to rainfed areas, with a major emphasis on afforestation and soil conservation project organised on a watershed basis.

2. Investment in soil conservation practices including creation of infrastructure as well as water harvesting system such as farm ponds has to be undertaken on a village-by-village basis.

3. Weather aberrations continue to plague dry land farmers. Since seed is the primary input in the adoption of improved farm technologies, seed bank must be established with Government support in order to help farmers adopt contingent strategies.

4. Draft power is a serious constraint in dry land farming. Individual farmer cannot afford to purchase mechanical implements. In this case, a system of custom hiring in the villages would help farmer to complete their operation timely at an affordable cost.

5. High risk is involved in rainfed farming which does not allow farmers to adopt improved crop production technologies. Therefore, availability of crop insurance for drought protection involving selected dry land crops should be implemented.

6. Since farm holdings are small and excessively fragmented, further division of land should be prevented. This can be done by encouraging the development of small scale, agro-based industries and services in the rainfed region.

7. In addition to low productivity in rainfed areas there is also an acute scarcity of fodder. Silvi -pastoral systems on marginal land should be encouraged through liberal financing, and should be established to cope with scarcity during drought years.
- India receives 400 M ha m of rainwater annually (392 M ha m from rainfall and 8 M ha m from other sources).
- Out of 400 M ha m only 105 M ha m (26.25 %) is available for utilization. Out of which 77 M ha m (19.25 %) is available for irrigation and 19 M ha m (4.75 %) for industries and 9 M ha m (2.25 %) for domestic utilization.
- About 160 M ha m falls on agricultural land
- Nearly 24 M ha m is available for harvesting in small scale water harvesting structures
- About 186 M ha m goes to rivers as runoff
- Around one-fourth of the total annual rainfall is received before or after cropping season.

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x-x-x-x-x
Soil

Soil is the uppermost part of the earth crust containing a mixture of minerals. It is a three-phase system containing solid, liquid and gaseous components existing in certain equilibrium.

Ideal dry land soils

Soil texture has a profound influence on the productivity of soil. In general depth, texture, structure, drainage conditions and soil moisture relationship are very important soil properties, which decide the crop growth. Advantages and disadvantages of coarse and fine textured soils regarding crop cultivation are listed in Table 3.1.

Table 3.1 Suitability of coarse and fine textured soils for dry land agriculture

<table>
<thead>
<tr>
<th>Character</th>
<th>Course textured soil</th>
<th>Fine textured soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Example</td>
<td>Sandy soil</td>
<td>Clay soil</td>
</tr>
<tr>
<td>2. Plant’s nutrients</td>
<td>Low</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>3. Moisture holding capacity</td>
<td>Less</td>
<td>High</td>
</tr>
<tr>
<td>4. Bulk density</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>5. Pore space</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>6. pores</td>
<td>Large and continuous</td>
<td>Minute and discontinuous</td>
</tr>
<tr>
<td>7. Infiltration / Percolation</td>
<td>Very rapid</td>
<td>Low</td>
</tr>
<tr>
<td>8. Permeability</td>
<td>High</td>
<td>Slow</td>
</tr>
<tr>
<td>9. Water Stagnation</td>
<td>Nil</td>
<td>High</td>
</tr>
<tr>
<td>10. soil erosion</td>
<td>Less</td>
<td>High (Especially in slopes)</td>
</tr>
<tr>
<td>11. dry land agriculture</td>
<td>With uniform distribution of rainfall and sufficient moisture conservation measures</td>
<td>Preferable and possible for double cropping in case of stored up/residual soil moisture</td>
</tr>
</tbody>
</table>

Dry land soils and their characteristics:

In India, dry land occurs in almost all the regions of the country and the major soil types in these dry regions are red soils (Alfisols), black soils (Inceptisols and Vertisols), Laterite soils (Ultisols) and desert soils (Aridisols). The characteristics, features of the major soil groups and the prospects for raising crops in these soils under dry land conditions are described hereunder.

1. Red soils (Alfisols):

Red soil is an important soil group in India and especially in dry land. These soils are moderately weathered and derived from granites, gneiss and other metamorphic rocks, either in-situ or from these decomposed rock materials washed down to lower level by rain. They are generally red or reddish brown or yellowish brown in colour due to the coating of ferric oxides on soil particles. Morphological types are red loams and red earth with loose topsoil.

Main features of red soils are light texture, friable structure, absence of lime concretions and free calcium carbonates and contents of soluble salts. These soils are slightly acidic to slightly alkaline nature, medium in cation exchange capacities and near base
saturated. Dominant clay mineral is \textit{kaolinite} with an admixture of \textit{illite}. Red soils are well drained with a moderate permeability. Excessive gravel, surface crust formation and susceptibility to erosion in high slopes are some of the problems in these soils. They are low in organic matter content and nutrients like nitrogen and phosphorus. Occasionally, micronutrients like zinc is deficient in red soils. Potassium content in these soils is generally adequate for raising crops and the soil pH range is 6 to 7.

Most of the red soils have been classified in the order alfisols and these type of soils occur widely in the states of Andhra Pradesh, Bihar, Assam, TN, West Bangal, Goa, Daman, Diu and parts of Kerala, Maharastra and Karnataka.

\textbf{Crop cultivation in red soils under dry land conditions:}

Rooting depth of crops is affected in the red soils as it consists of distinct gravel and weathered rock fragments. Crops grown under red soils in dry land conditions are susceptible to drought if the rainfall is poorly distributed during the cropping season. The soil lacks aggregation property leading to surface roughness, rapid seal of the soil surface after rainfall and results in soil crusting on drying. Tilling the soil is easier on wet conditions, but becomes hard and difficult on drying. Tillage with high wetness may lead to compaction and ploughing will be perfect only under limited soil moisture conditions.

Establishment of a good crop is risky and the rapid surface drying due to poor rainfall distribution may affect the crop growth under dry land conditions in the red soils. Cultivation of crops will increase the infiltration initially, but in due course, the rate of infiltration will be reduced. Soil erosion will be less in presence of crops or vegetation in red soils and on denudation or allowing the land, as fallow will lead to high runoff and erosion. Leaching of nutrients is common due to its well-draining capacity, which necessitates adequate and frequent application of nutrients in red soils.

Groundnut, sorghum, pearl millet, fox tail millet, red gram, green gram, cowpea, castor and horse gram are suitable crops for red soils. Groundnut + red gram, Groundnut + castor, sorghum+ red gram are the profitable intercropping systems which help in preventing crop loss during drought years.\textbf{Black soil (Vertisol/ inceptisol)}

Black soils are another important group of soils that occur in dry land conditions. They are characterized by dark Grey to black colour, high clay content, neutral to slightly alkaline in soil reaction and developing deep cracks during summer season. These are locally known as black cotton soil. Depth of the soil varies ranges from a low of 50 cm to several metres and in many cases it overlies decompose rocks (parent material) known as murram.

Black soil are formed from \textit{Deccan} basalt trap rocks either in-situ or on the transported parent material. In the formation of black soils, presence of a high proportion of alkaline earth in the weathering complex is of great importance. These soils have impeded drainage and low permeability. It occurs in areas under monsoon climate, mostly in semi-arid and sub humid type. High clay content and \textit{montmorillonite} type of clay mineral impart high swelling and shrinkage properties of these soils.

Black soils are low in organic matter content, available nitrogen and phosphorus and sometimes zinc, but reach in base nutrients like calcium, magnesium and potassium. Soil pH
is in the range of 7.5 to 8.5. Soil is highly clayey and the clay content varies from 35 to 60% and sometimes up to 80%.

Table 3.2: Improved technologies for red soils

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Technology</th>
<th>Aims</th>
<th>Suggestions/Observations</th>
</tr>
</thead>
</table>
| 1       | Land & water management    | Realigning and strengthening of field or boundary bunds for conservation of soil and water | • Establishment of vegetation cover on bunds  
• Formation of graded bunds  
• Growing vegetative filter strips on contours  
• Summer ploughing  
• Contour tillage in slope lands  
• Opening of dead furrows (at 10 feet interval)  
• Construction of dugout pond  
• For soil depth more than 20 cm, deep tillage once in three years for better infiltration of rainwater and to reduce pest and weed problems  
• Mulching with agricultural waste @ 5 t/ha, within 10 days after sowing of crop to prevent evaporation losses.  
• Water harvesting in farm ponds and subsequent use as supplementary/lifesaving irrigation to increase yields of rain fed crops. |
| 2       | Crop management            | Cropping season in coincidence with safe period of rainfall. Double cropping in deep and medium soils | • Depending on amount and distribution of rainfall and retention capacity of soil  
• Following double cropping / intercropping / sequential cropping  
• In case of surface crusting, application of sand @ 40 t/ha before sowing to decrease the crust strength, to facilitate better infiltration of water into soil and to improve germination and crop stand  
• Intercropping with pulses reduce runoff losses, reduce soil erosion, conserve more moisture, add more organic matter in the soil and ultimately improves soil productivity |
| 3       | Fertility management       | Increasing the crop response to applied nutrients especially phosphorus | • Application of phosphate fertilizers  
• Application of nitrogen in splits with sufficient moisture  
• Crop residue addition to improve soil physical properties  
• Addition of other nutrients as per soil test |

These soils are characterized by high swelling and shrinkage, plasticity and stickiness. Black soils are generally calcareous neutral to slightly alkaline in reaction, high base status and high cation exchange capacity. They possess high soil moisture holding capacity. Runoff is severe in black soil and it is prone to erosion and the soil loss is estimated to be in the range of 6 to 8 t/ha per year. Shallow black soils on slopes have been classified in
the order of Entisols and Inceptisols, while the deep medium black soils in the order of Vertisols. Black soil occur extensively in the states of Maharashtra, Madhya Pradesh and parts of Andhra Pradesh, Gujarat and Tamilnadu

**Table- 3.3 : Improved Technologies for black soil**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Technology</th>
<th>Aims</th>
<th>Suggestions/Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Land &amp; Water management</td>
<td>• Promotion of intake of water in soil</td>
<td>• Construction of water storage structures like farm ponds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Improvement of aeration and workability</td>
<td>• Following watershed concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduction in soil erosion and runoff</td>
<td>• Application of FYM @ 20 tons per hectare for better infiltration of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Facilitation of safe disposal of excess water</td>
<td>• Formation of graded Bund</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Formation of a channel with a slope of 1-0.25% along the graded Bund and merging this</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>channels into a grassed waterway to drain water without any soil erosion</td>
</tr>
<tr>
<td>2</td>
<td>Land configuration</td>
<td>• Reduction in Runoff</td>
<td>• Rough with ridges and furrow to facilitate ponding of water</td>
</tr>
<tr>
<td>3</td>
<td>Dry season tillage</td>
<td>• loosening of soil after harvest of post rainy season crop</td>
<td>• Blade harrowing after receipt of Pre-monsoon rain to break clods</td>
</tr>
<tr>
<td>4</td>
<td>Pre-monsoon dry seedling</td>
<td>• Utilisation of first rain, ensuring early establishment of crops</td>
<td>• Placing seeds in 5 cm depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and reduction in the difficulty in planting in wet and sticky soil</td>
<td>• Good results reported in crops of sorghum, cotton, main sunflower ii, green gram,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>red gram and poor results reported in in pearl millet, soybean and groundnut</td>
</tr>
<tr>
<td>5</td>
<td>Improved cropping system</td>
<td>• Increasing the crop productivity and Returns</td>
<td>• Best suited to areas with moderately dependable and favourable rainfall&gt;750 mm</td>
</tr>
<tr>
<td>6</td>
<td>Fertility management</td>
<td>• Increasing the crop response to applied nutrients especially</td>
<td>• Recommendation as per soil test/ application of nitrogenous fertilizers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>nitrogen</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Pest management</td>
<td>• Low cost and maintenance of environment (pesticides used only at</td>
<td>• Following integrated pest management practices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>threshold level of pests)</td>
<td></td>
</tr>
</tbody>
</table>

**Crop cultivation in black soils and dry land conditions**

A large area with Vertisols is under dryland conditions in India. Black soil is more productive than red soil. Important crops grown under the soils are coarse grains, cotton, oilseeds and pulses. Growing of crops is possible during post-rainy season (*rabi* season) with stored up soil moisture in shallow black soils (Entisols). In case of medium and deep black soils (i.e. Vertisols/ Inceptisols), growing crops is possible in season and post rainy season.
which stored up soil moisture (double cropping) depending on the quantity and distribution of rainfall. Cotton, Sorghum and other millets, pulses; especially chickpea, chillies, sunflower, safflower and coriander are suitable crops.

**Laterite soils (Ultisols)**

Laterite soils are well-drained soil with good hydraulic conductivity. They are formed by soil forming process called *laterization*. Laterite is a geological term, which means literally rock. Under high rainfall conditions, silica is released and leached downwards and upper horizons of the soil become rich in oxides of iron and Aluminium. This process is called *laterization*. Laterites are subdivided into high and low level laterites. High level laterites are found capping the summits of hills and plateau of the high lands and they are not useful for agriculture as they are thin and gravely. Low level laterites comprising of clay and loam occur in coastal regions on both sides of the peninsular region and are of considerable agricultural importance. *Laterization* is intensified with increase in rainfall with low intensity.

Texture of a laterite soil is generally loam in top layers and depth of the loamy layer varies and in eroded nature. These soils are Pale, gritty, shallow and poor in plant nutrients in top layer. Soils in lower layers are of fine texture, darker and rich in plant nutrients and organic matter. All laterite soils are very poor in base materials like calcium and magnesium. The pH of the soil is low and acidic in nature. Soil clay type is generally *kaolinite* with traces of *illite*. Most of the laterite soils are classified under the order ultisols. These soils are well developed on the summits of Hills of the Deccan, Karnataka, Kerala and Madhya Pradesh, the Ghat regions of Orissa, Maharashtra, Kerala, West Bengal, Tamil Nadu and Assam.

**Crop cultivation in laterite soils under dry land conditions**

At lower elevations, suitable crops for cultivation under dryland conditions are rice (either single or double cropping), minor millets, trees and shrubs. Soil and moisture conservation measures may become necessary in regions of low to medium rainfall. At higher elevation in laterite soil plantation crops like tea, coffee, cinchona, rubber and cashew are grown.

**Desert soil (Aridisols)**

These soils occur in hot desert region in India. Rainfall of the region is ranging from as low as 50 mm to the highest of 400 mm of which the major portion is received during monsoon season. Potential evapo-transpiration is very high and showing aridity. A major part of the region consists of sand dunes and undulations. A zone of accumulation of lime concretions at a depth of 60 to 120 cm and presence of alkaline earth carbonate are common futures of this type of soils. Clay content is very low ranging between 2 to 8% and presence of sodium clay make the soil susceptible to dispersion and less permeable. The pH of the soil ranges from 8 to 9. Clay type is *illite* with small amounts of *kaolinite*. Desert soils are classified under the order Aridisols. These soils are distributed in the regions of Rajasthan, southern Haryana and Punjab and northern Gujarat.

**Crop cultivation in desert soils under dryland conditions**

Soils are light textured and the moisture holding capacity and nutrient availability are less. They are generally poor in available nitrogen and phosphorus. Soil salinity is a common problem and effective soil depth is influenced by the presence of calcium and carbonate concretions at various depth. Crop cultivation is possible only in deep soils either during *kharif* or *rabi* season based on the rainfall quantity and its distribution.
Sub-Montane Soils

Sub-montane soils occur in undulating lands of sub Himalayan regions under coniferous forest. Regions with sub-montane soils are characterized by high rainfall, accumulation of organic matter, absence of free lime and acidic nature. Landslides and soil erosion are common problems associated with sub-montane soils which lead to the leaching of bases.

Crop cultivation in sub-montane soils under dry land conditions

Soil moisture storage varies from 20 to 30 cm per metre soil profile. As the regions are characterized by high rainfall, double cropping is possible in sub-montane soils. Soils are low in available nitrogen and phosphorus and crops respond well to the application of N and P for higher productivity.

Saline and sodic soils

Saline and sodic soils occur mainly in arid and semi-arid regions of the country where the annual temperature are high and rate of evaporation generally exceeds rainfall. The situation leads to accumulation of salts in surface layers of the soil. In India, such soils are spreading over 8.5 million hectare of land and they are found with poor organic carbon, available nitrogen and Zinc.

Saline soils contain excessively soluble salts and the dominant soil type are chlorides and sulphates of sodium, magnesium and Calcium. Total salt concentration as expressed by soil EC is generally more than 4 dS/ m. These soils are associated with water logging, saline groundwater and aridity.

Sodic soils generally contain salts of carbonates and bicarbonates of sodium where the soil EC will be less than 4 dS/m and exchangeable sodium percentage more than 15%. These soils can be observed with stagnation of muddy water after rain for many days and they are very hard when dry and very soft when wet. Sodic soils contain insoluble calcium carbonate at high pH level (>9.5).

Crop cultivation in saline sodic soils under dry farming conditions

Reclamation Technologies for growing crops in Salt affected soil differ depending upon the availability of source of water. For areas which depend only on rainfall as the source of moisture, cultivation of salt tolerant plants species and planting techniques are recommended. Crops have been identified to salt stress conditions and few such crops which are sensitive and tolerant to soil salinity and sodicity under dry land conditions are given in table 3.4.

Table 3.4 : Sensitive and tolerant to soil salinity and sodicity under dry land conditions

<table>
<thead>
<tr>
<th>Saline soils</th>
<th>Alkaline/ sodic soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitive</strong></td>
<td><strong>Tolerant</strong></td>
</tr>
<tr>
<td>Highly sensitive</td>
<td>Highly tolerant</td>
</tr>
<tr>
<td>Legumes like green gram, black gram, lentil, gram and peas</td>
<td>Direct sown rice, wheat, pearl millet, barley, oats, mustard</td>
</tr>
<tr>
<td>Moderate sensitive</td>
<td>Medium Tolerant</td>
</tr>
<tr>
<td>Major and minor millets</td>
<td>Sunflower, cotton, kernel grass, Trees like acacia, tamarind, ber</td>
</tr>
</tbody>
</table>
Climate

The behaviour of atmospheric phenomenon at a given place and time is defined as weather and the composite day-to-day weather elements for a given place or region over a period is referred as climate.

Dry climate

A dry climate is one in which the average annual precipitation is definition in relation to evaporation. It can be divided into arid and semi-arid climate.

Arid climate

It can be defined as an extreme dry climate where the average annual precipitation is less than 500 mm and usually in the range of 250–2500 mm. Generally, the rainfall is well short of evapotranspiration demand of the atmosphere. The precipitation is insufficient for crop production.

Semi-arid climate

It can be defined as a climate where the average annual precipitation is greater than 500 mm and generally, crop production is possible with dry farming methods or with supplemental irrigation.

The tropical retreat and semi-arid climate I have many features in common the distinct character of this climate is lack of sufficient rainfall to sustain crop production. They are centre on the latitudes from 20 to 25 degree north and South.

Climate largely limits crop and animal production, ensures the human comfort, influences on health determine clothing and housing etc. Its influence on agriculture is enormous throughout the world and in a country like India where agriculture is the backbone of development, importance is manifold. The success of failure of farming is closely related to the prevailing weather condition. However, there are possibilities to optimise farm production by existing cropping pattern and agronomic practices to suit the climate of a locality. Weather resumes significance in nearly every phase of Agricultural activity from the preparatory tillage to harvesting and storage. Therefore, a sound knowledge of climate factors and an understanding of the complex processes of interaction between the climate and the biological processes of the plants are essential to a scientific approach on farming.

The principal climatic factors limiting crop production in the order of priority under dryland conditions are precipitation temperature, sunlight, wind length of growing season etc.

1. Effect of precipitation in dryland

The common forms of precipitation are drizzle, rain, snow, sleet and hail. In dry lands rainfall limitation is the greatest factor in influencing the crop growth and yield. Rainfall plays a major role in determining the real potential of a crop and the region. It also has an influence on deciding the sequence and timing of farming operation and farming system

General advantages of precipitation

- Recharge of groundwater
- Decision on various agricultural operations
- Decision on pattern of land utilisation
- Selection of crops, varieties, cropping and farming system
- Storage in reservoirs
- Decision on vegetation
- Development of irrigation sources
- Hydro power generation.
Forms of precipitation and their effect on crop growth.
General forms of precipitation are rainfall, snow and hail. Their common characteristics in dry regions and its effects on crop growth are discussed as under.

### Table 3.5 Rainfall and its characteristics in dry lands

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>General effects</th>
<th>If excess</th>
<th>If deficient</th>
</tr>
</thead>
</table>

Table 3.6 Hail and its characteristics in dry lands

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>General effects</th>
<th>Effects in crop growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>General 1. Rare occurrence in tropics 2. Rare occurrence in high latitudes 3. Common in warm season</td>
<td>1. Common in sub-montane areas in India 2. Rare occurrence in southwest monsoon season</td>
<td>1. Floods under high temperature/storms 2. Road or path closure 3. Mechanical damage to trees 4. Hazards to air crafts</td>
</tr>
</tbody>
</table>

2. Effect of solar radiation in dry lands

Sun is a primary source of heat and light on the earth and radiant energy striking the earth is called as insolation. The insolation consists of the sunlight and temperature, which act as the important factors of weather and climate. Distribution of insolation is closely related to latitude and it is greater at equator and decrease towards poles regularly. Influence of solar radiation decides the rate at which plants develop at various stages of growth. Every crop has limitations in their temperature and sun light requirements.
Table 3.7 Snow and its characteristics in dry lands

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>General</th>
<th>In dry regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Present in mountainous regions in mid-latitudes</td>
<td></td>
<td>Significant to water users in arid lands adjacent to snow-capped mountains</td>
</tr>
<tr>
<td>2. Release by rising temperature</td>
<td></td>
<td>1. Floods under high temperature/storms</td>
</tr>
<tr>
<td>3. Ground water recharge</td>
<td></td>
<td>2. Road or path closure</td>
</tr>
<tr>
<td>4. Generally more on leeward side of mountains and uplands from oceans</td>
<td></td>
<td>3. Mechanical damage to trees</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Problems in housing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Sheet or reel type of erosion</td>
</tr>
</tbody>
</table>

1. Run off
2. Soil erosion
3. Suffocation to crop plants

Table 3.8. Sunlight and its characteristics in dry lands

<table>
<thead>
<tr>
<th>Duration (Relative length of day and light)</th>
<th>Intensity</th>
<th>Quality (Wave length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Varies with latitude and season</td>
<td>a. Energy source for whole plant process</td>
<td>a. Wave length ranging from 0 to 0.25 micron is harmful to plants</td>
</tr>
<tr>
<td>b. Equal day and night at equator</td>
<td>b. Extreme low (&lt; 500 candles) and extreme high intensities inhibit photosynthesis.</td>
<td>b. Wave length ranging from 0.30 to 0.55 micron has photoperiodic effect</td>
</tr>
<tr>
<td>c. Day light ranging from zero (winter to 24 hours (summer) at polar regions</td>
<td>c. Wave length ranging from 0.40 to 0.79 micron is good for photosynthesis</td>
<td></td>
</tr>
<tr>
<td>d. Crops flowering behaviour depends on duration of light</td>
<td>d. Wave length more than 0.79 micron has no effect on photosynthesis</td>
<td></td>
</tr>
<tr>
<td>e. Division as short day, long day and day neutral plants</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Effects on crop growth in arid region

a. Arid and semi-arid crops are mostly short day plants (< 10 hours) and they require long nights for flowering
b. Most sun shine in dry areas (20-30° latitude on both sides).
c. More dry matter production (if moisture is not a limiting factor).
### Table 3.9 Effect of temperature and its characteristics in dry lands

<table>
<thead>
<tr>
<th>General Characteristics</th>
<th>Characteristics in arid regions</th>
<th>Effects on crop growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Decrease from equator to poles</td>
<td>1. Seasonal higher</td>
<td>1. Temperature limit for each stage of every crop</td>
</tr>
<tr>
<td>2. Wind direction and movement influence mean temperature in a locality</td>
<td>2. Diurnal variation more</td>
<td>2. High temperature is not a serious problem if soil moisture is adequate</td>
</tr>
<tr>
<td>3. Mountains act as barriers on horizontal temperature distribution</td>
<td>3. Highest in arid and semi-arid tropical climates</td>
<td>3. Slow or stop in growth rate at very high temperature</td>
</tr>
<tr>
<td>4. Temperature reduction by 3.3°F for every 1000 feet elevation.</td>
<td>4. Occasionally below freezing temperature in tropical deserts</td>
<td>4. Premature fall of leaves and fruits</td>
</tr>
<tr>
<td></td>
<td>5. Lesser at higher attitudes in arid and semi-arid climates.</td>
<td>5. Prolonged chilling or freezing reduce water flow in plants leading to retardation or killing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Disastrous dry and hot conditions</td>
</tr>
</tbody>
</table>

### 3. Effect of wind in dry lands

#### General effects of wind

- Favours cross pollination
- Affects pollination by insects
- Causes mechanical damage to plants
- Leading to shattering of flowers and seeds
- Stripping of fruits and nuts
- Dispersal of weed seed
- Wind erosion and removal of soil fertility
- Increase evapo-transpiration
- Reduces germination (by covering seeds)
- Prevention of frost (on occasions)
- Dispersal of pollen and seeds
- Decides monsoon pattern
- Desiccation of plants
- Blow from desert may have reduction in photosynthesis and translocation of food materials
- Influence migration of insects and pathogens
Various types of wind are gale, storm and hurricane and their sub types. They have differential effects on crop growth.

**Table 3.10 Gale and its effects**

<table>
<thead>
<tr>
<th>Types of Gale</th>
<th>Speed (km/hour)</th>
<th>General effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Moderate gale</td>
<td>56 to 60</td>
<td>1. Swaying to uprooting of trees</td>
</tr>
<tr>
<td>2. Fresh gale</td>
<td>61 to 74</td>
<td>2. Slight to heavy structural damage</td>
</tr>
<tr>
<td>3. Strong gale</td>
<td>75 to 88</td>
<td>3. Causing obstructions to traffic</td>
</tr>
<tr>
<td>4. Whole gale</td>
<td>89 to 102</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.11 Storm and its effect**

<table>
<thead>
<tr>
<th>Type of storm</th>
<th>General Characteristics</th>
<th>General effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Thunder storms (89 to 102 km/hr)</td>
<td>1. Unknown polar regions 2. Diameter from 5 to 35 miles 3. Heavy rainfall with large drops 4. Chances of hail/snow/snow pellets 5. Thunder storm followed by lighting</td>
<td>1. Severe damage to air planes in flight 2. Run off and severe soil erosion</td>
</tr>
<tr>
<td>3. Tornadoes (102 to 117 km/hr)</td>
<td>1. Violent storms 2. Maximum width of one to two miles 3. Accompanied by thunder storms, rain, hail and lighting 4. Funnel shaped column from the base of the cloud 5. Funnel diameter of 50 m or more</td>
<td>1. Unbelievable destruction in its pathways including explosion of buildings</td>
</tr>
</tbody>
</table>

**Table 3.12 Hurricane and its effects**

<table>
<thead>
<tr>
<th>General Characteristics</th>
<th>General Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Speed in the range of 117 to 132 km/hr.</td>
<td>1. Structural destruction</td>
</tr>
<tr>
<td>2. Energy depends on moisture content in warm air</td>
<td>2. Flooding</td>
</tr>
<tr>
<td>3. Diameter from 100 to 6000 miles/hr (minimum of 25 miles/hr)</td>
<td>3. Shipping affected</td>
</tr>
<tr>
<td>4. Eye diameter from 5 to 30 miles</td>
<td></td>
</tr>
<tr>
<td>5. Also called cyclones, typhoons and tropical storms</td>
<td></td>
</tr>
</tbody>
</table>
4. Effect of other climatic factors
   a. Humidity
   Humidity refers the measure of moisture content in atmosphere and it plays a significant role in climate and weather. Air can hold a certain quantity of water vapour at a given temperature and several expressions are used for denoting the humidity. They are:
   1. **Specific humidity**: It can be defined as the ratio of the mass of water vapour actually in the air to unit mass of air.
   2. **Dew point or Saturated Vapour Pressure**: It is all the water vapour that can be held by the air at a given temperature and pressure.
   3. **Absolute humidity**: It is defined as the actual amount of water vapour in the air.
   4. **Relative Humidity**: It is referred as the ratio of water vapour actually present in the atmosphere to the amount of water vapour required for saturating it at that temperature (expressed in percentage).

   Among these expressions, the best known and mostly used reference to water vapour is relative humidity (RH%) and it is found to be maximum during early morning hours and the minimum is afternoon.

   **Table 3.13: Humidity and its characteristics in dry lands**

<table>
<thead>
<tr>
<th>General Characteristics</th>
<th>Characteristics in arid region</th>
<th>Effects in crop growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Greater on land surface in winter</td>
<td>1. RH low in arid regions (12 to 30 %)</td>
<td>1. Evaporation will be less under high RH condition</td>
</tr>
<tr>
<td>2. RH will increase on decreasing temperatures</td>
<td>2. High RH may compensate low rainfall in part</td>
<td>2. Plants can withstand low humidity if soil moisture is adequate</td>
</tr>
<tr>
<td>3. Low specific humidity in polar regions</td>
<td>3. RH depends on direction of prevailing winds in semi arid regions</td>
<td>3. Water requirement of crops can be decided with prevailing RH</td>
</tr>
<tr>
<td></td>
<td>4. Absolute humidity will always be low</td>
<td></td>
</tr>
</tbody>
</table>

   b. Dew:
   Dew formation mostly occurs at night because of its dependence on radiational cooling of leaf and soil surface. Clear sky, low wind speed, high atmospheric humidity and vegetation of low heat capacity are the main factors contributing to dew formation. The absorption of dew by the plants depends on type of plant species, its intensity, duration of dewfall and soil moisture conditions. Under moisture deficit conditions, effect of dew is important as it can accelerate the restoration of turgor pressure at night and delay the stress at day time.

**ECO SYSTEMS UNDER ARID AND SEMI ARID CONDITIONS IN INDIA**

**A. ARID ECOSYSTEM**

**Agro eco region number 1 (cold arid eco region)**

**Location**: North Western Himalayas covering Ladakh and Gilgit districts of Jammu and Kashmir and consisting of 15.2 million hectare.
**Climate:** Mild summer and severe winter with the mean annual rainfall less than 150 mm. Precipitation is always lesser than potential evapotranspiration.

**Soil type:** skeletal and calcareous soils with alkalinity and low to medium organic matter content.

<table>
<thead>
<tr>
<th>Rain:</th>
<th>Water vapour condenses around condensation nuclei (such as dust) and falls when the droplet is heavy enough.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleet:</td>
<td>Same formation as rain, but it freezes somewhere along its path from the clouds to the ground. Sleet is a mixture of snow and rain.</td>
</tr>
<tr>
<td>Snow:</td>
<td>Water droplets form and then freezing occurs slowly, allowing for the development of uniquely designed ice crystals know as snow. Snow is formed when water vapour is deposited in the higher reaches of the atmosphere at a temperature less than zero degrees Centigrade, and then falls to the ground. Snowflakes are typically symmetrical, hexagonally shaped groups of ice crystals that form while falling in and below clouds. Simply put - Snow forms if the air in a cloud is below freezing. The water vapour then turns to ice instead of rain and the tiny ice crystals stick together until they form snowflakes. When they get heavy enough to fall, they drop out of the clouds. At this point though, we still don’t know whether they will end up as rain or remain as snow. This depends on the temperature of the air they travel through on the way down to the ground. If it gets warmer, they turn into rain, but if the air stays close to freezing all the way down, then the snowflakes will make it without melting and so fall as snow. If this occurs in a mountain area, it is possible for snow to be falling on the mountaintop while lower down in the valley the air is warmer and so it is raining instead.</td>
</tr>
<tr>
<td>Hail:</td>
<td>Water droplets are carried high into the atmosphere by thunderstorm updrafts, which cause them to freeze. Multiple drops tend to freeze together, which is why the diameter of hail can be large.</td>
</tr>
<tr>
<td>Dew:</td>
<td>Water vapour on the ground condenses on objects such as blades of grass when the surface temperature is equal to the dew point</td>
</tr>
<tr>
<td>Frost:</td>
<td>Dew forms and then it freezes. This commonly occurs when night time. Radiational cooling drops the ground temperature down enough. There are three kinds of frost: Delicate crystallized ice on windowpanes is called <em>hoar frost</em>. <em>Glazed frost</em> consists of thick coatings of ice on cold surfaces. <em>Rime frost</em> is formed when super-cooled water droplets freeze on contact with cold surfaces. It often occurs when freezing fogs or drizzle blanket the ground.</td>
</tr>
<tr>
<td>Freezing rain:</td>
<td>Forms and falls as rain. At the surface or near the surface, the temperature is at or below freezing, which causes the rain to freeze on contact.</td>
</tr>
<tr>
<td>Fog:</td>
<td>A thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapour.</td>
</tr>
<tr>
<td>Mist:</td>
<td>A very thin fog.</td>
</tr>
<tr>
<td>Drizzle:</td>
<td>A light steady rain in fine drops (0.5 mm) and intensity &lt; 1 mm/hr.</td>
</tr>
</tbody>
</table>

**Land use:** Sparse forest trees. Regular cropping programs include vegetables, millet, wheat, fodder, pulses, barley and fruit crops like apple and apricot.

**Livestock:** Dominated by mule and followed by sheep, goat and yak rearing.

**Constraints:**

- Severe climatic conditions limiting crop growth
- Length of growing season is less than 90 days in a year which limits crop production
- Nutrient imbalance due to Sandy and gravelly and moderate to calcareous soil.
Potential of the region

- Dry fruit crops apricot and off season vegetables peas

Agro Eco region number 2 (Hot arid eco region 1)

**Location**: South western part of Punjab and Haryana, Western parts of Rajasthan, *kutch* and North *kathiawad* Peninsula in Gujarat. Area under this Zone extends to 31.9 million hectares.

**Climate**: Hot summer and cold winters with a minimum annual rainfall less than 400 mm. Potential evapotranspiration demand ranges between 1500 and 2000 mm annually. Length of growing season is less than 90 days per year.

**Soil type**: Desert and Sandy soils with calcareous and alkaline nature

**Vegetation and cropping pattern**: Drastically reduced, sparses and tropical thorn forest. Rainfed mono-cropping with short duration crops like pearl millet and pulses. In irrigated land crops like sugar cane, cotton, mustard, gram and wheat are grown.

**Constraints**:
- Indiscriminate deforestation
- Scanty and Erratic rainfall pattern leading to draught at critical stages of Crop growth
- Soil salinity and nutrient imbalance

**Potential of the zone**
- Developing irrigation sources can further increase the productivity
- Dryland Agroforestry and forestry may sustain the productivity

Hot arid eco region 2

**Location**: *Deccan* Plateau covering the districts of Bellary, Tumkur, North Chitradurga, South west parts of Bijapur, Raichur of Karnataka and Anantapur of Andhra Pradesh. The total spread of the region is 4.9 million hectares.
Climate: Hot and dry summer and mild winters with the mean annual rainfall ranging from 400 to 500 mm. Severe drought prone area throughout the year and length of growing period is less than 90 days in a year.

Soil type: Shadow to medium red loam soil and deep clayey black soil

Vegetation and cropping pattern: Tropical dry deciduous and tropical thorn forests. Irrigated farming includes growing of sugarcane, cotton, safflower and groundnut. Rainfed Mono-cropping is carried out during rainy season pearl millet or post rainy season with stored residual moisture sorghum or safflower

Constraint:
- Soil erosion during rainy season
- Poor and ill distributed rainfall and occasional crop failure due to prolonged dry spell
- Poor Workability of black soil

SEMI ARID ECOSYSTEM

Agro Eco region number 4 (Hot semi-arid eco region 1)

Location: Parts of Gujarat (5 districts), Haryana (8 districts), Punjab (7 districts), Union Territory of Delhi, Uttar Pradesh (29 districts) and Rajasthan (11 districts). This region extends to 2.2 million hectares.

Climate: Hot and dry summers and cold winters with the mean annual rainfall ranging between 500 to 1000 mm. Length of growing period is 90 to 150 days in a year.

Soil type: Course to fine loam and sand dunes

Vegetation and cropping pattern: Tropical deciduous and tropical thorn forest. Irrigated farming is followed in 65% of the total cultivable area and the crops cultivated are wheat, rice, millet, maize, pulses, berseem, mustard and sugarcane. Rainfed agriculture is followed in 35% of the area with mono-cropping of seasonal crops like sorghum, soybean and pigeon pea and post seasonal crops like ok pulses, lentil and wheat on residual moisture.

Constraints:
- Nature of soil with low water holding capacity
- Lowering water table
- Salinity and sodicity due to in perfect drainage condition

Potential of the region:
- Introduction of irrigation facilities and changes in cropping pattern from low value crops like millets to high value crops like cotton, sugarcane and wheat
- Crop diversification to oil seeds

Agro Eco region number 5 (Hot semi-arid eco region 2)

Location: Western Madhya Pradesh (10 districts), South Eastern parts of Rajasthan (5 districts) and Gujarat (10 districts) and Union Territory of Diu. This zone covers 17.6 million hectares.

Climate: Hot and wet summer and cold winter with a mean annual rainfall of 500 to 1000 mm and the length of growing period 90 to 150 days. Certain districts of the states of Madhya Pradesh, Rajasthan and Gujarat are prone to drought once in three years.

Soil type: Deep loam to clay and black soils. Coastal areas in Gujarat have clay and sandy soils with slight alkalinity.

Vegetation and cropping pattern: This region is characterized by dry deciduous forest. Dry farming is practised in most areas with kharif crops like sorghum, pearl millet, pigeon pea,
groundnut, soybean, maize and pulses and with Rabi crops like safflower, sunflower and gram

**Constraints:**
- Intermittent or occasional drought occurrence
- Soil salinity or alkalinity due to imperfect drainage or inundation of seawater leading to crop failure

**Potential of the region:**
- Development through minor irrigation project
- Forestry and dryland horticulture activities

**Agro Eco region number 6 hot semi-arid eco region 3**

**Location:** Western parts of Maharashtra (20 districts), Northern parts of Karnataka (6 districts) and Western parts of Andhra Pradesh (2 districts). The zone spreads over 31 million hectares.

**Climate:** Hot and humid summer and mild and dry winter with an annual rainfall of 600 to 1000 mm. Length of growing period is between 90 and 150 days. Some districts are drought prone and the drought spell may be severe once in 3 years.

**Soil type:** Shallow loam to Clay soils with calcareous or alkaline nature

**Vegetation and cropping pattern:** The region is found with tropical dry deciduous tropical thorn forest. Mono-cropping is followed under rainfed condition with *kharif* crops like pearl millet or post rainy season crops like safflower and sunflower. With irrigation facilities crops like cotton and groundnut are grown.

**Constraints:**
- Prolonged dry spells leading to reduced growth and crop failure
- Soil erosion
- Nutrient imbalance in soil

**Potential of the region:**
- Achievable high productivity with better water management practices
- Dryland Agroforestry and horticulture

**Agro Eco region number 7 (Hot semi-arid eco region 4)**

**Location:** Deccan Plateau and Eastern parts of Andhra Pradesh (14 districts). This region spreads over 16.5 million hectares.

**Climate:** Hot and moist summer and mild and dry winter with the mean annual rainfall of 600 to 1100 mm. Length of the growing period is ranging between 90 and 150 days in a year. In this zone 6 districts are prone to drought.

**Soil type:** Black cotton soils are calcareous and strong alkaline in nature. Isolated track are found with red soils, which is non-calcareous and neutral in reaction.

**Vegetation and cropping pattern:** Tropical dry deciduous and thorny forest. Traditional farming under rainfed condition is followed with *kharif* crops like sorghum, cotton, pigeon pea, rice, groundnut and castor and *rabi* crops like sorghum, sunflower, safflower and other oil seeds, rice is the major crop under irrigated condition.

**Constraints:**
- Soil erosion due to high runoff leading to loss of soil and nutrients
- Crop failure due to frequent drought under rainfed condition
- Imperfect drainage under irrigated conditions leading to salinity and sodicity
Potential of the region:
- Achievable high productivity with better water management practices
- Dryland Agroforestry and horticulture
- Watershed program

Agro Eco region number 8 (Hot semi-arid eco region 5)
Location: Eastern Ghats and Southern parts of Deccan Plateau covering the parts of Andhra Pradesh (one district), Karnataka (9 districts) and Tamil Nadu (15 districts) and extending over an area of 19.1 million hectares.
Climate: Hot and dry summer and mild winter with a mean annual rainfall of 600 to 1000 mm and the length of growing period is 90 to 150 days in a year. Parts of Karnataka receive rainfall in summer season and rest of the region receives rain during winter.
Soil type: Red loamy soil
Vegetation and cropping pattern: Tropical dry deciduous and thorny forest. Under irrigated conditions, cotton, sugar cane and rice are the major crops. Rainfed cultivation is the traditional practice with crops like millets, pulses and oilseeds especially groundnut in kharif season and with crops like sorghum and oilseeds especially safflower in Karnataka in Rabi season.
Constraints:
- Severity of soil erosion
- Severity of drought due to poor moisture holding capacity of soil

Potential of the region:
- Dryland Horticulture with suitable fruit crops
- Floriculture under irrigated condition
Soil Erosion:

Soil erosion is the process of detachment of soil particles from the top soil and transportation of the detached soil particles by wind and/or water.

The agents causing erosion are wind and water. The detaching agents are falling raindrop, channel flow and wind. The transporting agents are flowing water, rain splash and wind.

Nature and extent of erosion

The problem of soil erosion exists all over the country. Out of the 329 m. ha of India’s geographical area about 175 m. ha (53.3%) is subjected to soil erosion and some kind of land degradation (Druvanarayana, 1993). About 150 m. ha is subjected to wind and water erosion. It is estimated that about 5,333 Mt of soil is detached annually. Out of this 29% is carried away by rivers to seas and about 10% is deposited in reservoirs resulting in 1-2% of loss of storage capacity annually. The estimated annual soil loss is 16.35 tones/ha/year.

Losses due to erosion

1. Loss of fertile top soil
2. Loss of rain water
3. Loss of nutrients
4. Silting up of reservoirs
5. Damage to forests
6. Reduction in soil depth
7. Floods
8. Adverse effect on public health
9. Loss of fertile land
10. Economic losses

Types of erosion:

There are two major types of soil erosion

a) Geological erosion (Natural or normal erosion): is said to be in equilibrium with soil forming process. It takes place under natural vegetative cover completely undisturbed by biotic factors. This is very slow process.

b) Accelerated erosion: is due to disturbance in natural equilibrium by the activities of man and animals through land mismanagement, destructing of forests over grazing etc., Soil loss through erosion is more than the soil formed due to soil forming process.

Based on the agents causing erosion, erosion is divided into

a. Water erosion
b. Wind erosion
c. Wave erosion

A. Water erosion

Loss of soil from land surface by water including run off from melted snow and ice is usually referred to as water erosion.

Major erosive agents in water erosion are impacting/falling raindrops and runoff water flowing over soil surface.

Process of water erosion

Detachment of soil particles is by either raindrop impact or flowing water. Individual raindrops strike the soil surface at velocities up to 9 m/s creating very intensive hydrodynamic force at the point of impact leading to soil particle detachment. Over land flow
detaches soil particles when their erosive hydrodynamic force exceeds the resistance of soil to erosion. Detached soil particles are transported by raindrop splash and runoff. The amount of soil transported by runoff is more than due to raindrop splash. Thus the falling raindrops break the soil aggregates and detach soil particles from each other. The finer particles (silt and clay) block the soil pores and increase the rate of runoff and hence loss of water and soil. 

**Forms/Types of water erosion**

Water erosion occurs in stages identified as sheet erosion, rills, gullies, ravines, landslides and stream bank erosion.

a) **Sheet erosion**: It is the uniform removal of surface soil in thin layers by rainfall and runoff water. The breaking action of raindrop combined with surface flow is the major cause of sheet erosion. It is the first stage of erosion and is least conspicuous, but the most extensive.

b) **Rill erosion**: When runoff starts, channelization begins and erosion is no longer uniform. Raindrop impact does not directly detach any particles below flow line in rills but increases the detachment and transportation capacity of the flow. Rill erosion starts when the runoff exceeds 0.3 to 0.7 mm/s. Incisions are formed on the ground due to runoff and erosion is more apparent than sheet erosion. This is the second stage of erosion. Rills are small channels, which can be removed by timely normal tillage operations.

c) **Gully erosion**: It is the advanced stage of water erosion. Size of the unchecked rills increases due to runoff. Gullies are formed when channelized runoff form vast sloping land is sufficient in volume and velocity to cut deep and wide channels. Gullies are the spectacular symptoms of erosion. If unchecked in time no scope for arable crop production.

d) **Ravines**: They are the manifestations of a prolonged process of gully erosion. They are typically found in deep alluvial soils. They are deep and wide gullies indicating advanced stage of gully erosion.

e) **Landslides**: Landslides occur in mountain slopes, when the slope exceeds 20% and width is 6 m. Generally, landslides cause blockage of traffic in ghat roads.

f) **Stream bank erosion**: Small streams, rivulets, torrents (hill streams) are subjected to stream bank erosion due to obstruction of their flow. Vegetation sprouts when streams dry up and obstructs the flow causing cutting of bank or changing of flow course.

**Factors affecting water erosion**

a) **Climate**: Water erosion is directly a function of rainfall and runoff. Amount, duration and distribution of rainfall influences runoff and erosion. High intensity rains of longer duration causes severe erosion. Greater the intensity, larger the size of the raindrop. Rainfall intensity more than 5 cm/hr is considered as severe. Total energy of raindrops falling over a hectare land with rainfall intensity of 5 cm /hr is equal to 625 H.P. This energy can lift 89 times the surface 17.5 cm of soil from one ha to a height of 3 ft. Two thirds of the above energy is used for sealing soil pores. Runoff may occur without erosion but there is no water erosion without runoff. The raindrop thus breaks down soil aggregates, detaches soil particles and leads the rainwater with the fine particles. These fine particles seal the pores of the surface soil and increases runoff causing erosion.

b) **Topography**: The degree, length and curvature of slope determine the amount of runoff and extent of erosion. Water flows slowly over a gentle slope where as at a faster rate over a
steeper one. As water flows down the slope, it accelerates under the forces of gravity. When runoff attains a velocity of about 1 m/s it is capable of eroding the soil. If the percent of slope is increased by 4 times the velocity of water flowing down is doubled. Doubling the velocity quadruples the erosive power and increases the quantity of soil that can be transported by about 32 times and size of the particles that can be transported by about 64 times.

c) Vegetation: Vegetation intercepts the rainfall and reduces the impact of raindrops. It also decreases the velocity of runoff by obstructing the flow of water. The fibrous roots are also effective in forming stable soil aggregates, which increases infiltration and reduces erosion.

d) Soil Properties: Soil properties that influence soil erodability by water may be grouped into two types.

i. Those properties that influence the infiltration rate and permeability
ii. Those properties that resist the dispersion, splashing, abrasion and transporting forces of rainfall and runoff.

The structure, texture, organic matter and moisture content of upper layers determine the extent of erosion. Sandy soils are readily detachable but not readily transportable. Soils of medium to high clay content have low infiltration capacities and they are readily transported by water after they are dispersed, but their detachability is generally low.

e) Man and beast

Man and beast accelerates erosion by extensive farming and excessive grazing. Faulty practices like cultivation on steep slopes, cultivation up and down the slope, felling and burning of forests etc., leads to heavy erosion. Excessive grazing destroys all vegetation and increases the erosion.

Estimation of soil loss by water erosion

Based on the mechanism and factors influencing soil erosion, a universal soil loss equation (USLE) developed by Wischmeier (1959) is most useful for predicting soil loss due to water erosion. It is an empirical equation and estimates average annual soil loss per unit area as a function of major factors affecting sheet and rill erosion. It enables determination of land management erosion rate relationships for a wide range of rainfall, soil slope and crop and management conditions and to select alternative cropping and management combinations that limit erosion rates to acceptable limits.

\[ A = R \times K \times L \times S \times C \times P \]

where,

- **A**: predicted soil loss in t/ha/year
- **R**: rainfall erosivity factor or index
- **K**: soil erodibility factor
- **L**: length of slope factor
- **S**: slope steepness factor
- **C**: soil cover and management factor and
- **P**: erosion control factor
B. Wind erosion

Erosion of soil by the action of wind is known as wind erosion. It is a serious problem on lands devoid of vegetation. It is more common in arid and semi-arid regions. It is essentially a dry weather phenomenon stimulated by the soil moisture deficiency. The process of wind erosion consists of three phases:

a. initiation of movement b. transportation and c. deposition.

About 33 m.ha in India is affected by wind erosion. This includes 23.49 m.ha of desert and about 6.5 m.ha of coastal sands. The Thar Desert is formed mainly by blow in sand.

Mechanism of wind erosion

Lifting and abrasive action of wind results in detachment of tiny soil particles from the granules or clods. The impact of these rapidly moving particles dislodge other particles from clods and aggregates. These dislodged particles are ready for movement. Movement of soil particles in wind erosion is initiated when the pressure by the wind against the surface soil grains overcomes the force of gravity on the grains. Minimum wind velocity necessary for initiating the movement of most erodable soil particles (about 0.1 mm diameter) is about 16 km/hr at a height of 30.5 cm. Most practical limit under field conditions, where a mixture of sizes of single grained material present is about 21 km/hr at a height of 30.5 cm.

In general movement of soil particles by wind takes place in three stages: saltation, surface creep and suspension.

a. Saltation:

It is the first stage of movement of soil particles in a short series of bounces or jumps along the ground surface. After being rolled by the wind, soil particles suddenly leap almost vertically to form the initial stage of movement in saltation. The size of soil particles moved by saltation is between 0.1 to 0.5 mm in diameter. This process may account for 50 to 70% of the total movement by wind erosion.

b. Surface creep:

Rolling and sliding of soil particles along the ground surface due to impact of particles descending and hitting during saltation is called surface creep. Movement of particles by surface creep causes an abrasive action of soil surface leading to break down of non-erodable soil aggregates. Coarse particles longer than 0.5 to 2.0 mm diameter are moved by surface creep. This process may account for 5 to 25% of the total movement.

c. Suspension:

Movement of fine dust particles smaller than 0.1 mm diameter by floating in the air is known as suspension. Soil particles carried in suspension are deposited when the sedimentation force is greater than the force holding the particles in suspension. This occurs with decrease in wind velocity. Suspension usually may not account for more than 15% of total movement.
Soil & Water Conservation Techniques

Definition of soil conservation
Soil conservation is using and managing the land based on the capabilities of the land itself involving application of the best management practices leading to profitable crop production without land degradation.

Control of water erosion
Water erosion occurs simultaneously in two steps: detachment of soil particles by falling raindrops and transportation of detached particles by flowing water. Hence preventing the detachment of soil particles and their transportation can minimize water erosion.

Principles of water erosion control are….
- Maintenance of soil infiltration capacity
- Soil protection from rainfall
- Control of surface runoff and
- Safe disposal of surface runoff

For a sound soil conservation program every piece of land must be used in accordance with the land capability classification.

Measures of water erosion control
1. Agronomic measures
2. Mechanical measures (Engineering measures)
3. Agrostological measures

AGRONOMIC MEASURES OF SOIL CONSERVATION
In soil and water conservation programs agronomic measures have to be considered in co-ordination with others for their effectiveness. These measures are effective in low rainfall areas particularly in fairly erosion resistant soils having gentle slope (< 2 %).

The different agronomic measures include
1. Land preparation
2. Contour cultivation
3. Choice of crops
4. Strip cropping
5. Crop rotation / cropping systems
6. Cover crops
7. Mulching
8. Application of manures and fertilizers
9. Application of chemicals

a) Land preparation: Land preparation including post-harvest tillage influence intake of water, obstruction to surface flow and consequently the rate of erosion. Deep ploughing or chiseling has been found effective in reducing erosion. Rough cloddy surface is also effective in reducing erosion.
b) Contour cultivation (Contour farming): A line joining the points of equal elevation is called contour. All the cultural practices such as ploughing, sowing, inter-cultivation etc. done across the slope reduce soil and water loss. By ploughing and sowing across the slope,
Each ridge of plough furrow and each row of the crop act as obstruction to the runoff and provide more time for water to enter into the soil leading to reduced soil and water loss.

c) **Choice of crops**: Row crops or tall growing crops such as sorghum, maize, pearl millet etc. are not effective in conserving soil as they expose majority of the soil and hence they are known as erosion permitting crops. Whereas close growing crops such as cowpea, groundnut, green gram, black gram etc., which protect soil are known as erosion resisting crops as they are very effective in reducing soil loss by minimizing the impact of rain drop and acting as obstruction to runoff.

d) **Strip cropping**: It is a system of growing of few rows of erosion resisting crops and erosion permitting crops in alternate strips on contour (across the slope) with the objective of breaking long slopes to prevent soil loss and runoff. Close growing erosion resisting crops reduce the transporting and eroding power of water by obstructing runoff and filtering sediment from runoff to retain in the field. The width of the erosion permitting and erosion resisting crops vary as per the slope of the field. The strip cropping resembles the intercropping.

With increase in per cent slope of the soil, the width of erosion permitting and erosion resisting crops decreases. **The normal ratio between the erosion resisting crops and erosion permitting crops is 1: 3.**

The strip cropping is divided into four types as follows

i) **Contour strip cropping**: The erosion permitting crops and erosion resisting crops are grown in alternate strips along the contours.

ii) **Field strip cropping**: Alternate strips of erosion permitting crops and erosion resisting crops are raised across the general slope not necessarily on exact contour

iii) **Wind strip cropping**: Strip cropping of erosion permitting and erosion resisting crops across the direction of the most prevailing wind irrespective of the contour.

iv) **Buffer strip cropping**: this type of strip cropping is practiced in areas having steep slopes and badly eroded soils where strips of permanent cover crops or perennial legumes or grasses or shrubs are alternated with field crops.

*The strip cropping is simple, cheap and effective soil conservation practice and can be adopted by the farmers.*

e) **Crop rotation / cropping system**: Mono-cropping of erosion permitting crops accelerates soil and water loss year after year. Intercropping of erosion permitting crops and erosion resisting crops or their rotation has been found effective for reducing soil and water loss. Inclusion of legumes like lucerne in crop rotation reduces soil loss even in soils having 13% slopes.

f) **Cover crops**: Good grounds cover by canopy gives the protection to the land like an umbrella and minimize soil erosion. Besides conserving soil and moisture, the cover crops hold those soluble nutrients, which are lost by leaching. The third advantage of the cover crops is the addition of organic matter. The legumes provide better cover and better protection. Among the legumes cowpea has been found to produce maximum canopy followed by horsegram, green gram, black gram and dhaincha.

g) **Mulching**: Mulching of soil with available plant residues reduce soil loss considerably by protecting the soil from direct impact of raindrop and reducing the sediment carried with runoff. A minimum plant residue cover of 30 per cent is necessary to keep runoff and soil...
loss within the acceptable limits. Vertical mulching also reduce soil loss particularly in vertisols by increasing infiltration.

h) **Application of manures and fertilizers**: Organic manures besides supplying nutrients improve soil physical conditions thereby reduce soil loss. Fertilizers improve vegetative canopy, which aid in erosion control.

i) **Use of chemicals**: Breakdown of aggregates by the falling raindrops is the main cause of detachment of soil particles. Soils with stable aggregates resist breakdown and thus resist erosion. Aggregate stability can be increased by spraying chemicals like poly vinyl alcohol @ 480 kg/ha (rate will depend on the type of soil). Soils treated with bitumen increase water stable aggregates and infiltration capacity of the soil.

### MECHANICAL MEASURES (ENGINEERING MEASURES)

The basic principle are: (i) shaping the land surface manually or with implements in such a way as to reduce the velocity of runoff, (ii) to allow more time for rainfall to stand on soil surface, and (iii) to facilitate more infiltration of rainfall into soil layers.

Choice of any particular method under a given situation is influenced by rainfall characters, soil type, crops, sowing methods and slope of land.

- **Basin listing**: Formation of small depressions (basins) of 10–15 cm depth and 10–15 cm width at regular intervals using an implement called basin lister. The small basins collect rainfall and improve its storage. It is usually done before sowing. It is suitable for all soil types and crops.

- **Bunding**: Formation of narrow based or broad based bunds across slope at suitable intervals depending on slope of field. The bunds check the free flow of runoff water, impound the rainwater in the inter-bund space, increase its infiltration and improve soil moisture storage. Leveling of inter-bund space is essential to ensure uniform spread of water and avoid water stagnation in patches. It can be classified into three types:
  - **Contour bunding**: Bunds of 1 m basal width, 0.5 m top width and 0.5 m height are formed along the contour. The distance between two contour bunds depends on slope. The inter-bund surface is leveled and used for cropping. It is suitable for deep red soils with slope less than 1%. It is not suitable for heavy black soils with low infiltration where bunds tend to develop cracks on drying. Contour bunds are permanent structures and require technical assistance and heavy investment.
  - **Graded/field bunding**: Bunds of 30-45 cm basal width, and 15-20 cm height are formed across slope at suitable intervals of 20-30 m depending on slope. The inter-bund area is leveled and cropped. It is suitable for medium deep-to-deep red soils with slopes up to 1%. It is not suitable for black soils due to susceptibility to cracking and breaching. Bunds can be maintained for 2-3 seasons with reshaping as and when required.
  - **Compartmental bunding**: Small bunds of 15 cm width and 15 cm height are formed in both directions (along and across slope) to divide the field into small basins or compartments of 40 sq. m. size (8 × 5 m). It is suitable for red soils and black soils with a slope of 0.5-1%. The bunds can be formed before sowing or immediately after sowing with local wooden plough. It is highly suitable for broadcast sown crops. CRIDA has recommended this method as the best *in situ* soil moisture conservation measure for Kovilpatti region of Tamil Nadu. Maize, sunflower, sorghum performs well in this type of bunding.
(iii) **Ridges and furrows:** Furrows of 30-45 cm width and 15-20 cm height are formed across slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep to deep black soils and deep red soils. It can be practiced in wide row spaced crops like cotton, maize, chillies, tomato etc. It is not suitable for shallow red soils, shallow black soils and sandy/ gravelly soils. It is not suitable for broadcast sown crops and for crops sown at closer row spacing less than 30 cm. Since furrows are formed usually before sowing, sowing by dibbling or planting alone is possible. Tie ridging is a modification of the above system of ridges and furrows where the ridges are connected or tied by a small bund at 2–3 m interval along the furrows. Random tie ridging is another modification where discontinuous furrows of 20–25 cm width, 45–60 cm length and 15 cm depth are formed between clumps or hills of crops at the time of weeding. Yet another modification of ridges and furrows method is the practice of sowing in lines on flat beds and formation of furrows between crop rows at 25–30 DAS. This enables sowing behind plough or through seed drill.

(iv) **Broad Bed Furrow (BBF):** Here beds of 1.5 m width, 15 cm height and convenient length are formed, separated by furrows of 30 cm width and 15 cm depth. Crops are sown on the beds at required intervals. It is suitable for heavy black soils and deep red soils. The furrows have a gradient of 0.6%. Broad bed furrow has many advantages over other methods.

- It can accommodate a wide range of crop geometry *i.e.*, close as well as wide row spacing.
- It is suitable for both sole cropping and intercropping systems.
- Furrows serve to safely guide runoff water in the early part of rainy season and store rainwater in the later stages.
- Sowing can be done with seed drills.
- It can be formed by bullock drawn or tractor drawn implements. Bed former cum seed drill enables BBF formation and sowing simultaneously, thus reducing the delay between rainfall receipts and sowing.

(v) **Dead furrow:** At the time of sowing or immediately after sowing, deep furrows of 20 cm depth is formed at intervals of 6–8 rows of crops. No crop is raised in the furrow. Sowing and furrowing are done across slope. It can be done with wooden plough in both black and red soils.

**AGROSTOLOGICAL METHODS**

The use of grasses to control soil erosion, reduce run off and improve soil moisture storage constitutes the agrostological method. Grasses with their close canopy cover over soil surface and profuse root system, which binds soil particles, provide excellent protection against runoff and erosion. The following are the various agrostological methods of *in situ* moisture conservation.

(i) **Pastures/grass lands:** Raising perennial grasses to establish pastures or grass lands is recommended for shallow gravelly, eroded, degraded soils. Grass canopy intercepts rainfall, reduces splash erosion, checks runoff and improves soil moisture storage from rainfall.

(ii) **Strip cropping with grasses:** Alternate strips of grasses and annual field crops arranged across slope check runoff and erosion and help in increasing moisture storage in soil.
(iii) **Ley farming:** It is the practice of growing fodder grasses and legumes and annual crops in rotation. Grasses and legumes like *Cenchrus, styloare* grown for 3–5 years and followed by annual crops like sorghum for 2 year. When the field is under grasses or legumes, soil moisture conservation is improved.

(iv) **Vegetative barriers:** Vegetative barrier consists of one or two rows of perennial grasses established at suitable interval across the slope and along the contour. It serves as a block to free runoff and soil transport. *Vetiver, Cenchrus* etc., are suitable grasses. Vetiver can be planted in rows at intervals of 40 m in 0.5% slope. Plough furrows are opened with disc plough first before commencement of monsoon. 5–8 cm deep holes are formed at 20 cm interval and two slips per hole are planted in the beginning of rainy season. The soil around the roots is compacted. Vetiver barriers check runoff and prevent soil erosion. While they retain the soil, they allow excess runoff to flow through their canopy without soil loss. It is adapted to drought and requires less care for maintenance. It does not exhibit any border effect on crops in adjacent rows. It allows uniform spread of water to lower area in the field resulting in uniform plant stand thus increasing yield of a crop by 10–15%. It facilitates better storage of soil moisture. If fodder grasses like *Cenchrus glaucus* or marvel grass are used, fodder can also be harvested and given to the animal. Vegetative barriers are best suited for black soil. Unlike contour bunding, which gives way due to development of crack in summer in black soils, vegetative barriers do not allow such phenomenon in black soil. Hence, the vegetative barriers can be effectively maintained in black soil for 4–5 years. After 4–5 years, replanting material can also be had from the old barrier by ‘quartering’.
5.1 Introduction

Low rainfall or failure of monsoon rain is a recurring feature in India. This has been responsible for droughts and famines. The word drought generally denotes scarcity of water in a region. However, aridity and drought are due to insufficient water, aridity is a permanent climatic feature and is the culmination of a number of long-term processes. However, drought is a temporary condition that occurs for a short period due to deficient precipitation for vegetation, river flow, water supply and human consumption. Drought is due to anomaly in atmospheric circulation.

Aridity Vs. Drought

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Aridity</th>
<th>Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Permanent feature</td>
<td>Temporary condition of scarcity of varying duration</td>
</tr>
<tr>
<td>Factors</td>
<td>Culmination of many long term processes, considers all climatic features</td>
<td>Caused by deficient rainfall</td>
</tr>
<tr>
<td>Aspect described</td>
<td>Description of Climate</td>
<td>Description of Water availability</td>
</tr>
</tbody>
</table>

5.2 Definition of drought

There is no universally accepted definition for drought.

- Early workers defined drought as prolonged period without rainfall.
- According to Ramdas (1960) drought is a situation when the actual seasonal rainfall is deficient by more than twice the mean deviation.
- American Meteorological Society defined drought as a period of abnormally dry weather sufficiently prolonged for lack of water to cause a severe hydrological imbalance in the area affected.
- Prolonged deficiencies of soil moisture adversely affect crop growth indicating incidence of agricultural drought. It is the result of imbalance between soil moisture and evapo-transpiration needs of an area over a fairly long period so as to cause damage to standing crops and to reduce the yields.
- The irrigation commission of India defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall.

Criteria of Drought:

- NCA (1976) Agricultural drought as an occasion when at least four consecutive weeks receive rainfall half of the normal (normal rainfall being 5 mm or more) during
the *kharif* crop season

- **Drought areas**: Regions which experienced drought in more than 20 per cent of years
- **Chronic drought areas**: Regions which experienced drought in more than 40 per cent of the years
- **Drought free period**: When cumulative AE curve is above cumulative PE/2 curve
- **Moderate drought period**: When cumulative AE curve lies b/w cumulative PE/2 and PE/4 curves.
- **Severe drought period**: When cumulative AE curve is below cumulative PE/4 curve

**Annawary system:**

Crop condition assessed through visual estimates

1. Production above 75% of normal: No drought
2. Production 50 to 75% of normal: Moderate drought
3. Production 25 to 50% of normal: Severe drought
4. Production less than 25% of normal: Disastrous drought

**5.3 Classification of drought**

Drought can be classified based on duration, nature of users, time of occurrence and using some specific terms.

**5.3.1 Based on duration**

- **a. Permanent drought**: This is characteristic of the desert climate where sparse vegetation growing is adapted to drought and agriculture is possible only by irrigation during entire crop season.

- **b. Seasonal drought**: This is found in climates with well defined rainy and dry seasons. Most of the arid and semiarid zones fall in this category. Duration of the crop varieties and planting dates should be such that the growing season should fall within rainy season.

- **c. Contingent drought**: This involves an abnormal failure of rainfall. It may occur almost anywhere especially in most parts of humid or sub humid climates. It is usually brief, irregular and generally affects only a small area.

- **d. Invisible drought**: This can occur even when there is frequent rain in an area. When rainfall is inadequate to meet the evapo-transpiration losses, the result is borderline water deficiency in soil resulting in less than optimum yield. This occurs usually in humid regions.

**5.3.2 Based on relevance to the users (National Commission on Agriculture, 1976)**

- **a) Meteorological drought**: It is defined as a condition, where the annual precipitation is less than the normal over an area for prolonged period (month, season or year).

- **b) Atmospheric drought**: It is due to low air humidity, frequently accompanied by hot dry winds. It may occur even under conditions of adequate available soil moisture. It refers to a condition when plants show wilting symptoms during the hot part of the day when...
transpiration exceeds absorption temporarily for a short period. When absorption keeps pace with transpiration the plants revive. (Mid day wilt).

c) **Hydrological drought:** Meteorological drought, when prolonged results in hydrological drought with depletion of surface water and consequent drying of reservoirs, tanks etc. It results in deficiency of water for all sectors using water. This is based on water balance and how it affects irrigation as a whole for bringing crops to maturity.

d) **Agricultural drought (soil drought):** It is the result of soil moisture stress due to imbalance between available soil moisture and evapotranspiration of a crop. It is usually gradual and progressive. Plants can therefore, adjust at least partly, to the increased soil moisture stress. This situation arises because of scanty precipitation or its uneven distribution in both space and time.

Relevant definition of agricultural drought appears to be a period of dryness during the crop season, sufficiently prolonged to adversely affect the yield. The extent of yield loss depends on the crop growth stage and the degree of stress. It does not begin when the rain ceases, but actually commences only when the plant roots are not able to obtain the soil moisture rapidly enough to replace evapo-transpiration losses.

5.3.3 Based on time of occurrence

a) **Early season drought:** It occurs due to delay in onset of monsoon or due to long dry spells after early sowing

b) **Mid season drought:** Occurs due to long gaps between two successive rains and stored moisture becoming insufficient during the long dry spell.

c) **Late season drought:** Occurs due to early cessation of rainfall and crop water stress at maturity stage.

5.3.4. Other terms to describe drought

a) **Relative drought:** The drought for one crop may not be a drought situation for another crop. This is due to mismatch between soil moisture condition and crop selection. For eg. A condition may be a drought situation for growing rice, but the same situation may not be a drought for growing groundnut.

b) **Physiological drought:** Refers to a condition where crops are unable to absorb water from soil even when water is available, due to the high osmotic pressure of soil solution due to increased soil concentration, as in saline and alkaline soils. It is not due to deficit of water supply.

5.5 Periodicity of drought

The Indian Meteorological Department examined the incidence of drought for the period from 1871 to 1967, utilizing the monthly rainfall of 306 stations in the country. It was seen that during 1877, 1899, 1918 and 1972 more than 40 per cent of the total area experienced drought. General observation on the periodicity of drought in respect of different meteorological sub divisions of India is given below.
### Meteorological sub divisions | Period of recurrence of drought
---|---
Assam | Very rare, once in 15 years
West Bengal, MP, Konkan, Coastal AP, Kerala, Bihar, Orissa | Once in 5 years
South interior Karnataka, Eastern UP, Gujarat, Vidharbha, Rajasthan, Western UP, TN, Kashmir, Rayalaseema and Telangana | Once in 3 years
Western Rajasthan | Once in 2.5 years

### 5.6 Important causes for agricultural drought are
- Inadequate precipitation
- Erratic distribution
- Long dry spells in the monsoon
- Late onset of monsoon
- Early withdrawal of monsoon
- Lack of proper soil and crop management

### 5.7 Effect of drought/water deficit on physio-morphological characteristics of plants

#### Effect on water deficit on crop

- **a) Water relations:** Alters the water status by its influence on absorption, translocation and transpiration. The lag in absorption behind transpiration results in loss of turgor as a result of increase in the atmospheric dryness.

- **b) Photosynthesis:** Photosynthesis is reduced by moisture stress due to reduction in Photosynthetic rate, chlorophyll content, leaf area and increase in assimilates saturation in leaves (due to lack of translocation).

- **c) Respiration:** Increase with mild drought but more serve drought lowers water content and respiration.

- **d) Anatomical changes:** Decrease in size of the cells and inter cellular spaces, thicker cellwall, greater development of mechanical tissue. Stomata per unit leaf tend to increase.

- **e) Metabolic reaction:** All most all metabolic reactions are affected by water deficits.

- **f) Hormonal Relationships:** The activity of growth promoting hormones like cytokinin, gibberlic acid and indole acetic acid decreases and growth regulating hormone like abscisic acid, ethylene, etc., increases.

- **g) Nutrition:** The fixation, uptake and assimilation of nitrogen are affected. Since dry matter production is considerably reduced, the uptake of NPK is reduced.

- **h) Growth and Development:** Decrease in growth of leaves, stems and fruits.
Maturity is delayed if drought occurs before flowering while it advances if drought occurs after flowering.

i) **Reproduction and grain growth:** Drought at flowering and grain development determines the number of fruits and individual grain weight, respectively. Panicle initiation in cereals is critical while drought at anthesis may lead to drying of pollen. Drought at grain development reduces yield while vegetative and grain filling stages are less sensitive to moisture stress.

j) **Yield:** The effect on yield depends hugely on what proportion of the total dry matter is considered as useful material to be harvested. If it is aerial and underground parts, effect of drought is as sensitive as total growth. When the yield consists of seeds as in cereals, moisture stress at flowering is detrimental. When the yield is fiber or chemicals where economic product is a small fraction of total dry matter moderate stress on growth does not have adverse effect on yields.
6.1 Crop Adaptations

The ability of crop to grow satisfactorily under water stress is called drought adaptation. Adaptation is structural or functional modification in plants to survive and reproduce in a particular environment.

Crops survive and grow under moisture stress conditions mainly by two ways: (i) escaping drought and (ii) drought resistance (Fig. 6.1)

![Flow chart showing different mechanisms for overcoming moisture stress](image)

6.1.1 Escaping Drought

Evading the period of drought is the simplest means of adaptation of plants to dry conditions. Many short duration desert plants, (ephemerals), germinate with rains and mature in five to six weeks. These plants have no mechanism for overcoming moisture stress and are, therefore, are not drought resistant.

In cultivated crops, the ability of a cultivar to mature before the soil dries is the main adaptation to growth in dry regions. However, only very few crops have such a short growing season to be called as ephemerals. Certain varieties of pearl millet mature within 60 days after sowing. Short duration pulses like cowpea, greengram, black gram can be included in this category. In addition to earliness, they need drought resistance because there may be dry spells within the crop period of 60 days. The disadvantage about breeding early varieties is that yield is reduced with reduction in duration.
6.1.2 Drought Resistance

Plants can adopt to drought either by avoiding stress or by tolerating stress due to different mechanisms. These mechanisms provide drought resistance.

i. Drought avoidance

<table>
<thead>
<tr>
<th>(water savers)</th>
<th>(water spenders)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Restricting transpiration</td>
<td>1. Efficient root system</td>
</tr>
<tr>
<td>1. Early stomata closer</td>
<td>2. High root/shoot ratio</td>
</tr>
<tr>
<td>2. Increased photosynthetic efficiency</td>
<td>3. Increases osmotic potential</td>
</tr>
<tr>
<td>3. Low rates of cuticular respiration</td>
<td></td>
</tr>
<tr>
<td>4. Lipid deposition on foliage</td>
<td></td>
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<tr>
<td>5. Reduced leaf area</td>
<td></td>
</tr>
<tr>
<td>6. Morphology of leaf surface</td>
<td></td>
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<tr>
<td>7. Water storage in the plant</td>
<td></td>
</tr>
</tbody>
</table>

ii. Drought tolerance

<table>
<thead>
<tr>
<th>(water savers)</th>
<th>(water spenders)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mitigating stress</td>
<td>1. Metabolic strain</td>
</tr>
<tr>
<td>1. Resistance to dehydration</td>
<td>2. Plastic strain</td>
</tr>
<tr>
<td>2. Thick cuticle</td>
<td></td>
</tr>
<tr>
<td>3. Maintenance of high osmotic pressure</td>
<td></td>
</tr>
</tbody>
</table>

6.1.3 Avoiding Stress

Stress avoidance is the ability to maintain a favorable water balance, and turgidity even when exposed to drought conditions, thereby avoiding stress and its consequences. A favorable water balance under drought conditions can be achieved either by: (i) conserving water by restricting transpiration before or as soon as stress is experienced; or (ii) accelerating water uptake sufficiently so as to replenish the lost water.

6.2 Strategies for drought management

The different strategies for drought management are discussed under the following heads.

6.2.1 Adjusting the plant population: The plant population should be lesser in dryland conditions than under irrigated conditions. The rectangular type of planting pattern should always be followed under dryland conditions. Under dryland conditions whenever moisture stress occurs due to prolonged dry spells, under limited moisture supply the adjustment of plant population can be done by

a) Increasing the inter row distance: By adjusting more number of plants within
the row and increasing the distance between the rows reduces the competition during any part of the growing period of the crop. Hence it is more suitable for limited moisture supply conditions.

b) **Increasing the intra row distance:** Here the distance between plants is increased by which plants grow luxuriantly from the beginning. There will be competition for moisture during the reproductive period of the crop. Hence it is less advantageous as compared to above under limited moisture supply.

6.2.2 **Mid-season corrections:** The contingent management practices done in the standing crop to overcome the unfavorable soil moisture conditions due to prolonged dry spells are known as mid-season conditions.

a) **Thinning:** This can be done by removing every alternate row or every third row which will save the crop from failure by reducing the competition

b) **Spraying:** In crops like groundnut, castor, red gram, etc., during prolonged dry spells the crop can saved by spraying water at weekly intervals or 2 per cent urea at week to 10 days interval.

c) **Ratooning:** In crops like sorghum and bajra, ratooning can practiced as mid-season correction measure after break of dry spell.

6.2.3 **Mulching:** It is a practice of spreading any covering material on soil surface to reduce evaporation losses. The mulches will prolong the moisture availability in the soil and save the crop during drought conditions.

6.2.4 **Weed control:** Weeds compete with crop for different growth resources ore seriously under dryland conditions. The water requirement of most of the weeds is more than the crop plants. Hence they compete more for soil moisture. Therefore the weed control especially during early stages of crop growth reduces the impact of dry spell by soil moisture conservation.

6.2.5 **Water harvesting and lifesaving irrigation:**

The collection of runoff water during peak periods of rainfall and storing in different structures is known as water harvesting. The stored water can be used for giving the life saving irrigation during prolonged dry spells.

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Rainfed Agriculture and Watershed Management: Mevada K. D., Poonia T. C, Saras Piyush and Deshmukh S.P.  Page 48
7.1 Meaning of water harvesting:

The process of runoff collection during periods of peak rainfall in storage tanks, ponds etc., is known as water harvesting. It is a process of collection of runoff water from treated or untreated land surfaces/ catchments or roof tops and storing it in an open farm pond or closed water tanks/reservoirs or in the soil itself (in situ moisture storage) for irrigation or drinking purposes. Runoff farming and rainwater harvesting agriculture are synonymous terms, which imply that farming is done in dry areas by means of runoff from a catchment.

Runoff farming is basically a water harvesting system specially designed to provide supplemental or lifesaving irrigation to crops, especially during periods of soil moisture stress.

Collecting and storing water for subsequent use is known as water harvesting. It is a method to induce, collect, store and conserve local surface runoff for agriculture in arid and semiarid regions. All water harvesting systems have three components viz., the catchment area, the storage facility and the command area. The catchment area is the part of the land that contributes the rain water. The storage facility is a place where the runoff water is stored from the time it is collected until it is used. The command area is where water is used.

Water harvesting is done both in arid and semi-arid regions with certain differences. In arid regions, the collecting area or catchment area is substantially in higher proportion compared to command area. Actually, the runoff is induced in catchment area in arid lands whereas in semi-arid regions, runoff is not induced in catchment area, only the excess rainfall is collected and stored. However, several methods of water harvesting are used both in arid and semiarid regions.

Water harvesting (WH) is generally considered as a rudimentary form of irrigation. The difference is that with WH the farmer’s has no control over timing. Runoff can only be harvested when it rains. Water harvesting in its broadest sense will be defined as the "collection of runoff for its productive use". Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral water courses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term ‘rainwater harvesting’ while all systems which collect discharges from water courses are grouped under the term ‘flood water harvesting’.

In regions where crops are grown entirely rainfed, a reduction of 50% in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area, reasonable yields will be received. In a year of severe drought there may be no runoff to collect, but an efficient water harvesting system will improve plant growth in the majority of the years. Hence, collecting and storing rainwater for subsequent use is called as ‘water harvesting’. It is a method to induce, collect, store and conserve local surface runoff for arid and semi-arid regions. It is also known as ‘runoff farming’ in rainfed areas.

7.2 Components and principles of water harvesting:

All water harvesting systems have three components viz., the catchment area, the storage area and the command area. The catchment area (donor area) is the part of the land that contributes the rainwater. The storage facility is a place where the runoff water is stored
from the time it is collected until it is used for human beings and their needs. The area in which collected water is used is called command area (recipient area). The donor area is generally not suitable for crop production.

Water harvesting is a process of collection of peak rainfall runoff water from treated or untreated land surfaces / catchments / roof tops and storing it in an open farm pond or closed water tanks / reservoirs or in the soil itself (in-situ moisture storage) for agriculture or domestic purposes. In runoff farming, a water harvesting system is specially designed to provide supplemental irrigation to crops, especially during periods of soil moisture stress.

**Fig.** Components of a water harvesting system

The aim of water harvesting is to mitigate the effects of temporal shortage of rain, so called dry spells, groundwater recharge, risk minimizing in drought-prone areas, combating desertification by tree plantation, to cover both household needs (for drinking, cooking, sanitation, etc.) as well as for productive use (protective irrigation).

The implementation of water harvesting might, however, bring about a number of drawbacks. The main **disadvantages of rainwater harvesting technologies** are mainly due to the limited supply and uncertainty of rainfall. The others are:

1. Increased soil erosion when slopes are cleared for higher runoff rates.
2. Loss of habitat of flora and fauna on these slopes and depressions.
3. Upstream-downstream conflicts among the beneficiaries.
4. Competition among the farmers and the herders.

### 7.3 The importance of water harvesting

The **importance of water harvesting** can be summarised as:

1. In arid and semi-arid areas where rainfall is low and unfavourably distributed, water harvesting makes farming possible on part of the land provided other production factors are favourable.
2. It can provide additional water to supplement rainfall to increase and stabilize crop production in dryland areas.
3. It can alleviate the risk associated with the unpredictability of rainfall in drought-prone areas.
4. In remote areas (islands and deserts) where public water supply for domestic and animal rearing is not available, inducing runoff from treated area and stored in a reservoir/ cistern for later use is a common practice.
5. In islands and high hilly areas, due to limited extent of fresh water aquifers, rainwater harvesting is the most preferred source of water for domestic use.
6. The arid lands suffering from desertification, water harvesting would improve the vegetative cover and help to halt the environmental degradation.
7. Water harvesting arrest decline in groundwater levels, to overcome the inadequacy of surface water to meet our demands.

### 7.4 Water harvesting structures
At present most water harvesting structures are built under the holistic programme of watershed development which includes:

- Roof top rainwater harvesting for domestic use;
- Creating surface water storages in the form of check dams, dug ponds for irrigation and drinking;
- Recharging ground water through check dams, percolation tanks, sub-surface dykes to augment water availability in wells, tube wells, hand pumps etc.;
- Soil conservation through afforestation, gully plugging, contour cropping, control and regulation of grazing;
- Soil moisture conservation especially in rainfed hilly areas, through bench terracing, contour bunding, khadins to suppress soil salinity;
- Improving cropping pattern, crop calendar etc. for enhancing farm income;
- Improving marketing facilities for farm produce;
- Providing additional livelihood options such as dairy farming, poultry farming, bee keeping, sericulture etc.;
- Promoting social forestry to meet the fuel wood requirement where alternative sources of fuel are not feasible.

7.5 Techniques of Inducing Runoff

Rainwater harvesting is possible even in areas with as little as 50 to 80 mm average annual rainfall. Ancient desert dwellers harvested rain by redirecting the water running down the slopes into fields or cisterns (storage structures). This small amount of runoff collected over large area may be useful for supplying water to small villages, households, cattle etc. For collection of higher amount of rainfall, runoff is induced either by inter-plot water harvesting or by land alteration or by surface chemical treatment.

a) Land alterations:

Land smoothing reduce surface depression storage and infiltration losses. Clearing away rocks and vegetation and compacting the soil surface can increase runoff. However, land alteration may lead to soil erosion except where slope is reduced. When erosion is not excessive and low cost hill side land is available, land alteration can be very economical way to harvest rainwater in arid lands.

b) Surface chemical treatment:

A promising method for harvesting rainwater is to treat soils with chemicals that fill pores or make soil repellent to water. Some materials used for this purpose are sodium salts of silicon, latexes, asphalt and paraffin wax. Surface treatment of soil with bitumen and asphalt is effective for inducement of runoff. Most of the treatments for inducing runoff are location-specific and depends on importance of runoff collection and cost associated with the treatment.

c) Soil cover:

Surface modifications may be required to get more runoff. Runoff may be induced by using low density polyethylene sheets, butyl rubber, asphalt and fibre glass, compacting surface or spreading sodic soil on surface as soil cover. In cropping systems, crop is sown in narrow strips between wide intervals that are ridged as artificial miniature watersheds. Compacting the soil surface is the cheapest way to induce runoff in rainfed areas.

7.6 Techniques of Rainwater Harvesting:
The water harvesting techniques are classified into five groups. These are sketched as given below:

Water harvesting is done both in arid and semi-arid regions with certain differences. In arid regions, the collecting area or catchment area is substantially in higher proportion compared to command area. Actually, the runoff is induced in catchment area in arid lands whereas in semi-arid regions, runoff is not induced in catchment area, only the excess rainfall is collected and stored. However, several methods of water harvesting are used both in arid and semi-arid regions.

7.6.1 Arid Regions

The catchment area should provide enough water to mature the crop, and the type of farming practiced must make the best use of water. In general, perennial crops are suitable as they have deep root systems that can use runoff water stored deep in the soil which is not lost through evaporation.

a) Runoff farming:

Ancient runoff farms in the Negev desert (Israel) had several cultivated fields fed by water from watersheds of 10 to 50 ha. The watersheds were divided into small catchment areas of 1 to 3 ha that allowed runoff water to be collected in easily catchment channels on the hill sides and were small enough to prevent uncontrollable amount of water. The channels that led the water to cultivated fields were terraced and had stone spillways so that surplus water in one field could be led to lower ones. Farmers constructed small check dams with rocks across the small gullies and guided the water to fields.

The farmers of Madhya Pradesh (Rainfed central India) have developed a unique and indigenous rainwater management system based on water harvesting and runoff farming, locally
known as ‘Haveli’. In this system, rainwater is harvested (0.2–1.2 m depth) in the field during monsoon (June–September) by constructing embankments along the field boundary. The farmers allow rainwater to flow from one field to another. The impounded water is then drained out from the field during September–October. The winter crops (wheat, pea, lentil and chickpea) are grown which utilize the stored moisture seeped in the soil profile. ‘Haveli’ fields contribute 4–6 mm rainwater per day for 90–100 days in the rainy season, corresponding to 40–60 cm conserved moisture in upper soil profile. The drained water from ‘Haveli’ fields is also used for irrigation by the adjacent farmers to grow rice. It helps greatly to control weeds, soil moisture conservation and ground water recharge.

b) Water spreading:

In arid areas, the limited rainfall is received as short intense storms. Water swiftly drains into gullies and then flows towards the sea. Water is lost to the region and floods caused by this sudden runoff can be devastating often to areas otherwise untouched by the storm. Water spreading is a simple irrigation method for use in such a situation. Flood waters are deliberately diverted from their natural courses and spread over adjacent plains. The water is diverted or retarded by ditches, dikes or small dams. The wet flood plains or valley floods are used to grow crops. Sorghum and millets are the most common crops.

The major characteristic of water spreading bunds is that, as their name implies, they are intended to spread water, and not to impound it. They are usually used to spread floodwater which has either been diverted from a watercourse or has naturally spilled onto the floodplain. The earthen bunds slow down the flow of floodwater and spread it over the land to be cultivated, thus allowing it to infiltrate. The dikes can be constructed with a tractor and mouldboard plough or with a road grader.

Fig.

Water spreading system in Pakistan to divert excess flood water for agricultural use.
If a site received <200 mm annual precipitation or <100-130 mm during the growing season, it would typically not produce enough runoff to justify installation of a water spreader.

c) Micro-catchments (Negarim):

A plant can grow in a region with too little rainfall for its survival if a rainwater catchment basin is built around it. At the lowest point within each micro-catchment, a basin is dug about 40 cm deep and a tree is planted in it. The basin stores the runoff from micro-catchment. In Africa these are used for cultivation of sorghum, maize and millets. Appropriate for tree planting in situations where land is uneven or only a few trees are planted. Widely used micro-catchments are contour ridges, semi-circular and trapezoid bunds and small runoff basins. The main limitation is that it is not easily mechanised therefore limited to small scale. Not easy to cultivate between tree lines.
Macro-catchments having runoff water collected from relatively large natural catchments. Generally these catchments are located outside the farm boundaries where individual farmers have little or no control over them. Percolation tank is an example of macro-catchment WH system.

d) Traditional water harvesting systems:

Tanka, Virda, Kunds, Nadi, Johad and khadin are the important traditional water harvesting systems of Rajasthan. The maximum conservation of water is in the form of lakes. The GOI, reconstructed these traditional WH systems under MGNREGA all over the country.

**Tanka** is the most prevailing rainwater harvesting structure in Indian Thar desert. It is an underground circular tank or cistern constructed for collection and storage of runoff water from natural catchment or artificially prepared clean catchment or from a roof top. The vertical walls are lined with stone masonry or cement concrete and the base with 10 cm thick concrete. The capacity of the tank ranges from 1,000 to 6,00,000 L. A traditional *tanka* constructed with lime plaster and thatched with bushes has a life span of 3–4 years. CAZRI (Jodhpur) has designed an improved *tanka* (life-span 25 years) of 21,000 L capacity which gets filled with an annual rainfall of 125 mm. The catchment area needed for this capacity is 700 m².

**Virdas** are shallow holes which are made in the sands of dry riverbeds and lakes for collecting drinking water. These are found all over the *Banni* grasslands, a part of the great Rann of Kutch in Gujarat. The topography of the area is undulating, with depressions on the ground. In virdas, the sweet freshwater remains in the upper layer from which the water is collected, and the saline water remains below the freshwater zone because of its higher density and, hence, it is theoretically possible to keep the harvested sweet rainwater stored to float over the denser saline water.

With this knowledge, Maldharis (local nomadic people) first developed this unique structure in the Rann of Kutch, which is essentially like a well in a tank. A group of thorny bush branches enclosed a *virda* to ward off animals.
**Kunds** were more prevalent in the western arid regions of Rajasthan, and in areas where the limited groundwater available is moderate to highly saline. Usually it is constructed with local materials or cement. The kund consists of a saucer-shaped catchment area with a gentle slope towards the centre where a tank is situated. Openings or inlets for water to go into the tank are usually guarded by a wire mesh to prevent the entry of floating debris, birds and reptiles. The top is usually covered with a lid from where water can be drawn out with a bucket.

An area receiving rainfall of 25 mm/annum, a kund with a catchment of 100 km² could easily collect 10,000 L of water. Even if we assume that only 40 - 50% of rain will turn into runoff, a kund can still store 0.1 million litres of water. The catchment size of kunds varies from about 20 m² to 2 ha depending on the runoff needed, water use and the availability of spare land.

**Nadi** or dugout village pond (Pokhar) is constructed for storing water from natural catchments. It is more prevalent in western Rajasthan. The depth and capacity of the nadi may varies from 1.5 to 12 meters and 400 m³ to 70,000 m³, respectively. A large amount of sandy sediments were regularly deposited in them, resulting in quick siltation. The water is muddy and dirty which is unfit for human consumption. However, due to water scarcity peoples used this water for all purposes.

**Khadin** is unique land use system of Thar desert where in runoff water from rocky catchments are collected in valley plains during rainy season. It is practised where rock catchments and valley plains occur in proximity to sandy hills. This old water harvesting system was first practised by the Paliwal Brahmins of Jaisalmer, western Rajasthan in the 15th century.

The standing water in a khadin assists in continuous groundwater recharge. Its main feature is a very long (100–300 m) earthen embankment built across the lower hill slopes lying below gravelly uplands. Sluices and spillways allow excess water to drain off. Crops are grown in the winter season after water is receded in shallow pond on the residual soil moisture. At least one crop is cultivated even in the arid region on khadin bed. The soils in khadin are extremely fertile due to frequent deposition of fine sediment.
Johads are crescent-shaped small earthen bunds which is built across a slopping catchment/seasonal channels that capture and conserve rainwater, improving percolation and groundwater recharge. Unlike a normal dam, the rainwater is collected during monsoon and allowed to percolate into the soil. Since 1984, a total of 8600 johads have been built in 1086 villages of Alwar district in Rajasthan, covering 6500 km² area under the leadership of Tarun Bharat Sangh and its leader Rajendra Singh, the Water Man of Rajasthan. These johads have helped the farming communities from abject poverty to prosperity, a miraculous transformation. This has resulted in the shallow aquifer recharge in groundwater bringing up the water table from about 100–120 meter depth to 3–13 meter at present. The area under single and double cropping was 11% and 3%, which was increased to 70% and 50%, respectively. The forest cover, which used to be around 7%, increased to 40% through agro-forestry and social forestry, providing sufficient fuel wood and sequestering carbon from the atmosphere.

7.6.2 Semi-arid Regions

Water harvesting techniques followed in semi-arid areas are numerous and also ancient. These are-

a) Dug Wells:

Hand dug wells have been used to collect and store underground water and this water is lifted for irrigation. The quality of water is generally poor due to dissolved salts.

b) Tanks:

Runoff water from hill sides and forests is collected on the plains in tanks. The traditional tank system has following components viz., catchment area, storage tank, tank bund, sluice, spillway and command area. The runoff water from catchment area is collected and stored in storage tank on the plains with the help of a bund. To avoid the breaching of tank bund, spillways are provided at one or both the ends of the tank bund to dispose of excess water. The sluice is provided in the central area of the tank bund to allow controlled flow of water into the command area. Water from the tanks is used to irrigate the command area by gravity flow. The command area of many tanks ranges from 25 to 100 ha. Unlike wells, the quality of water is good in tanks.

c) Percolation Tanks:

Flowing rivulets or big gullies are obstructed and water is ponded. Water from the ponds percolates into the soil and raises the water table of the region. The primary purpose of percolation tank is to recharge groundwater. A strict regulation on the silt load entering the downstream reservoirs is an additional advantage of percolation tanks. The improved water level in the wells lower down the percolation tanks are used for supplemental irrigation.
d) Farm Ponds:

A portion of the excess runoff water after allowing maximum *in-situ* moisture conservation is collected in farm ponds. As far as possible, the pond should be location in the lower patches of the field to facilitate better storage and less seepage losses. The size of the farm should be worked out on the basis of annual rainfall, probable runoff and catchment area. Generally, 10-20% of the seasonal rainfall is considered as runoff in medium black soils. A farm pond of 150 m³ capacity with side slopes of 1.5:1 is sufficient for one ha of catchments area in black soils.

Depending upon their construction and suitability to different topographic conditions farm ponds are classified as:

- Excavated farm ponds: Suitable for flat topography
- Embankment ponds: Suitable for hilly terrains
- Excavated cum embankment ponds

There are three types of excavated farm ponds – square, rectangular and circular. Circular ponds have high water storage capacity. Farm ponds of size 100 to 300 m³ may be dug to store 30% of runoff. The problem associated with farm ponds in red soils is high seepage loss. This can be reduced by lining walls. Some of the traditional methods for seepage control are the use of bentonite, soil dispersants and soil-cement mixture. Bentonite has excellent sealing properties if kept continuously wet, but cracks develop when dried.

Soil-cement mixture can be used. A soil-cement lining of 100 mm thickness reduces seepage losses up to 100 per cent. The pit lined continuously develops cracks but no cracks develop when applied in blocks. The other alternative sealant for alfisols is a mixture of red and black soil in the ratio of 1:2.

![Fig. Typical layout of a farm pond](image)

In arid and semi-arid regions, rains are sometimes received in heavy down pours resulting in runoff. The runoff event ranges from 4 to 8 during the rainy season in arid and semi-arid region. The percentage of runoff ranges from 10 to 30% of total rainfall. The size of the farm

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pond depends on the rainfall, slope of the soil and catchment area. The dimensions may be in the range of 10×10 m × 2.5 to 15 × 15 m × 3.5 m. The side slope 1.5:1 is considered sufficient. A silt trap is constructed with a width of slightly higher than the water course and depth of 0.5 to 1 m and with side slope of 1.5:1.

The different types of lining materials are soil-cement, red and black soils, cement-concrete, bricks, *kadapa* slabs, stone pitching, polythene sheet *etc*. In alluvial sandy loam to loamy sand soils of Gujarat and red sandy loams soils of Bangalore, a soil + cement (8:1) mixture is the best lining material.

Soil without sieving and cement in 6:1 ratio is very effective and cheap lining material for red sandy loam soils. In laterite silty clay loam soils of Ooty, medium black soils of Kota, bitumen was effective. Clay soil linings are generally the most economical for farm ponds. Evaporation losses can be reduced in farm ponds especially in arid regions by rubber or plastic floats.

e) Inter-row water harvesting (IRWH)

Under this system, furrows of about 30-40 cm width (15 cm deep) are alternated by ridges of 60-70 cm). The furrows and ridges are formed with ridger at right angles to the slope. The water collected from the ridge is stored in furrow and the crop is benefitted by high moisture. The ridge may be left without ploughing while cultivation is done in the furrow only. The ridge provides partial shading of the furrow for 6 to 7 hours a day and reduces evaporation by 25-35% immediately after rain. It is, particularly, suitable for heavy textured soils. In light soils, crops are grown in furrows whereas in heavy soils, planting is usually on ridges to eliminate the problem of water-logging. In this system, the raindrops absorbed where it falls and does not flow out of the field. Generally it is practiced in areas having annual rainfall between 200-300 mm.

Raised and sunken bed system is the traditional system followed by the farmers of Chhattisgarh. Rice is grown in the sunken bed and soybean is sown on the raised bed, thereby meeting the water requirement of both the crops.

f) Inter-plot water harvesting (IPWH):

In this method, harvested water is diverted to the cropped area. It is suitable where rainfall is scanty (<500 mm) and even there is difficulty of harvesting a single crop. In this technique, runoff water is made available to cropped plots from adjacent bare plots either on one side or both sides. Adjacent plots are given certain slope to augment runoff towards cropped plot for improving profile moisture storage. Catchments with strips of 0.75 m width on either side of 3.0 m wide levelled area are desirable. Catchment to cultivated area ratio of 0.5 could be optimum for most crops.
Slopes on both sides of cropped area appear to be more appropriate for arid-fruit trees. The 1:1 cropped to non-cropped area on both side slopes gave better results followed by 1:1 and 1:2 one side slope.

![Diagram of slopes](image)

Fig. Inter-plot or micro-plot water harvesting for field crops

**g) Broad Bed & Furrows (BBF):**

When seedbed is made into wide beds alternated with furrows is called BBF. This practice has been recommended by ICRISAT for vertisols or black soils in high rainfall areas (>750 mm). The system involves creation of 90-150 cm wide, 15-20 cm high raised beds with 0.3 to 0.5% grades. The beds are separated by 50 cm wide furrows that drain into grassed waterways. The beds are stable for 2 to 4 years and conveniently adapted to planting of upland crops in rows spaced at 30, 45, 75 or 150 cm. The system tends to conserve soil, rainwater *in-situ* and improves crop yields and sustainability.

**Advantages of Broad Bed & Furrow**

- It helps in moisture storage.
- Safely dispose-off surplus surface runoff without causing erosion.
- Provide better drainage facilities.
- Facilitate dry seeding.
- It can accommodate a wide range of crop geometry *i.e.* close as well as wide row spacing.
- It is suitable for both sole cropping and intercropping systems.
- Sowing can be done with seed drills.

![Diagram of BBF](image)

**7.7 Storage, management and use of harvested rainwater:**

Storage is an important and integral part of any water harvesting system. In run-off farming, the storage reservoir will be the soil itself. But where water is to be used for domestic/supplemental irrigation purposes, a storage facility of some kind would be provided. There are three basic means of storing harvested water viz., excavated pits/ponds, masonry tanks and closed plastic storage bags. **At on-farm level, three approaches are being adopted in rainwater management viz.,**

a) Absorbed where it falls and does not flow out of the field.
Water Harvesting

a) Harvesting rainwater into dug out structures like farm ponds. To check the seepage losses from these ponds several sealing materials are used.

b) Recycling of stored water to donor area as supplemental /life-saving irrigation.

**Supplemental / life-saving / protective irrigation:**

The runoff collected from different water storage structures is of immense use for protecting the dryland crops from soil moisture stress during prolonged dry spells. In dry areas, water, not land is the most limiting resource for crop production. Maximizing the water productivity but not the yield per unit land is the better strategy for dry farming areas. Supplemental irrigation is a highly efficient practice for increasing productively of crops in arid regions. The response to supplemental irrigation varies with crops, time, depth & method of water and fertilizer application. *Irrespective of the stage of crop, irrigation is scheduled when soil moisture approaches PWP to save the crop. This is called life-saving irrigation.* The benefit of supplemental irrigation last for one week.

**a) Quantity of irrigation water:**

Crops differ in responding to amount of irrigation water by supplemented irrigation during dry spell.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Soil type</th>
<th>Critical stage</th>
<th>Quantity of water (mm)</th>
<th>Methods of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundnut</td>
<td>Alfisols</td>
<td>Pod development</td>
<td>10 mm</td>
<td>Sprinkler / drip</td>
</tr>
<tr>
<td>Cotton</td>
<td>Vertisols</td>
<td>Boll formation</td>
<td>30 mm</td>
<td>Sprinkler / drip</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Black soils</td>
<td>Flowering</td>
<td>30-40 mm</td>
<td>Sprinkler / drip</td>
</tr>
<tr>
<td>pigeonpea</td>
<td>Black soils</td>
<td>Pod development</td>
<td>20 mm</td>
<td>Drip</td>
</tr>
</tbody>
</table>

Life-saving irrigation can be provided near the row, covering about 20% of the cropped area, leaving 80% of inter-row zone. Pot watering, applying small quantity of water (around 250 ml) manually to each hill, is highly useful either for sowing or for transplanting in widely spaced crops like cotton, pigeonpea, castor, tomato, tobacco *etc.* Productivity of harvested water can be increased by applying small quantity of water to large areas than heavy irrigation to small area. If rains occur immediately after irrigation, there will be no impact of irrigation and in black soil, it may reduce yield.

**b) Time of irrigation:**

Unlike in irrigated agriculture, the critical stage concept does not suit well, as dry spell may reduce the growth and yield of crop at any stage. Vegetative stage is considered as, non-critical stage in irrigated agriculture but in arid regions, dry spell during vegetative stage prolongs the crop duration which may ultimately result in crop failure due to end season drought. Death of seedlings also cause reduction in yield due to dry spell in vegetative stage, therefore, the strategy for getting successful crop is providing small quality of water, if available, at any stage if the dry spell is >10 days in light soils and 15 days in heavy soils.

When critical stage for irrigation is to be chosen e.g. for *kharif* sorghum the flowering stage is most critical. In Tobacco, irrigation at 3 weeks before topping had the maximum pay off. For wheat and barley CRI stage is most critical stage. Long duration crops with deeper root systems that responded to higher levels of irrigation compared to short duration shallow rooted crops. Hence, it is important to wet the active root profile for best results.

**c) Method of irrigation:**
Surface methods of irrigation like check basin, basin, and furrow methods are not suitable for supplemental irrigation, mainly for three reasons: the rainfed lands are uneven, conveyance losses may go up to 30% and limited amount of water available for irrigation. Subsurface drip irrigation is very efficient for providing supplemental irrigation. The main drawback of micro-irrigation system is high initial cost of the system. Pot watering is another efficient method being used by the farmers for transplanting crops like tobacco, chilly, tomato etc.

d) Economics of water harvesting:
Water harvesting and use of water for sowing and supplemental irrigation increase the productivity of wheat and onion in mountainous watershed in Himachal Pradesh. The benefit-cost ratio ranges from 0.41 to 1.33 for water harvesting structures of different sizes with an estimated life of 25 and 40 years, respectively.

e) Water productivity:
The limited water productivity can be increased through timely sowing, use of improved varieties, STCR based fertilizer application, timely weeding and efficient irrigation system.

7.8 Efficient utilization of rainwater through soil management practices:
In rainfed agriculture, no other input can perhaps enhance the yield without effectively tackling the rainfall aberration related sub-optimal moisture availability by managing both soil and rainwater.

The important practices are-

1. Avoiding and rectifying soil degradation
The major forms of soil degradation are water and wind erosion and deterioration of both physical (crusting, compaction, waterlogging) and chemical (Loss of organic matter, acidification, salinization, pollution etc.). Soil crusting and compaction in arable soils may be rectified by cultivation, Increasing soil organic matter content by incorporating organic manures and pond sediments improve the stable soil aggregates. Salinization can be controlled by leaching the surface salts with rainwater irrigation. In alkali soils, application of gypsum resulted in increased infiltration rate. The best method of avoiding waterlogging is by providing surface drainage.

2. Managing soil nutrients
If yields are to be maintained and the soils used to produce crops on a continuing basis, a method by which N, P, K and other nutrients can be replaced has to be adopted. If yields are to be maintained and the soils used to produce crops on a continuing basis, a method by which nitrogen, phosphorus, potassium and other nutrients can be replaced has to be found. Nitrogen can be fixed by natural and symbiotic fixation like Rhizobia in legumes, Azolla in rice and by using biofertilizers. Maintaining P, K and other nutrients normally requires the use of inorganic fertilisers. Organic manures (FYM, compost, green manures, farm wastes) should be used for balanced supply of essential nutrients as well as having additional beneficial effects on the soil.

3. Managing soil physical conditions
Conservation tillage with lighter machinery is the most effective way to alter and improve soil physical conditions. Under Indian conditions, satisfactory soil physical condition of rainfed soils can be maintained by deep ploughing once in 3 to 5 years,
application of bulky organic manures in alternate years and shallow inter-cultivation for weed management.

4. **Improving soil moisture regime**

   There is no practical method by which available WHC of a soil can be increased. Addition of silt, clay, organic matter etc. increases field capacity and also raises wilting point leading to marginal increase in available WHC. If good soil is available, 1:1:1 ratio of soil, organic matter and sand make an excellent mixture. If the soil is sand, a mixture of 1:1:1 with soil, organic matter and clay soil is suitable. Never mix the heavy sticky clays in these soils. Contour farming and sub-surface barriers helps to reduce runoff as well as soil loss.

5. **Managing soil organic matter and soil biological conditions**

   Organic matter is a direct contributor to crop nutrition of crops and its role in stabilising soil aggregates and supporting the soil organisms which create the pores through which air and water move, has already been mentioned. In addition, it hinders the formation of insoluble complexes of iron and aluminium with phosphate in acid soils thus avoiding reduction in the amount of phosphate available to plants. Activities that promote the accumulation and supply of organic matter, such as use of FYM, crop rotation, cover crops and those that reduce decomposition rates, such as reduced and zero tillage, leads to an increase in the organic matter content in the soil and its biological activities.
Under rainfed conditions soil moisture is the most limiting factor for crop production. It is lost as evaporation from soil surface and as transpiration from the plant surfaces. The combined loss of moisture through these two processes is known as evapotranspiration.

**Crop management practices under rainfed areas:**

1. **Efficient cropping systems**

   Cropping intensity in dryland agriculture is, generally 100%, implying that single crop is taken during the year. Cropping intensities of these areas can be increased through intercropping and sequential cropping by way of more efficient use of resources. Crops and cropping systems selected should match the length of crop growing season to avoid soil moisture stress. **Double cropping**, either by sequential cropping or relay cropping, is possible in regions with rainfall >900 mm, extended rainy season and high soil moisture storage capacity. Double cropping is also possible with rainwater harvesting in farm ponds. **Intercropping** of groundnut + castor (4:1) was pursued vigorously in Rajkot (Gujarat). Even at Solapur, leafy vegetables and some short duration beans are grown as intercrops during the rainy season.

   **Some dominant intercropping systems in different dry lands of India**

<table>
<thead>
<tr>
<th>Locations</th>
<th>Soil</th>
<th>Rainfall (mm)</th>
<th>intercropping</th>
<th>Row ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anantapur</td>
<td>Alfisols</td>
<td>550</td>
<td>Groundnut + pigeonpea</td>
<td>7:1</td>
</tr>
<tr>
<td>Akola</td>
<td>Vertisols</td>
<td>825</td>
<td>Sorghum + pigeonpea</td>
<td>2:1</td>
</tr>
<tr>
<td>Rajkot</td>
<td>Vertisols</td>
<td>590</td>
<td>Groundnut + castor</td>
<td>4:1</td>
</tr>
<tr>
<td>Sholapur</td>
<td>Vertisols</td>
<td>560</td>
<td>Chickpea + safflower</td>
<td>3:1</td>
</tr>
<tr>
<td>Bangalore</td>
<td>Alfisols</td>
<td>890</td>
<td>Finger millet + pigeonpea</td>
<td>8:1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential cropping systems (CS) for dryland agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual rainfall (mm)</strong></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>600 - 750</td>
</tr>
<tr>
<td>750 - 900</td>
</tr>
<tr>
<td>&gt; 900</td>
</tr>
</tbody>
</table>
2. **Choice of crops and cultivars and crop substitution**
Crops and varieties for drylands should have following characteristics:

- Plants with erect leaves and stem.
- Short duration and early vigour.
- Deep root system with ramified roots.
- Dwarf and moderate tillering in case of tillering crops and varieties.
- Resistance/tolerance to biotic stresses.
- Lesser period between flowering and maturity so that the grain filling is least affected by adverse weather.
- Resistance/ tolerance to abiotic stresses.
- Low rate of transpiration.
- Less sensitive to photoperiod.
- Wider adaptability.

Traditional cultivars are of longer duration, photosensitive, inefficient users of soil moisture and often have poor response to PoP. The guiding principle of choice of crops, varieties and cropping systems for dry lands should be their suitability to vagaries of monsoon. It is imperative to select crops and varieties, which possess wider adaptability, shorter duration and evade or tolerate rainfall vagaries by virtue of their ability to maintain high internal water content with deep root system and less transpiration. Such crops and cultivars should be substituted with productive crops and cultivars.

Pulses and oilseed crops perform better than cereals if the sowings are delayed during *kharif*. Among the pulse crops, cluster bean, moth bean and horse gram are better choice for low rainfall areas relative to other *kharif* pulses. Among oilseed crops, castor and sunflower perform better than groundnut under conditions of delayed sowing. For crops on receding soil moisture during *rabi*, chickpea and lentil are preferred over peas and French bean. In the rapeseed-mustard group of crops, taramira is the best choice for light soil with low moisture storage capacity, followed by Indian mustard. Among the *kharif* cereals, coarse cereals (millets and sorghum) are better choice over maize and rice, similarly, in *rabi*, barley does well under conserved soil moisture than wheat. Among the millets, *setaria* (kodra) is most suited for late sown condition without any serious effect on productivity.

3. **Land preparation**
Tillage is a well-known soil and water conservation practice which makes soil surface more permeable to increase infiltration rate, which in turn reduces runoff, soil and nutrient losses and enhance crop yields. Deep tillage in problem soils promotes better root system development and helps in higher yields during low rainfall years, leading to more efficient use of sub-soil resources. Off-season or pre-monsoon tillage also has a marked impact on weed control and rainwater intake. All the cultural practices should be done across the slope (contour cultivation) to reduce soil and water loss. By ploughing and sowing across the slope, each ridge of plough furrow and each row of the crop act as obstruction to the runoff water.

4. **Early sowing of crops in the season**
It is an established fact that early sowing alone contributes to around 63% of the final crop yield. Early sowing leads to optimum yield due to efficient use of growth resources besides minimizing the incidence of pests and diseases. However, the problem is that how to sow the crop early in the season when the onset of monsoon is delayed. The practical solution to this problem appears to be land preparation for early/timely seeding, taking advantage of
summer showers. Taking advantage of these summer showers, the land can be prepared for taking advantage of the early monsoon rains.

In some regions, where heavy clay soils dominate, sowing after rains is impossible due to high stickiness of soil. As such, sowing may be done in dry soil, 2-3 weeks before the onset of monsoon (dry seeding). For sorghum on black soils, dry seeding is recommended at 1-2 weeks before onset of monsoon with depth of sowing at 5 cm and seed hardening with potassium di-hydrogen phosphate or potassium chloride. For cotton on black soils, dry seeding is recommended at 2-4 weeks before commencement of monsoon, with a sowing depth of 5 cm and seed hardening with CCC (500 ppm) or potassium chloride or 2% DAP.

5. **Planting patterns and plant densities**

Crop geometry refers to the arrangement of plant population (intra and inter-row spacing) in the field. Choosing the optimum plant population and width of row spacing continues to be one of the most difficult challenges for dryland farmers. At too densities, crop yields are reduced because too much of soil water is used up to vegetative growth early in the season; too low densities do not effectively exploit available moisture.

Recommendations are frequently made that do not differentiate between crop grown on stored moisture (Sept.-Oct. to Jan.-Feb.) and those grown during rainy season (June-July to Oct.-Nov.). For crops grown during rainy season, the usual recommendation is to increase the distance between plants within the row, to adjust to a low moisture supply.

6. **Managing soil crust problems**

Soil crusts are dry, thin and hard soil surface layers that develop due to the action of rain drop or irrigation water. On subsequent drying, it results in the development of continuous layer of closely packed soil particles. Soil crusts often hinder the emergence of seedlings and hence establishment of crop stand. Management practices to overcome crust problems include:

- Shallow and dense sowing.
- Dragging heavy thorny branches on crusted soil surface.
- Loosening the crusted surface by using spike-tooth harrow.
- Mulching.
- Light blade harrowing 2-3 days after rain.
- Planting on shallow furrows and on sides of ridge

7. **Minimizing Evaporation losses**

There are three principles of evaporation control under field conditions.

a. Decreasing the turbulent transfer of water vapor to the atmosphere by growing plants, raising wind breaks, straw mulches etc.,

b. Decreasing capillary conductivity by rapid drying of the surface soil layers.

c. Decreasing the capillary flow and moisture holding capacity of the surface soil layers.

For evaporation control, mostly mulches are used.

7.1 **Mulches**

Mulch is any covering material applied on the soil surface to reduce evaporation losses. This material may be grown and maintained in place, or any material grown and modified before placement or any material processed or manufactured and transported before placement. or
Mulch is any material (crop residues, leaves, bark, manure, paper, plastic films, petroleum products, gravel, coal etc.) used to cover the soil surface. Mulches are used for various reasons but water conservation and erosion controls are undoubtedly the most important for agriculture in dry lands.

7.1.2 Types of mulches

Based on the material used for mulching, mulches can be classified into following categories:

**a. Organic mulches:** In this, crop residues of cereals and pulses, straw or stalks of cotton, pigeonpea, rapeseed-mustard etc or stubbles of the crops such as maize, sorghum, sugarcane including roots or husks of the seed of various crops or saw dust are left on the soil surface or spread on the soil surface. Use of such materials as mulches help in soil and moisture conservation, enhances nutrient availability; reduce soil crusting, soil salinity control, soil structure improvement, crop quality control, weed control and moderate soil temperature.

**b. Soil mulch:** In soil mulching, a thin layer of loose soil surface that can be created by frequently stirring the soil with surface tillage implements like danthis, guntakas (blade harrows) etc. Surface mulch of dry soil of about 5 to 8 cm depth is created by stirring the surface soil to turn it into fine dust particles. By adopting this practice, some amount of moisture is lost from the upper layer. After the preliminary loss of moisture, the soil mulch effectively controls further evaporation from sub-soil by breaking the capillaries continuity. The soil mulch also prevents deep cracks in soils (especially black soils) by reducing the direct action of atmosphere and hence evaporation is also reduced. The repeated inter-cultivations done in rabi crops even in the absence of weeds help in reducing evaporation losses. This system of mulching is highly suitable for moisture conservation in medium to heavy texture soils, which tend to shrink and crack deeply on drying. Among the different mulches soil mulch is the cheapest.

**c. Dust mulching:** The cracks are filled and covered by the loose layer of dust mulch. It is used as a mid-season correction measure for moisture conservation.

**d. Straw and stubble mulch:** Straw and other crop residues like stubbles, groundnut shells, cotton stalks etc; can be used as mulches on soil surface for moisture conservation. Straw mulches reduce both the amount of energy absorbed by the soil and its movement above the soil and hence reduce evaporation. However, the availability of adequate crop residues is a problem for use as mulches.

**e. Chemical mulches:**

In chemical mulching, aluminum foils, plastic, polythene sheets etc. are spread on the soil surface to moderate soil temperature for controlling weeds, to optimise temperature for germination of seeds and to induce runoff of rainwater for ex-situ water conservation and harvesting. Beside this, some chemicals such as hexadecanol (a long chain alcohol) when mixed in the top 6 to 7 mm soil layer, results in a significant reduction of about 40% evaporation. The surface layer of a treated soil dries out more rapidly than that of untreated soil, creating a diffusional layer to evaporation.

**f. Plastic mulches:** Plastic mulches are very effective as mulches for evaporation control provided cost is not a limiting factor. The plastic mulches may be either white or black. Black
plastic mulches will absorb the solar radiation and enhance the soil temperature for hastening the germination of winter crops like wheat; barley etc., White plastic mulches will reflect the incident radiation and reduce evaporation of soil moisture.

g. **Vertical mulching:** In heavy black soils, where infiltration of rainwater is a problem, vertical mulching can be practiced keeping straw/ stalk/ stubbles as vertical mulch wherein trenches of 40 cm wide, 15 cm deep are dug at 2 to 4 m interval across slope and filled with stubbles or organic wastes to a height of 10 cm above soil surface. Around vertical mulching, soils remained porous for longer period, thus maintains high rate of infiltration during the rainy season. Vertical mulching has been found to enhance available soil moisture by 4 to 5 cm. Runoff is checked, collected in the shallow trenches and redistributed to adjoining soil layers and infiltration is increased in black soils.

h. **Live mulching:** Is the term used to describe the covering of soil surface through the plant canopy in intercropping system. Eg. Sorghum + forage cowpea, sorghum + sword bean

i. **Pebble mulch:** Where small pebbles like stone are placed on the soil surface. This mulching will be successful in dryland fruit tree culture. The pebbles placed on the basins of trees not only reduce evaporation but also facilitate infiltration of rain water into the basin.

Mulching is more advantageous during *rabi* /summer months than in *kharif* season. Organic mulches particularly under receding soil moisture conditions increase crop growth by conserving soil moisture.

7.1.3 **Effect of mulches on soil properties**

1. **Soil structure:** Surface mulches reduce the impact of falling raindrops, thus reducing dispersion and sealing of soil pores leading to crust formation. Hence the soil structure is protected. The mulches also improve soil structure due to decomposition of mulch.

2. **Soil salinity:** Under dry land conditions due to limited precipitation, soluble salts move only to a limited depth and readily return to the surface as the soil water evaporates. Due to salt accumulation in surface layers the germination and seedling establishment may be adversely affected. Hence, mulches will reduce soil salinity problem by increasing infiltration and reducing evaporation.

3. **Soil water:** The soil moisture content is improved by induced infiltration, reduced evaporation and reduced transpiration by weeds. Surface mulches also obstruct the free exchange of water vapor from soil surface into the atmosphere and hence increase soil water content.

4. **Soil temperature:** The effects of mulches on soil temperature are highly variable and depend up on the type of mulch material. White or reflective types of plastic mulches generally decrease soil temperature, while black plastic mulches may increase soil temperature. Crop residues moderate temperature by decreasing it in summer and by increasing in winter season. This is due to combined effect of radiation interception and evaporative cooling. The sugarcane trash mulch will enhance the germination of sugarcane setts during summer by temperature reduction.

5. **Soil erosion:** The ease by which soil particles are moved by wind and water is related to size of soil particles and wind and water velocity. The particles of size greater than 0.84 mm in diameter are generally not eroded by wind but they are easily eroded by water.
The mulches reduce the direct impact of falling raindrops on soil, thereby preventing soil dispersion and consequent sealing of soil pores leading to reduced soil erosion. Loss of soil moisture through evaporation from soil surface and through transpiration from plant surfaces can be minimised by using mulches and antitranspirants.

8. Reducing losses due to transpiration

Nearly 99% of water absorbed by the plant is lost in transpiration. Hence transpiration reduction is needed for maintaining favorable water balance in the plants. Transpiration has become unavoidable evil as the stomata, which allow CO$_2$ exchange also allows water vapour transfer into the atmosphere.

There are four principles of transpiration control
a. By increasing leaf resistance to water vapor transfer by application of materials, which tend to close or cover stomata (ex: both stomatal closing and film forming type of antitranspirants).
b. By reducing amount of energy absorbed by leaf surface (Eg: leaf reflectants)
c. By reducing top growth of plants (Eg: Growth retardants)
d. By increasing air resistance to water vapor transfer by shelter belts/ wind breaks

The transpiration losses can be controlled by use of Antitranspirants, use of Wind Breaks/Shelter Belts and Efficient Weed Control.

8.1 Antitranspirants

Any material that is applied to transpiring plant surfaces with the aim of reducing or inhibiting water loss from plant surface is called antitranspirants. The antitranspirants are also known as transpiration suppressants. The best antitranspirants reduce transpiration losses up to 30-40%. The possibility of reducing plant transpiration by chemical without reducing photosynthesis is of great practical importance in arid and semi-arid regions. Where crop production is limited by water scarcity, the maintenance of favourable water balances in plants is must. However, the potential use of antitranspirants is not restricted to water conservation.

8.1.1 There are four principles of transpiration control:
1. By increasing leaf resistance to water vapour transfer by application of materials which tend to close or cover stomata. Both stomatal closing and film forming type of antitranspirants are used for this purpose.
2. By reducing amount of energy absorbed by leaf surface (leaf reflectants).
3. By reducing top growth of plants (growth retardants).
4. By increasing air resistance to water vapour transfer by shelter belts/ wind breaks

8.1.2 There are four types of antitranspirants.

a. Stomatal closing type: Transpiration mostly occurs through stomata on the leaf surface. Some fungicides like PMA (phenyl mercuric acetate) and herbicides like atrazine in low concentrations serve as antitranspirants by closing of stomata. PMA is known to inhibit mesophyll photosynthesis. Though the success was reported from glasshouse studies, their effectiveness under field conditions is limited.

b. Film forming type: The plastic and waxy materials, which form a thin film on the leaf surface, retard the escape of water due to formation of physical barrier. The success of
these chemicals is limited since they also reduce photosynthesis. The desirable characteristics of film forming type of antitranspirants are: they should form a thin layer, they should be more resistant to the passage of water vapour than carbon dioxide and the film should maintain continuity and should not break. These film forming antitranspirants may be of either thin film or thick film.

Thin film forming type: Hexadeconol
Thick film forming type: Mobileaf, Polythene S-60

c. Leaf reflectant type: These are the white materials, which form a coating on the leaves and increase leaf reflectance (albedo). By reflecting the radiation they reduce leaf temperatures and vapour pressure gradient from leaf to atmosphere and hence reduces transpiration. About 5% of kaolin spray reduces the leaf temperature by 3- 4°C and decrease in transpiration by 22 to 28 per cent. Celite and hydrated lime are also used as reflectant type of anti transpirants.

d. Growth retardant type: These chemicals reduce shoot growth and increase root growth and thus enable the plants to reduce transpiring surface and resist drought conditions. They increase root/shoot ratio. Eg : Cycocel – (2-chloroethyl) Trimethyl ammonium chloride (CCC), Phosphon-D, Maleic Hydrazide (MH)

Antitranspirants generally reduce photosynthesis. Therefore, their use is limited to save the crop from death under severe moisture stress. If crop survives, it can utilize the rainfall that is received subsequently. Antitranspirants are also useful for reducing the transplantation shock of nursery plants. They have some practical use in nurseries and horticultural crops. Waxy materials are used for reducing post-harvest shrinkage of fruits.

Types of important antitranspirants

<table>
<thead>
<tr>
<th>Stomatal closing type</th>
<th>Film forming type</th>
<th>Reflectant type</th>
<th>Plant growth regulators (PGRs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Herbicides</strong>: 2,4-D, Phosphon-D, Atrazine</td>
<td>Mobileaf, Hexadeconol</td>
<td>Kaoline, China clay, CaCO₃, Celite, Lime water</td>
<td>CCC, Mepiquat chloride, Cytokinins, Salicylic acid, Brassinolide, Ascorbic acid</td>
</tr>
<tr>
<td><strong>Fungicide</strong>: PMA</td>
<td>Silicone, Waxol</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Metabolic-inhibitors</strong>: Hydroxy sulfonates, potassium metabisulphite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Growth hormones</strong>: ABA, TIBA, CCC, ethrel, succinic acid, ascorbic acid</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.2 Use of wind breaks and shelterbelts:

Wind breaks are any structures that obstruct wind flow and reduce wind speed while shelterbelts are rows of trees planted for protection of crops against desiccating wind, reduce soil erosion and create a suitable micro-climate. Generally, shelterbelts give protection from desiccating winds to the extent of 5-10 times their height on windward side and upto 30 times on leeward side. A conical cross-section of windbreaks will provide the best protection from the winds. A conical cross-section of windbreaks will provide the best protection from the winds.
The direction from which wind is blowing is called windward side and direction to which wind is blowing is called leeward side.

Shelterbelts are planted across the direction of wind. They do not obstruct the wind flow completely. Depending upon their porosity, certain amount of wind passes through the shelterbelts while the rest deflects and crosses over the shelterbelts. It thus reduces wind speed without causing turbulence.

The protection offered by the shelterbelts is dependent on the height of central tree row in the shelterbelts.

Generally, shelterbelts give protection from desiccating winds to the extent of 5 to 10 times their height on windward side and up to 30 times on leeward side. Due to reduction in wind speed, evaporation losses are reduced and more water is available for plants. The beneficial effect of shelterbelts is seen more clearly in drought years. In addition, shelterbelts reduce wind erosion.

8.3 Effective weed control:

Weeds transpire frequently greater amount of water per unit of dry matter production than the crop plants. Therefore controlling weeds especially at early stages of crop growth will be most effective means of increasing the amount of water available for crops. This is the most useful method to reduce transpiration losses.

Weed management can be achieved through judicious management using good crop agronomy and a variety of weed management strategies. Weed competition in crop field is invariably severe in early stages of crop growth than at later stages. Generally, in a crop of 100 days duration, the first 35 DAS should be maintained weed free for optimum yield. In general, crops must be maintained weed free during the first one-third period of life cycle. The IWM combines different agronomic practices, mechanical, biological and herbicides use to manage weeds, so that the reliance on any one weed control technique is reduced.

9. Nutrient management

Indian dryland are not only thirsty but also hungry. Studies on the extent of nutrient deficiencies indicated that dryland soils are universally deficient in N, medium in P and high in K content. The stained crop production on these soils requites regular nutrient inputs through chemical fertilisers and organic manures to replenish soil nutrient reserves depleted by crops. The quantum of nutrients available for recycling via crop residues and animal manures is grossly inadequate to compensate for the amounts removed.

Following are the salient findings on fertiliser use in dryland agriculture:

1. Soils of dry regions are deficient in N in all soils, P in some soils, K is limited and Zn and Fe are sporadically. Most economical responses were with low rates of 25-30 kg N ha\(^{-1}\). On heavy black soils, crops respond to about 30 kg P\(_2\)O\(_5\) ha\(^{-1}\). Legumes in cropping system contribute up to 25 kg N ha\(^{-1}\).
2. Response of post-rainy season crops to fertilisers will depend on stored moisture in the profile and hence should be band placed in soil as basal application.

3. For *kharif* crops, N can be applied in splits depending on rainfall. Second split may be avoided if the soil moisture is not adequate for top dressing in time. Legumes are more responsive to P fertilisation.

4. Balanced fertiliser use resulted in yield advantage during normal rainfall year. Thus, IPNS approach has come to play a key role in these areas. IPNS involves judicious and combined use of fertilisers, bio-fertilisers, organic manures and growing of legumes in the cropping systems. IPNS also encompasses balanced fertilisation and SSNM. In case of Zn deficiency, 30 kg of zinc sulphate is applied once in three years.

10. **Mid-season corrections**

    Aberrant weather like late onset of monsoon, dry spell immediately after sowing, prolonged breaks during the crop period and early withdrawal of monsoon are common features of rainfed agriculture. The success of the implementable recommendations, largely, depends on the severity of soil moisture stress and stage of crop growth at which the crop is subjected to soil moisture stress. To boost production some practices are adopted as per the situation exists like-

    **Late onset of monsoon**: Adopt dry seeding, transplantation and alternate cropping systems

    **Dry spell immediately after sowing** : Maintain optimum plant stand and crop substitution

    **Breaks during the crop period** : Intercropping for risk distribution, reducing the crop stand by thinning, rationing, mulching.

    **Early withdrawal of monsoon** : Reduce plant population depending on the level of stored soil moisture, surface mulching with organic residues at 5 t/ha to minimise evaporation losses, protective irrigation at moisture sensitive stages, if possible, increasing frequency of inter-cultivation and stripping of leaves and use of antitranspirants to control moisture loss temporarily.

11. **Alternate land use systems**

    Choice of land use systems viz., mono-cropping, double cropping, mixed cropping, mixed farming, agri-horticulture and silvi-pastoral should be practiced depending upon the rainfall, soil type and other climatic conditions.

12. **Protective irrigation** to crops from harvested rainwater is the best way to save crops.

    x-x-x-x-x
CONTIGENT CROP PLANNING FOR ABERANT WEATHER CONDITIONS

Rainfall behavior in dry farming areas is erratic and uncertain. The deviations in rainfall behavior include delayed onset, early withdrawal and intermediary dry spells during rainy season. The adverse effect of these rainfall aberrations on crop growth vary with the degree of deviation and the crop growth stage at which such deviations occur. Suitable manipulations in crop management practices are needed to minimize such adverse effects of abnormal rainfall behavior. These management decisions constitute contingency planning. Such management practices done after crop establishment and in the middle of growth are called midseason or midterm corrections.

Table 1: Effect of Rainfall aberration on crop

<table>
<thead>
<tr>
<th>Rainfall aberration</th>
<th>Effect on crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay in onset of rainfall</td>
<td>Length of cropping season or cropping duration is reduced - crop sowing is delayed</td>
</tr>
<tr>
<td>Early withdrawal or cessation of rainfall</td>
<td>Moisture stress at maturity grain filling is affected (terminal stress)</td>
</tr>
<tr>
<td>Intermediate dry spells</td>
<td></td>
</tr>
<tr>
<td>a. Immediately after sowing</td>
<td>Germination will be affected, plant population will be reduced</td>
</tr>
<tr>
<td>b. At vegetative phase</td>
<td>Affects stem elongation, leaf area expansion, branching or tillering</td>
</tr>
<tr>
<td>c. At flowering</td>
<td>Affects anthesis and pollination, grain / pod number is reduced</td>
</tr>
<tr>
<td>d. At ripening</td>
<td>Grain filling and grain size reduced</td>
</tr>
</tbody>
</table>

CONTINGENCY CROPPING

Contingency cropping is growing of a suitable crop in place of normally sown highly profitable crop of the region due to aberrant weather conditions. In dryland agriculture, contingency of growing another crop in place of normally grown crop arises due to delay in the onset of monsoon. Depending upon the date of receipt of rainfall, crops are selected. It is assumed that the rainfall for the subsequent period is normal and depending upon the economic status of the farmer, certain amount of risk is taken to get good profits if season is normal or better than normal.

Contingency cropping is highly location specific due to variation in amount and distribution of rainfall. Especially in arid regions, the spatial distribution of rainfall is highly variable. It is common to observe that rainfall received varies from field to field in the same location. Temperature gradually falls from August onwards reaching minimum in November and December. Contingency plan and midterm corrections vary with the type and time of occurrence of rainfall aberration.

Crops have to be selected with suitable crop duration to coincide with the length of the growing season. Generally short duration pulses like greengram, black gram and cowpea may suit the situation. However if the monsoon turns to be extraordinarily good, opportunity is lost if only short duration crops are sown. Farmers with economic strength and motivation for high profits with some amount of risk can go for crops of long duration. The long duration
crops with flexibility or elasticity in yield are more suitable. For example, pearl millet, and sorghum can be ratooned if monsoon extends. Sunflower can be introduced for higher profits with certain amount of risk. Crops like sorghum, pearl millet, can be grown for grain if monsoon extends and if not, fodder can be obtained.

Table 2: Contingency Planning for Rainfall Abnormalities

<table>
<thead>
<tr>
<th>Rainfall abnormality</th>
<th>Contingency plan and midterm correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Delayed onset of rainfall</td>
<td></td>
</tr>
<tr>
<td>a) Delay exceeding 4 weeks</td>
<td>Alternate crops of short duration to be sown</td>
</tr>
<tr>
<td>Delay in South west monsoon</td>
<td></td>
</tr>
<tr>
<td>Normal – June</td>
<td>Groundnut</td>
</tr>
<tr>
<td>Delay – July</td>
<td>Ragi / Pearl millet</td>
</tr>
<tr>
<td>Extreme Delay - August</td>
<td>Sama (Little millet / Ragi)</td>
</tr>
<tr>
<td>Delay in North east monsoon</td>
<td></td>
</tr>
<tr>
<td>Normal – October</td>
<td>Cotton / Sorghum</td>
</tr>
<tr>
<td>Delay – Early November</td>
<td>Sunflower / Pearl millet / Ragi</td>
</tr>
<tr>
<td>Extreme Delay - Late November</td>
<td>Coriander / Bengal gram</td>
</tr>
<tr>
<td>b) Delay of 1 to 2 weeks</td>
<td>Alternate varieties of short duration of the same crop e.g. Sorghum Co 19 (150 days), Co 25 (110 days), Red gram local (180 days), Co 5 (130 days)</td>
</tr>
</tbody>
</table>

2. Early withdrawal of rainfall

Antitranspirants spray, harvesting for fodder (millet), harvesting at physiological maturity

3. Intermediary dry spell

a. Immediately after sowing

Gap filling with subsequent rains if stand reduction is less than 20%. Re-sowing if stand reduction is more than 20%, mulching between crop rows. Stirring soil surface to create dust mulch to reduce evaporation.

b. At vegetative phase

Mulching, antitranspirants spray, spraying potassium chloride, thinning of 33-50% population

c. At flowering

Antitranspirants spray, harvesting for fodder and ratooning with subsequent rains in millets (e.g. sorghum)

d. At ripening

Antitranspirants spray, harvesting for fodder and harvesting at physiological maturity

Crop planning for successful crop production under water scarcity and dry farming condition:

In low rainfall and water scarcity situations during kharif, the crops like Bajra, Castor and legumes crop like Tur, Moong, Black gram, Kidney bean, Guar and Cowpea. Crop planning for successful crop production under water scarcity and dry farming condition should be as under:

1. Bunding and leveling should be done to conserve the rain water in situ.
2. Sowing the crop at optimum time.
3. Tillage and sowing of the crop across the slope.
4. Use higher amount of organic manures like FYM, compost, vermicompost and cake.
5. Apply fertilizers at sowing under adequate soil moisture or as top dressing after irrigation.
6. Use drip irrigation in wide spaced crops and sprinkler irrigation in narrow spaced crops, if possible.
7. Inter culturing, weeding and crop protection measures should be done as and when required.
8. Adopt mixed and inter cropping systems.
9. Raise crop in strip cropping.
10. Create farm pond for life saving irrigation.

**Table 3: Suggested Contingency Crop Planning For Some of the Dryland Regions of Gujarat**

1. **Latest Released varieties of major crops**
   
   The latest released varieties of major crops grown in Gujarat state are as under:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddy</td>
<td>Mahisagar, GAR 3, GR 14 and Gurjari</td>
</tr>
<tr>
<td>Maize</td>
<td>Gujarat Anand Yellow Maize Hybrid 1 and Gujarat Anand White Maize Hybrid 2 – early maturity hybrids for rainfed tribal areas</td>
</tr>
<tr>
<td>Bajra</td>
<td>GHB 558, GHB 744, GHB 905 and GHB 732</td>
</tr>
<tr>
<td>Tur</td>
<td>AGT 2 and GT 104</td>
</tr>
<tr>
<td>Moong</td>
<td>Gujarat Anand Moong 5, GM 6 and GM 7</td>
</tr>
<tr>
<td>Guar</td>
<td>Gujarat Guar 1 and Gujarat Guar 2</td>
</tr>
<tr>
<td>Cotton (Desi)</td>
<td>Anand Desi Cotton 1 (ADC 1), GADC 2, Gujarat Cotton 13 &amp; 21 are recommended for desi cotton growing area of Vagad and Bhal regions</td>
</tr>
<tr>
<td>Cotton (Irrigated)</td>
<td>Gujarat Cotton Hybrid 6, Gujarat Cotton Hybrid 8, Gujarat Cotton Hybrid 10, Gujarat Cotton Hybrid 12 and GTHH 49</td>
</tr>
<tr>
<td>Tobacco</td>
<td>MRGTH 1, GABTH 2 and Gujarat Anand Bidi Tobacco 11 (GABT 11)</td>
</tr>
<tr>
<td>Fodder sorghum</td>
<td>COFS 29, GAFS 11 and GAFS 12</td>
</tr>
<tr>
<td>Fodder Bajra</td>
<td>Gujarat Anand Forage Bajra 4</td>
</tr>
<tr>
<td>Castor</td>
<td>Gujarat Castor Hybrid 7, Gujarat Castor Hybrid 8, Gujarat Castor Hybrid 9 and Gujarat Anand Castor 11</td>
</tr>
<tr>
<td>Sesame</td>
<td>Gujarat Till 3 &amp; Gujarat Till 6, Purva</td>
</tr>
<tr>
<td>Soybean</td>
<td>NRC 37</td>
</tr>
<tr>
<td>Groundnut</td>
<td>GG 20, GJG 9, GJG 17 and GJG 22</td>
</tr>
<tr>
<td>Okra</td>
<td>GAO-5</td>
</tr>
</tbody>
</table>

3. **Recommendation for late onset of monsoon**

   Generally, the period between 15\textsuperscript{th} June to 15\textsuperscript{th} September is considered as *kharif* season. However, it is required to change the crop planning in *kharif* season, if the rainfall pattern is...
found uneven. If there is a late onset of monsoon, then select the crops and their varieties as under:

1. **Onset of monsoon in the first week of July** - Groundnut varieties Gujarat Groundnut 2, Gujarat Groundnut 5 and Gujarat Groundnut 7 as well as cowpea variety Gujarat 1 should be grown.

2. **If sufficient rainfall occurs during first fortnight of July** - Crops like bajra, moong, black gram, sesame, castor and tur should be grown.

3. **If sufficient rainfall occurs at the end of July** – Sesame (Purva 1) and forage sorghum variety Gundari should be grown.

4. **Recommendation for regular monsoon:**

   **Table 4 : Selection of the crop and their varieties**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cotton</td>
<td>High yielding <em>Bt</em> cotton varieties as well as Gujarat Hybrid 8 and Gujarat cotton 10,13,15,18 and 21. ADC 1 and 2 for rainfed cotton</td>
</tr>
<tr>
<td>2</td>
<td>Pearl millet</td>
<td>GHB 558, GHB 538, GHB 732, GHB 744 and GHB 905</td>
</tr>
<tr>
<td>3</td>
<td>Soybean</td>
<td>NRC 37</td>
</tr>
<tr>
<td>4</td>
<td>Groundnut</td>
<td>Spreading varieties</td>
</tr>
<tr>
<td>5</td>
<td>Castor</td>
<td>GCH 7, GCH 8, GCH 9 and Gujarat Anand Castor 11</td>
</tr>
<tr>
<td>6</td>
<td>Sesame</td>
<td>GT3, GT 4, GT 6 and Purva</td>
</tr>
<tr>
<td>7</td>
<td>Pigeon pea</td>
<td>AGT 2, GT 104 and Vaishali</td>
</tr>
<tr>
<td>8</td>
<td>Green gram</td>
<td>GAM5, GM 6, GM 7 and Meha</td>
</tr>
<tr>
<td>9</td>
<td>Mootbean</td>
<td>Gujarat Moot bean 1 and Baleshwar</td>
</tr>
<tr>
<td>10</td>
<td>Black gram</td>
<td>T 9 and Gujarat Black gram 1</td>
</tr>
<tr>
<td>11</td>
<td>Cowpea</td>
<td>Pusa falguni, Gujarat cowpea 1 and 2, AVCP 1</td>
</tr>
<tr>
<td>12</td>
<td>Sorghum (Fodder)</td>
<td>COFS 29, GAFS 11 and GAFS 12</td>
</tr>
<tr>
<td>13</td>
<td>Cluster bean</td>
<td>Gujarat Cluster bean 1 and Gujarat Cluster bean 2</td>
</tr>
</tbody>
</table>

5. **Recommendations under long dry spell**

   There is a shortage of moisture in the soil, if the duration between two rainfall is extended even under normal on set on monsoon. If this period between rainfall is extended for longer time, than there is a partial or full failure of the crop. Under this situation crop planning should be done as under

1. Do interculturing and weeding. Keep crop weed free and do mulching.
2. When moisture stress prevails, thinning should be done. If more moisture stress prevails, remove alternate row and thin the plant in the field
3. Provide lifesaving irrigation to the crop if irrigation facility available
4. When sufficient rainfall received after dry spell, nitrogen fertilizer should be given as top dress to the crops except groundnut.
5. When crop failed due to long dry spell, after receiving sufficient rainfall farmers can grow hybrid pearl millet GHB 558, GHB 577.
6. Farmers should grow Sesame variety Purva 1 or Gujarat Til 1 or Castor variety GAUCH 1 and GAC 11. In addition farmers can also grow fodder sorghum or rajaka bajri.

7. Reduce the plants by harvesting the matured plants frequently, to save the conserved

6. **Recommendations when heavy rainfall occurs at the end of monsoon during August – September**

   Many times during end of September or beginning of October late rainfall received. Under such situation following crop planning can be done.

   1. For getting the benefits of good late rainfall sowing of fodder sorghum, short duration semi rabi and rabi crops *i.e.* castor, mustard, gram, safflower, fodder crops (maize/oat and lucerne) should be grown as relay crops between two rows of long duration crops *i.e.* cotton, tur and fennel.
   2. Gram, mustard and fodder sorghum can be grown after harvesting of early maturing *Kharif* crops.

7. **Recommendations made by Anand Agricultural University, Anand**

   1. The farmers willing to grow pigeon pea under organic farming system are recommended to grow variety BDN 2 with vermicompost 1 t/ha or FYM 5 t/ha.
   2. In pigeon pea cv. AGT 2 recommended for fertilizer dose and additional 20 kg S/ha should be applied.
   3. It is recommended that vegetable pigeon pea (GT 1) should be fertilized with 5 t FYM/ha.
   4. For getting higher yield of soybean cv. NRC37, it is recommended to sow the crop at the onset of monsoon.
   5. Farmers growing nematode resistant * bidi* tobacco variety ABT 10 are recommended to topping the plant at 18 leaves and give 4-5 irrigations at 15-20 days intervals.
   6. The farmers growing vegetable cowpea (Vegetable cowpea 1) are recommended to fertilize with 5 t FYM/ha and 10:20:00 kg NPK/ha as basal dose. Sowing should be done at 45 X 45 cm after seed treatment with *Rhizobium* and PSB culture (Both @ 5 ml/kg seed).
   7. Drilled paddy varieties DDR 97 and Ashoka 200 F are recommended for rainfed areas.
   8. For rainfed areas, Gujarat Anand Yellow Maize Hybrid 1 as early variety and Gujarat Anand White Maize Hybrid 2 is recommended for unirrigated *kharif* cultivation.
   9. For semi rabi castor cultivation, the sowing of GCH 7 variety should be done up to 10 to 25\textsuperscript{th} September at spacing of 120 cm x 75 cm.
   10. *Desi* cotton early maturity variety Anand *Desi* Cotton 1 and 2 is recommended for *Vagad* and *Bhal* regions.
   11. It is not beneficial to apply phosphorus to *desi* cotton in North-Western Agro-climatic Zone areas. It is recommended to apply 100 % nitrogen from FYM (8 t/ha) or apply 75 % nitrogen from chemical fertilizer (30 kg/ha) + 25 % nitrogen from vermicompost (600 kg/ha).
12. The farmers of Middle Gujarat Agro-climatic Zone growing semi-*rabi* green gram are recommended to sow the crop during 3rd week of September at 30 cm spacing for obtaining higher yield and net return.

13. The farmers of *Bhal* and Coastal Agro-climatic Zone growing rainfed *desi* cotton are recommended to sow cotton variety Gujarat Cotton 21 at 60 x 30 cm spacing to get higher seed cotton yield.

14. The farmers of Middle Gujarat Agro-climatic Zone are advised to adopt semi *rabi* pearl millet by transplanting one month old seedlings of GHB 744 or GHB 732 during 20th to 30th September for getting higher grain and dry fodder yield as well as net return.
Introduction

Soil, water and vegetation are the most vital natural resources for the survival of the life on the biosphere. The prosperity and development of a nation depends, to a great extent on natural resources and their management. Today these resources are under tremendous stress due to ever increasing biotic pressure and mismanagement of resources. The optimal management of these natural resources with minimal adverse environmental impact is a desirable not only for sustainable development but also for human survival. For the efficient management, one has to look for suitable units of management so that these resources are handled and manages effectively, collectively and simultaneously. The soil, water and vegetation can be managed efficiently by the unit system. The watershed is an ideal unit for the natural resources management.

History of Watershed Development in India:

The earliest record of water management by manipulating the natural water regime in India is found in Inamgaon near Pune. During the rule of the Mauryan Dynasty (320 BC) the construction of water harvesting structure (WHS) and sustainable irrigated agriculture in semi-arid regions attained a high level of perfection. The golden age of tank construction in the Deccan Plateau was the reign of Chalukyas of Lakyan (973 to 1336 AD).

At national level, Soil Conservation Board was established in the Ministry of Food and Agriculture during the first five year plan (1951-56). Under the control of this Board, a chain of Soil Conservation Research, Demonstration and Training centres were established in the latter period of first plan and early period of second plan.

<table>
<thead>
<tr>
<th>Location</th>
<th>Establishment Date</th>
<th>Problem area covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehra Dun</td>
<td>20th September, 1954</td>
<td>North-western Himalayan Region</td>
</tr>
<tr>
<td>Ootacamund</td>
<td>20th October, 1954</td>
<td>Southern hilly high rainfall region</td>
</tr>
<tr>
<td>Kota</td>
<td>19th October, 1954</td>
<td>Ravine problem on the banks of Chambal river</td>
</tr>
<tr>
<td>Bellary</td>
<td>20th October, 1954</td>
<td>Black soil region (semi-arid)</td>
</tr>
<tr>
<td>Vasad</td>
<td>11th May, 1955</td>
<td>Ravine problem on the banks of Mahi river (Gujarat)</td>
</tr>
<tr>
<td>Agra</td>
<td>1st October, 1957</td>
<td>Ravine problem on the banks of Yamuna river</td>
</tr>
<tr>
<td>Chandigarh</td>
<td>1st October, 1957</td>
<td>Sub-mountain tracts in NE region of India (Shiwalik hills)</td>
</tr>
<tr>
<td>Ibrahimpatnam</td>
<td>12th October, 1962</td>
<td>Red soil region (semi-arid)</td>
</tr>
</tbody>
</table>

Watershed development (WSD) projects in the country has been sponsored and implemented by GOI from early 1970s. Various WSD programmes were launched subsequently in various hydro-ecological regions which were primarily focused on soil conservation and water harvesting during 1980s and before. The GOI appointed a committee in 1994 under the chairmanship of Prof. C.H. Hanumantha Rao. The committee gave new guidelines for WSD programmes in 1995 and strongly emphasised on collective action and participation of primary stakeholders, local community, NGOs and Panchayati Raj Institutions.
Need for unification of multiplicity of watershed development programmes within the framework of a single national initiative was felt in 2001. A sub-committee constituted for this purpose suggested common guidelines for watershed development projects through Nation Authority for Development of Rainfed Areas (NAFDORA). This finally resulted in set up of National Rainfed Area Authority (NRAA) in November, 2006. The Common guidelines for WSD were released in 2008 (called Neeranchal guidelines) and revised in 2011 and 2013.

**Chronology** of watershed development (WSD) programmes and policies adopted in India are given below:

1973-74 : Drought Prone Area Programme (DPAP)
1977-78 : Desert Development Programme (DDP)
1987 : National Research Centre for Agroforestry, Jhansi
1989-90 : Integrated Wasteland Development Programme (IWDP)
1989 : Integrated Afforestation and Eco-Development Scheme (IAEPS)
1990-91 : National Watershed Development Project for Rainfed Areas (NWDPRA)
1992 : Indo-German Watershed Development Programme (IGWDP)
1994 : Guidelines for Watershed Development
1998 : National Agricultural Technology Project (NATP)
1999-2000 : Watershed Development Fund
2001 : Common Guidelines for Watershed Development (Revised)
2002 : National Afforestation Programme
2003 : Hariyali Guidelines released
2005 : Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)
2006 : Parthasarathy Committee report
2006 : National Rainfed Area Authority (NRAA)
2008 : Common Guidelines for WSD (called Neeranchal) released
2009 : Integrated Watershed Management Programme (IWMP)
2011 : Revised Common Guidelines for WSD were released
2013 : Revisions added to 2008 Neeranchal Guidelines

**What is Watershed?**

All land everywhere is part of some watershed. It is a land area that captures rainfall and conveys the overland flow and runoff to an outlet in the main flow channel. The term ‘watershed’ strictly refers to the division separating one drainage basin from another. At present, the term ‘watershed’ is defined as ‘land area from which rainwater drains to a common point’. In this context, watershed is considered to be synonymous with ‘catchment’ and ‘drainage basin’. The word ‘watershed’ introduced in 1920 was used for the ‘water parting boundaries’. Watershed or catchment or drainage basin is that land area which drains to a common point called ‘outlet’. With respect to the outlet, the watershed consists all of the land area that collects water which flows to the outlet during a rainstorm. The watershed is also known as ridgeline in U.K.
In physical terms, a watershed refers to the area lying above a given drainage point. It may cover from <1 ha to thousands of hectares depending upon the point of reference. Rainwater from a few hectares of land may drain into a common small stream. The few hectares of land will, therefore, be the watershed area of that stream. This small stream runs into a larger stream. The land area drained by the small stream makes up the watershed of the larger stream into which they flow.

The watershed boundary is called the drainage divide. Precipitation received on the opposite side of a drainage divide does not contribute to the runoff of the particular adjoining watershed. Thus, watershed is a geo-hydrological unit of delineated area from which the rainwater drains through a common outlet. The people, animals and vegetation are part of the watershed community. All depends of the watershed and they, in turn, influence what happens on the topography of that area—whether for good or bad.

**Why Need of Watershed?**

Since, watershed is a hydrological entity; natural resources management and their utilization are best attempted by taking it as a unit of development planning. Proper rainwater management, conservation, runoff control and development of water resources is essential for meeting water demands of domestic, drinking, irrigation and industrial needs is possible through it. Apart from development of agriculture, it may encourage areas of infrastructure development, energy, health, education and prosperity among the community. Management on watershed basis is now accepted as an essential feature for full and integrated development of any area. Hence, a watershed approach is needed for overall sustainable development.

**Hierarchy of a watershed**

Watershed is a smaller geographical unit of a river system. It is also a self-contained replica of the river system. The river system and its total catchment have a hierarchical relationship with its smaller watershed units. Generally, rainwater on a ridge is divided in the
direction of the slopes. The ridges acts as water divide, meaning that the rainwater diverges from here in two or more directions following the slope of the land. Within the area surrounded by the ridge (catchment area), the surface runoff of water converges to feed the drainage system. The rainfall in the watershed turns into surface and groundwater flows and passes through its drainage system, tending to exit the area through the lowest part of the trunk stream.

The River Basin
  ↓
Basin of a Tributary
  ↓
Watershed or Sub-basin of a Stream
  ↓
Watershed of a Stream of a Lower Order
  ↓
Micro-Watershed of a Minor Stream

Fig. Watershed hierarchy and its river system

Small watersheds are drainage areas of a few thousands to a few tens of thousands of hectares. Larger drainage areas are usually called river basin. The micro-watersheds of agricultural fields may be considered as units which may range from a few hectares to hundreds of hectares. In an agricultural watershed, there may be several fields of farmers. The runoff collected from a watershed drains off into a natural water course. The movement of runoff depends on the topography of the land. Soil conservation measures adopted in a few fields in an isolated manner do not serve the purpose. Runoff, from fields where erosion control measures are not adopted, enters the fields situated at lower end of the watershed. It is necessary to adopt resource conservation measures over an entire watershed instead of individual fields. In addition, development is taken in the entire watershed area including wastelands, forests in addition to agricultural land from ridgeline to the outlet.

Delineation and Types of Watersheds:

The boundary of a watershed is defined by all points that shed water to the outlet. The delineation of a watershed is important for hydrologic design. A Watershed Atlas of India has been prepared by the Soil and Land Use Survey of India, 2018-19 which divides India into 6 major water resource regions, 37 river basins, 117 catchments, 588 sub-catchments and 3,854 watersheds, 49,618 sub-watersheds and 3,21,324 micro-watershed. There is both a macro level and micro level delineation (the action of indicating the exact position of a border or boundary).

Size of the watershed:

Questions are often asked on unit watershed size, particularly in the context of large-scale watershed development. However, a particular size of a watershed is depends on the objective of development. For major and medium irrigation projects, a watershed of thousands of km² in size has to be considered. At small storage structure on a farm, the watershed size may be only a few ha. However, the Government regards small catchments of 300–500 ha as a unit watershed. Large watersheds can be preferred in the plains valley areas.
where pasture and forest development is the major objective. From the land management point of view, a convenient size of watershed may vary from 500 – 1000 ha. On an average, the watershed size of 2,000 ha is considered reasonable for agricultural development. The most appropriate size of the *micro-watershed* for development at field level is around 500 hectares.

The technique adopted by SLUSI for classification of watersheds is tabulated below:

<table>
<thead>
<tr>
<th>S. N.</th>
<th>Category of Hydrological Units</th>
<th>Size Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro delineation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Regions</td>
<td>270 – 1130 lakh ha</td>
</tr>
<tr>
<td>2.</td>
<td>Basins</td>
<td>30 – 300 lakh ha</td>
</tr>
<tr>
<td>3.</td>
<td>Catchments</td>
<td>10 – 50 lakh ha</td>
</tr>
<tr>
<td>4.</td>
<td>Sub-catchments</td>
<td>2 – 10 lakh ha</td>
</tr>
<tr>
<td>5.</td>
<td>Watersheds</td>
<td>0.2 – 1.5 lakh ha</td>
</tr>
<tr>
<td><strong>Micro delineation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Macro-watersheds</td>
<td>&gt; 50,000 ha</td>
</tr>
<tr>
<td>7.</td>
<td>Sub-watersheds</td>
<td>10,000 – 50,000 ha</td>
</tr>
<tr>
<td>8.</td>
<td>Milli-watersheds</td>
<td>1,000 – 10,000 ha</td>
</tr>
<tr>
<td>9.</td>
<td>Micro-watersheds</td>
<td>100 – 1000 ha</td>
</tr>
<tr>
<td>10.</td>
<td>Mini-watersheds</td>
<td>1 – 100 ha</td>
</tr>
</tbody>
</table>

**Problems of Watersheds:**

Although, India has enormous potentiality to use water, the watershed areas of the country are suffered from various problems like:

a) **Physical problems:** Steep slopes, badlands, weak geological formations. Siltation of reservoirs, *etc.* can be found by observation of the existing maps. Problems such as heavy and intense rainfall, excessive runoff and strong winds can be identified from the weather and hydrological data.

b) **Resource use problems:** Problems such as shifting cultivation, excessive cropping, forest destruction, fire, over grazing, human and animal pressure, poor road construction and uncontrolled mining.

c) **End problems:** The final effects of watershed degradation *i.e.* soil erosion, landslides, heavy sedimentation, water pollution, floods and droughts.

c) **Socio-economic and other problems:** Serious-socio-economic problems can be major obstacles in carrying out watershed work. Any serious problem should be identified at the beginning of the stage. These may include land tenure, poverty, lack of education, low acceptance of innovations, seasonal shortage of labour *etc.*

Soil loss is a natural process and cannot be avoided completely but can be reduced to a maximum acceptable rate. A mean soil loss of 11 t/ha is generally accepted as appropriate. This value is as low as 2 t/ha where soils are shallow and highly erodible. It has been estimated that in India, about 5334 MT of soil is eroded annually. Out of which 29% is
permanently lost to the sea, 10% is deposited in reservoirs and 61% is transported from place to place.

**What is Watershed Management?**

*Watershed management* is the rational utilization of land, water and vegetation resources for optimum production with minimum hazards. It involves management of land surface and vegetation so as to conserve the soil and water for immediate use and long term benefits for the farmers and the society as a whole. In a watershed management system having favourable topography where improved land-use practices could be introduced easily and precipitation distribution is not much uneven or erratic, such a system may be termed as well-managed.

*Watershed management* is an integration of technologies within the natural boundaries of the drainage area for optimum development of land, water and plant recourses to meet the basic needs people in a sustained manner.

*Watershed management* may be defined as the process of formulating and carrying out a course of action involving manipulation of natural, agricultural and human resources of a watershed to provide resources that are desired by and suitable to the watershed community, but under the condition that soil and water resources are not adversely affected.

**Concepts of Watershed Management:**

It is not that watershed concept is not known, but many times the technical aspects of the development either not well understood or are badly applied. Since, no ‘package of practices’ of wade-scale application of watershed technologies exists.

The intensification of land use in the traditional agricultural setting is self-defeating because it is exploitive. The present agricultural practices greatly increase runoff and soil erosion, reduce groundwater recharge, cause floods and sedimentation of reservoirs etc. As a result, the cultivated land resource base is shrinking and its productive capacity is diminishing.

The management of watershed resources to produce more than one product is called “multiple use concepts”. Most of the development activities are closely associated with the development and use of water resources. The main aim of multiple use management should be to manage natural resources for the most beneficial combinations in present and future uses. It is not necessary that every watershed is managed for all possible natural resource products simultaneously. In the ‘watershed concept’ development is not confined to agricultural land alone but covers the entire watershed area.

*Watershed management* is a holistic development concept that encompasses land, water, agriculture, forestry and all related enterprises matters in relation to the people who inhabit the area and their socio-cultural system.

Watershed management envisages not only adoption of soil and water conservation measures, but all other measures for increasing productivity, production and economic return for the farmers in the watershed area. The object of watershed management is to meet the problems of land and water use not in terms of any one measure, but on the basis that all resources are interdependent and must be considered together.
As the entire process of agricultural development is depends on status of water resources. Hence, it is essential to have various developmental programmes on watershed basis in conjunction with basic soil and water conservation measures. The developmental activities need to be taken up from ridgeline to outlet point (ridge to valley).

Watershed management programme in drylands aimed at optimizing the integrated use of land, water and vegetation for providing an answer to alleviate drought, moderate floods, prevent soil erosion, improve water availability and increase food, fodder, fuel and fibre on sustained basis. The watershed is the natural framework for resource development in relation to crop production.

**Objectives of Watershed Management:**

There are various descriptions of the objectives of watershed management, mostly depending on the emphasis given in the proposed management programme. The main objective of its development and management is proper use of all the available recourses of watershed for optimum production with minimum hazards to natural resources. The overall objectives of a watershed management either single or in combinations are outlined as:

1. To control damaging runoff and soil erosion.
2. To protect, conserve, and improve the natural resources for efficient and sustained production.
3. To manage the watershed in order to minimize floods, droughts, landslides, etc.
4. To protect and enhance water resources, reducing silting of conservation structures and conserving rainwater.
5. To increase the groundwater recharge through in-situ conservation and water harvesting structures.
6. To rehabilitate the deteriorating lands.
7. To utilize the natural local resources for improving agriculture and allied occupations so as to improve the socio-economic conditions of the beneficiaries.

The objectives of watershed management programme can also be described in symbolic form of POWER. Here the letters symbolizes as:

\[ \begin{align*}
P &= \text{Production of food-fodder-fuel-fruit-fibre-fish-milk on sustained basis} \\
  &= \text{Pollution control} \\
  &= \text{Prevention of floods} \\
O &= \text{Over exploitation of resources minimization by controlling excessive biotic pressure} \\
  &= \text{Operational practicability of all on farm operations and follow up programmes} \\
W &= \text{Water storage at convenient locations for different purposes} \\
  &= \text{Wild animal and indigenous plant life conservation at selected places} \\
E &= \text{Erosion control} \\
  &= \text{Ecosystem safety} \\
  &= \text{Economic stability} \\
  &= \text{Employment generation}
\]
R = Recharge of groundwater
= Reduction of drought hazards
= Reduction of siltation in multipurpose reservoirs
= Recreation

Principles of Watershed Management:
The important principles of watershed management techniques are:
1. Utilizing the land according to its land capability classification (LCC)
2. Putting adequate vegetative cover on the soil surface for controlling soil erosion, mainly during the rainy season.
3. Conservation of maximum rainwater at the place where it falls on arable land by conservation practices.
4. Draining out excess water with safe velocity to avoid soil erosion and storing it in different rainwater harvesting structures for efficient future use.
5. Preventing gully formation and putting check dams and gully plugs at suitable intervals to control soil erosion and increase groundwater recharge.
6. Safe utilization of marginal lands through alternate land use systems.
7. Maximizing productivity per unit area, per unit time and per unit water.
8. Improving sustainability of ecosystem and socio-economic status of the inhabitants.

The principles of modern watershed management programmes are holistic and flexible, people-centred and participatory, multi-sectorial/multi-holders negotiations and dialog process, integration of multi-disciplinary sectors and effective collaboration and coordination.

The land is classified into 8 land capability classes, where class I to IV falls under suitable for cultivation and V to VIII not suitable for cultivation but exclusively suitable for other uses. The detailed ‘LCC for Watershed Management’ is presented in the book ‘Fundamentals of Watershed Management Technology’ (Singh and Poonia, 2003).

Steps for watershed management action plan:
Watershed management involves determination of alternative land management measures, for which it is essential that as much information as possible is obtained about the problems of soil, land, vegetation, water, animals and inhabitants involved in the watershed. In order to arrive at a practical solution to these problems, it is necessary to go through ten distinct steps:
1. Identification and selection of watershed.
2. Description of watershed.
4. Designing the technology components.
5. Preparation of base maps of watershed.
6. Cost-benefit analysis to indicate estimated cost.
7. Fixing the time frame.
8. Monitoring and evaluation to assess the progress of the project.
9. On-farm research to identify solutions for site-specific problems.
10. Good organizational structure.

FACTORS AFFECTING WATERSHED MANAGEMENT

The factors affecting watershed management are divided into five groups:

1. Watershed characteristics
2. Climatic characteristics
3. Land use patterns
4. Social status of inability
5. Organization

1. Watershed Characteristics

Watershed characteristics influencing watershed management include size, shape, topography, slope, soils, vegetative cover and drainage density.

Size

Size of watershed determines the quantity of rainfall received, retained and surface runoff. A small watershed is pronounced by overland flow which is the main contributor to peak flow. The longer the watershed, the higher is the time of concentration while broader the watershed the smaller is the time of concentration. A large watershed has no overland flow, but channel flow is significant. Large watersheds are also affected by basin storage.

Shape

Shape contributes to the speed with which the runoff reaches the river. A long catchment area will take longer to drain than a circular catchment. Basin shape is not usually used directly in hydrologic design methods. A circular shaped watershed would results in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis (having the same area as the circular watershed) would cause the runoff to spread out over time, thus producing a smaller flood peak than that of circular watershed.

Topography

Topographic configuration like slope, length, degree and uniformity of slope affect both disposal of water and soil loss. Time of concentration and infiltration of water are a function of degree and length of slope. Topography determines the speed with which the runoff will reach a river. If the land slope increases four times, the velocity of water flowing down the slope is doubled. When velocity is doubled, the erosive capacity increased four times. Clearly, rain that falls on steep mountainous areas will reach the primary river in the watershed faster than flat/sloping areas.

Slope

Watershed slope affects the momentum of runoff. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the end points of the main flow path divided by the length. Elevation difference may not necessarily be the maximum elevation difference within the watershed.
Soils

Soil of the watershed determines the amount of water that percolates, runoff and silt which will be washed down the valley. Erodibility and transportation of a soil depends on different soil characteristics.

Vegetative Cover

Vegetative cover is an important landscape element in any watershed. The type of vegetation and its extent of vegetation on watershed lands affect the infiltration, water retention, runoff production, erosion, sedimentation and the rate of evaporation. Vegetation intercepts rainfall, impedes overland flow and promotes infiltration. All of these factors reduce the quantity of runoff to streams. Vegetation binds and stabilizes soil, thereby reducing the potential for erosion. Vegetation also stabilizes stream banks and provides habitat for aquatic and terrestrial fauna. Vegetation functions to slow runoff and reduce soil compaction, allowing better percolation of rain into soil and groundwater recharge. In addition, the patterns, sizes and composition of the vegetation affect reduction of soil erosion.

Leaves and branches intercept the falling rain and reduce the effect of raindrop splash. The lesser the falling height of the raindrops, the lesser will be its energy to cause splash erosion. Vegetative litter builds up an organic surface that provides protection of the soil layer. Root systems also help to keep soil material stable from moving down slope.

Drainage density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well / poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow. Rivers that have a high drainage density will often have a more 'flashy' hydrograph with a steep falling limb. High drainage density indicates a greater flood risk.

2. Climatic Characteristics

The greatest factor controlling stream flow is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out and a stream will often continue to flow where there is no direct runoff from recent precipitation.

Climate parameters like intensity and frequency of rainfall, temperature, humidity, wind velocity and direction affects watershed functioning. It regulates factors like soil properties and vegetation of the region. In the same way, the vegetation type of a region depends totally on its climate type. It is estimated that the total energy of the raindrops equals 100 HP on one ha land during the one cm rainfall for one hour. Thus, all climatic factors determine the amount of surface runoff and transportability of soil particles.

3. Land Use Pattern

Watersheds maintain the health of forests, fisheries, wetlands, coastal resources, agricultural landscapes, habitat and local communities. Protecting watersheds ensures sustainable environment that supports recreational activities and a healthy economy.

Type of land use, its extent and management are the key factors which affect watershed behaviour. Judicious land use by users is of vital importance to watershed management and functioning. Change of land use within the watershed, especially within the
variable source area, greatly affects the collection capacity and consequent runoff behaviour of the watershed. If the land use changes are local, then the impact of such changes is especially apparent in the storm hydrograph.

4. **Social Status of Inability**

    Common contributors to water pollution are nutrients and sediment which typically enter stream systems after rainfall washes them off poorly managed fields. These types of pollutants are considered *nonpoint sources of pollution* because the exact point where the pollutants originated cannot be identified. Such pollutants remain a major issue for water ways because of the difficulty to control their sources hinders any attempt to limit the pollution. Point source pollution originates a specific point of contamination such as if a manure containment structure fails and its contents enter the drainage system.

5. **Organization**

    The success of any WSD programme is depends on the type of organization. This is the crucial factor for watershed development. Land use questions can only be tackled in close collaboration with the owners and the local participatory inhabitants. To augment such interaction, the size of the watershed should not be too large or too small. People’s participation is only effective when a watershed have an organized development agency.

**COMPONENTS OF WATERSHED MANAGEMENT PROGRAMME**

The main components of watershed management programmes include:

1. Soil and water conservation
2. Water harvesting
3. Crop management and
4. Alternate land use systems

1. **Soil and water conservation measures:**

    *Soil conservation* is using and managing the land based on the capability of the land itself involving the application of the best management practices leading to profitable crop production without land degradation. The basic principle behind soil conservation measures is to minimize the velocity of surface runoff by transforming undulating topography into relatively flat surfaces which increases the opportunity time of the rainwater to infiltrate into the soil for future use by the crops.

    Based on the nature and type of hydraulic barriers and their cost, the conservation measures in arable lands can be divided into three categories:

    **A. Permanent treatments (Hardware treatments):**

    Bunds, terraces and waterways are the permanent measures in watershed management project. These measures are provided to improve relief, physiography and drainage features of watershed, aimed at controlling soil erosion, regulating surface runoff and reducing peak flow rates. Contour bunds are suitable for low rainfall areas (<600 mm) and in permeable soils having slope up to 6%. Graded bunds are suitable for high rainfall areas (>600 mm) and for poor permeable soils having 2-6% slope. Bench terracing is suitable for soils having slopes 16-33%. Bench terraces reduce both slope length and degree of slope. At Ootacamund erosion rate decreased from 39 t/ha to less than 1.0 t/ha on 25% sloping land by bench terracing.
B. Semi-permanent treatments (medium software treatments):

These are usually inter-bund treatments where field sizes are large in conventionally bunded area. They are adopted to minimize the velocity of overland flow. It includes key-line bunds, strip levelling, live beds and vegetative. These measures may last for 2 to 5 years. In vegetative barriers, one or two barriers of close growing grasses or legumes along the bund and at mid length of slope can filter the runoff water or slow down over land flow. Khus grass (Chrysopogon zizanioides) is widely recommended as vegetative barrier.

C. Temporary treatments (short software treatments):

These are simple treatments for in-situ moisture conservation and needs renovation every year. Simple practices like contour farming, compartmental bunding, BBF, dead furrows, tillage and mulching have gained wide acceptance in the recent past.

**Ridges and furrows:** The field must be formed into ridges and furrows. Furrows of 30-45 cm width and 15-20 cm depth are formed across the slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep to deep black soils and deep red soils. It can be practiced in wide row spaced crops like cotton, maize, chillies, tomato etc. It is not suitable for shallow red, shallow black and sandy soils.

**Tied ridging:** It is a modification of the ridge and furrow system, wherein; the ridges are connected or tied by a small bund at 2-3 m interval along the furrows to allow the rainwater collection in the furrows; which slowly percolated into the soil.

**Dead furrows:** At the time of sowing or immediately after sowing, deep furrows of 20 cm depth are formed at intervals of 6 to 8 rows of crops. No crop is raised in the furrow. The dead furrows can also be formed between two rows of the crop, before the start of heavy rains. The dead furrows increase the infiltration opportunity time.

**Compartmental bunding:** Small bunds of 15 cm width and 15 cm height are formed in both directions to divide the field into small basins or compartments of square or rectangular shape of 6×6 m to 10×10 m size using bund former. They are useful for temporary impounding of rain water which facilitates high infiltration resulting in high moisture storage in the soil. It is recommended for black soils with a slope of 0.5 to 1 per cent. Maize, sunflower, sorghum performs well in this type of bunding.

**Scooping:** Scooping the soil surface to form small depressions or basins help in retaining rain water on the surface for longer periods. They also reduce erosion by trapping eroding sediment and this practice can reduced runoff by 50% and soil loss by 3 to 8 t/ha.

**Inter row/plot water harvesting:** Water is drawn from part of a small catchment and used in lower portion for crop production.

**Zing/ bench terracing:** These are developed by A.W. Zing in USA. Zing terracing is practiced in low to medium rainfall areas in black soils with contour bunds. It is a method of land shaping where lower one third portion of the land adjacent to the contour is levelled to spread to the runoff water coming from the remaining two-third portion of the field. This rainfall multiplication technique ensures at least one good crop in one-third area even in low rainfall years. Usually during medium rainfall years water intensive crops (like paddy) are cultivated in the levelled portion (receiving area) while dry crops are cultivated in the unlevelled (donor) area.
2. **Water harvesting in rainfed agricultural areas:**

Runoff farming and rainwater harvesting agriculture are synonymous terms, which imply that farming is done in dry areas by means of runoff from a catchment. It is a process of collection of runoff water from treated or untreated land surfaces/catchments or roof tops and storing it in an open farm pond or closed water tanks/reservoirs or in the soil itself (*in situ* moisture storage) for irrigation or drinking purposes. Runoff farming is basically a water harvesting system specially designed to provide supplemental irrigation to crops, especially during periods of soil moisture stress. The rainwater harvested from catchment is used in command area.

3. **Crop management in rainfed agricultural areas:**

Location-specific package of practices for dryland crops have been developed by dryland research centres and SAUs for all the crops. The important crop management practices are:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>d. Strip cropping</td>
<td>e. Mulching</td>
<td>f. Cover crops</td>
</tr>
<tr>
<td>g. Effective weed control</td>
<td>h. Organic manures/residues</td>
<td>i. IPNM</td>
</tr>
<tr>
<td>j. Cropping systems</td>
<td>k. Use of antitranspirants</td>
<td>l. Windbreaks/shelterbelts</td>
</tr>
</tbody>
</table>

**a. Choice of crops:** Tall growing row crops (sorghum, maize, bajra etc.) are not effective in conserving soil as they expose majority of the soil, hence known as *erosion-permitting crops*. Whereas close growing crops (cowpea, peanut, greengram, blackgram etc.) protect the soil are known as erosion-resisting crops as they are very effective in reducing soil loss by minimising the impact of raindrop and acting as obstruction to runoff.

**b. Land preparation:** Tillage is a well-known soil and water conservation practice which makes soil surface more permeable to increase infiltration of water into the soil, which in turn reduces runoff, soil and nutrient losses and enhance crop yields. Tillage makes the soil surface permeable and thus, support water intake. **Deep tillage** (25-30 cm) assists in opening up of hard soil layers and faster penetration of rainwater. Deep tillage in problem soils promotes better root system development and helps in higher yields during low rainfall years. **Off-season tillage** has a marked impact on weed control and rainwater intake. **Conservation tillage**, which ensures at least 30% coverage of the soil surface with crop residue play very important role in organic carbon build up and soil and moisture conservation. Conservation tillage includes stubble mulch tillage, minimum tillage and zero tillage. Low intensity tillage favours consolidation of soils and imparts erosion resistance.

**c. Contour cultivation:** A line joining the points of equal elevation is called contour. All cultural practices such as ploughing, sowing, inter-cultivation etc. are done across the slope to reduce soil and water loss.

**d. Strip cropping:** It is a system of growing of few rows of *erosion-resisting crops* (ERC) and *erosion-permitting crops* (EPC) in alternate strips on contour (across the slope) with the objective of breaking long slopes to prevent soil loss and runoff. Close growing ERC reduce the transporting and eroding power of water (*erosivity*) by obstructing runoff and filtering sediment from runoff to retain in the field. The normal ratio of ERC and EPC is 1: 3. The
strip cropping is simple, cheap and effective soil conservation practice and can be adopted by the farmers.

**It is divided into four types:**

Contour strip cropping: When EP & ER crops are grown in alternate strips along the contours.

Field strip cropping: Alternate strips of EP and ER crops are raised across the general slope not necessarily on exact contour.

Wind strip cropping: When EP and ER crops are grown across the direction of the most prevailing wind irrespective of the contour.

Buffer strip cropping: This type of strip cropping is practiced in areas having steep slopes and badly eroded soils. Here strips of permanent cover crops (perennial legumes, grasses, shrubs) are alternated with field crops.

**Strip widths of EP and ER crops at various slopes**

<table>
<thead>
<tr>
<th>Slope %</th>
<th>Width of EP strip (m)</th>
<th>Width of ER strip (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>1 - 2</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>2 - 3</td>
<td>13.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

e. **Mulching:** Mulching of soil with available plant residues reduce soil loss considerably by protecting the soil from direct impact of raindrop and reducing the sediment carried with runoff. A minimum plant residue cover of 30% is necessary to keep runoff and soil loss within the acceptable limits. *Vertical mulching* reduces soil loss particularly in Vertisols by increasing infiltration. The types of mulching are dust mulch, straw/stubble mulch, plastic mulch, chemical mulch, live mulch, pebble mulch, etc.

f. **Cover crops:** Good ground cover by canopy gives the protection to the land like an umbrella and minimizes soil erosion. Besides conserving soil and moisture, the cover crops hold those soluble nutrients, which are lost by leaching, adds organic matter and control weeds. The legumes provide better cover and better protection. Among the legumes cowpea has been found to produce maximum canopy followed by horsegram, greengram, blackgram and dhaincha.

g. **Effective weed control:** In rainfed areas, limited generation of weeds occurs due to shorter period of water availability. However, their control is must. Weeds are removed in very early stage (before flowering) by repeated blade harrowing. Intercultivation is very common practice of weed control in rainfed areas.

h. **Organic manures and residues:** Organic manures, besides supplying nutrients improve soil physical conditions by way of soil aggregation. Improvement in soil aggregation improves water intake rate of soil leading to reduced runoff.

i. **Integrated plant nutrient management (IPNM):** Inadequate supply of plant nutrients and continuous use of inorganic fertilisers resulted in soil degradation. Soil health restoration should be the major in sustaining crop productivity in rainfed agriculture. Use of manures and
bio-fertilisers along with limited use of inorganic fertiliser appears ideal for restoring the degraded soils for sustained productivity of rainfed soils.

j. Cropping systems: Mono-cropping of EP crops accelerate soil and water loss year after year. Intercepting EP and ER crops or their rotation has been found effective for soil and water conservation. As the pulse crops are effective for soil conservation due to their smothering effect, they should be sown in time to develop adequate canopy by the time of peak rate of runoff. Intercropping is recommended in areas receiving rainfall in the range of 600-850mm/annum. Double cropping is highly suitable to areas receiving rainfall >900 mm and moisture storage capacity of 200 mm/m depth.

4. Alternate land use systems (ALUS)

To cope up with increasing population of both human and livestock and rising demand for food, fodder and fibre, more and more marginal and sub-marginal lands are brought under cultivation. These lands are unable to sustain productivity. Cultivating such lands leads to imbalances in the ecosystem. Hence, a pattern of land use that is different from the conventional can be described as an alternative land use system. When land is put under alternative production system to match its capability more appropriately to the new land use and achieve more sustainable biological and economic productivity on long term, it is known as alternative land use.

Advantages of alternative land use systems

1. Optimising resource use by enhancing biological productivity and profitability,
2. Conserving and enhancing the quality of resource base,
3. Integrating crops (arable and pastoral) and livestock,
4. Making agriculture less dependent on off-farm inputs,
5. Generating employment potential, and
6. Improving overall quality of farm life.

Depending upon component of farming systems, various types of land use can be integrated on watershed system mode. Alternate land use systems are applicable to all classes of land aiming at generation of assured income with minimum risk through efficient utilisation of available resources. Commonly known alternate land use systems are agroforestry, tree farming and ley farming.

5. Agroforestry:

Agroforestry is a collective name for a land use system in which woody perennials (trees/ shrubs) are deliberately mixed on the same land management unit as crop and/or animals either in some forms of spatial arrangement or in time sequence. Agroforestry based ALUSs reduces runoff erosivity and soil erodibility through dissipation of rainfall energy by canopy at low height, surface litter, obstructing overland flow, root binding and improving soil health. Satisfactory crop yield can be obtained when compatible species are grown and soil-water resources are sufficient to meet the water needs of both the species. Trees, crops and animals are the three basic sets of elements of components of an agroforestry. These are classified as:

1. Agri-silvicultural : Crops and trees including shrubs/vines/trees
2. Silvi-pastoral : Pastures, animals and trees
3. Agri-silvi-pastoral : Crops/pasture animals and trees
4. Agri-horticulture : Crops (short duration) and fruit species
5. Silvi-horticulture : Trees and fruit species
6. Silvi-horti pastoral : Trees/fruit species, animal and pastures

However, prolific seeding habit of component trees like *subabul* resulting in more weed growth and reduced crop yields; root and shade effects of trees on cultivated crops upto 20 m in case of *Acacia nilotica*; harbouring birds, pests and diseases; reduced scope of mechanisation, more labour intensive and allelopathic effects of trees on cultivated crops are the major disadvantages of the agroforestry based land management system.

6. **Alley Cropping:**

   Alley cropping is broadly defined as the planting of rows of trees/shrubs (single or multiple) at wide spacing, creating alleyways within which agricultural crops are produced. The shrub/tree rows are called *hedgerows* and the space between where the crops are grown are called *alleys*. Alley cropping is an agroforestry practice intended to place trees within agricultural cropland systems. The purpose is to enhance/add income diversity (both long and short range), reduce wind and water erosion, improve crop production, improve utilisation of nutrients, improve wildlife habitat or aesthetics, and convert cropland to forest. Based on the objectives, three types of alley cropping systems are recognised:

   1. **Forage-alley cropping**

      In this system, both yield of crop and forage assume importance. The tree species suitable for hedge rows are *Leucaena leucocephala*, *Colliendra* and *Sesbania*. Pigeonpea or castor crops are suitable for growing in the alleys of *Leucaena*.

   2. **Forage-cum-mulch system**

      In this system, hedgerows are used for both forage and mulch. Loppings are used for mulching during the crop season and used as fodder during off season. Substantial increase in crop yields of sorghum, groundnut, greengram and blackgram have been observed at several places.

   3. **Forage-cum-pole system**

      *Leucaena* alleys are established at 5 m intervals along the contours. Hedgerows are established by direct seeding and topped every two months at 1 m height during crop season and every 4 months during the off-season. A *Leucaena* plant for every 2 m along hedgerows is allowed to grow into a pole.

7. **Tree farming:**

   Trees can flourish and yield abundantly where arable crops are not profitable. Farmers of dry lands are inclined to tree farming because of labour cost, scarcity at peak periods of farm operations and frequent crop failure due to drought. Multipurpose tree species (MPTS) are those trees, which are purposely grown to provide more than one significant product or service function in the land use system in which they grow. On small farms, this, generally, means both wood and foliage use from the same tree. Their ability to provide fuel and timber, nitrogen, fodder, food, resins, fibre, medicines, shade etc. make them MPTS. For Gujarat plains and hills, *Prosopis cineraria* is the best MPTS followed by *Eucalyptus hybrid, Ailanthus excelsa, Dalbergia sissoo* and *Leucaena*. 
8. Ley farming:

This system involves rotation of legume forages with cereals. A rotation system which includes pasture (ley) for grazing and conservation is called alternate husbandry or mixed farming. It is a low risk system for dry lands. Inclusion of *Stylosanthes hamata* (legume fodder) in rotation improved soil fertility besides increasing crop yields.

### Recommended ALUS Options for Different Agroclimatic Conditions

<table>
<thead>
<tr>
<th>Annual rainfall</th>
<th>Soil type/depth</th>
<th>Land use systems</th>
<th>Suitable tree/grass/legume species</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500 mm</td>
<td>Shallow (0-0.30 m)</td>
<td>Tree farming</td>
<td><em>Prosopis cineraria, P. juliflora, Acacia aneura, A. nilotica, A. tortils, Pithecellioibium duice</em></td>
</tr>
<tr>
<td>Medium (0-0.45 m)</td>
<td>Pasture management</td>
<td><em>Lasiurus sindicus</em> (light textured soils), <em>Cenchrus setigerus, Sehima nervosum, Stylosanthes scabra, Clitoria ternatea</em></td>
<td></td>
</tr>
<tr>
<td>500 - 750 mm</td>
<td>Shallow (0-0.30 m)</td>
<td>Silvi-pastoral system</td>
<td><em>Acacia nilotica, Colophosphermum mopane, Dalbergia sissoo, Hardwickia binata, Cassia sturti, Albizia amara, Leucaena leucocephala, Cenchrus ciliaris, C. setigerus, Dianthium annulatum, Panicum antidotale, Stylosanthes hamata, Macroptilium atropurpureum.</em></td>
</tr>
<tr>
<td>Medium (0-0.45 m)</td>
<td>Horti-pastoral system</td>
<td><em>Annona squamosa, Zizyphus mauritiana, Syzigium cuminil, Emblica officinalis, Tamarindus indica, Feronia limonia, Aegle marmelos, Cenchrus ciliaris, Panicum antidotale, Urichula mosambicensis, Stylosanthes hamata, Macroptilium atropurpureum, Clitoria ternatea.</em></td>
<td></td>
</tr>
<tr>
<td>&gt; 750 mm</td>
<td>Shallow (0-0.30 m)</td>
<td>Ley farming / Silvi-pastoral system</td>
<td>3 years <em>Stylosanthes hamata</em> and 4th year arable crop (sorghum on heavier soils, pearl millet on lighter soils) Silvi-pastoral system as above.</td>
</tr>
<tr>
<td>Medium (0.30-0.45 m)</td>
<td>Ley farming / Horti-pastoral system</td>
<td>Ley farming as above.</td>
<td><em>Mangifera indica, Achras zapota, Psidium guajava, Emblica officinalis, Stylosanthes hamata/ Macroptilium atropurpureum</em></td>
</tr>
<tr>
<td>Deep (&gt;0.45 m)</td>
<td>Agri-silvi or Agri-horti system</td>
<td><em>Acacia ferruginea, Prosopis cinneraria, Tectona grandis, Hardwickia binata, Dalbergia sissoo + arable crops. Mangifera indica, Achras zapota, Psidium guajava + arable crops.</em></td>
<td></td>
</tr>
</tbody>
</table>
Integrated Watershed Management:

In dry farming areas, watershed approach provides an ideal means for integrated development. This approach will further the cause of sustainability which requires the best land and water use and ecological sustenance. There is need for a multi-pronged approach to maximize crop production and also ensuring stability in rural incomes. The various steps used in this are in situ moisture conservation, water harvesting and crop production; conjunctive use of rainwater; crop substitution with site-specific crop production techniques; afforestation and dryland horticulture, discouraging faulty practices, encouraging dairying, sericulture, cottage industries; custom-hire services for employment generation and training of inhabitants to develop a participatory model watershed.

Issues before Watershed Management Programmes: The major issues are-

1. Stakeholders were neither involved in selection of project ingredients nor encouraged others to participate in various project activities.
2. Benefits of watershed management accrued mainly to farming community where as the livelihood securities of the landless families have not been taken care.
3. The portfolio of alternate livelihood opportunities created for the beneficiaries could not cope with stress and shock and the primary stakeholders could not maintain activities after the completion of project period.
4. In majority of the cases sustainability had been causality mainly due to absence of primary stakeholders in project planning and implementation stages.

Planting and maintaining trees were considered noble acts. They were considered better than having sons, as has been said in Agnipuran (1000 BC)

दशक्रुप समावापी दशवापी समाहदः ।
दशहद समपुत्रौ दशपुत्र समातरः ॥

Ten wells are equal to one tank, ten tanks are equal to one lake, ten lakes are equal to one son and ten sons are equal to one tree for giving Punya. In the Purans it is said

अपुत्रस्य पुत्रत्वं पाद्यः इह कुर्वते ।

Which means for those who do not have sons; trees are like sons for them.
Glossary of Selected Terms

**Accelerated erosion:** Erosion much more rapid than normal, natural geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals.

**Afforestation:** Conversion of bare land into forest land by planting of forest trees. The planting of a forest crop on land that has not previously, or not recently, carried a forest crop.

**Agroforestry system:** A land-use system in which woody perennials (trees, shrubs, palms, bamboos) are deliberately used on the same land management unit as agricultural crops (woody or not), animals or both, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components.

**Agroforestry:** Any type of multiple cropping land-use that entails complementary relations between trees and agricultural crops.

**Agrostology:** The study of grasses.

**Alley cropping:** An agroforestry intercropping system in which species of shrubs or trees are planted at spacings relatively close within row and wide between row, to leave room for herbaceous cropping between, that is, in the 'alleys' (syn: hedgerow intercropping).

**Aquifer:** A saturated, permeable layer of sediment or rock that can transmit significant quantities of water under normal pressure conditions.

**Arable land:** Land that is capable of being cultivated and supporting agricultural production.

**Arboriculture:** A general term for the cultivation of trees.

**Badland:** A land type generally devoid of vegetation and broken by an intricate maze of narrow ravines, sharp crests, and pinnacles resulting from serious erosion of soft geologic materials. Most common in arid or semi-arid regions. A miscellaneous land type. Term used to describe a semi-arid landscape that has been influenced by heavy fluvial erosion. Characterized by deep ravines and gullies, shape ridges, and a generally barren surface.

**Base flow:** Stream discharge derived from effluent ground-water seepage.

**Bed load:** Portion of the stream load that is carried along the stream bed without being permanently suspend in the flowing water.

**Bedrock:** The solid rock underlying soils and the regolith in depths ranging from zero to several hundred metres.

**Bench mark:** A point of reference in elevation surveys.

**Bench terrace:** A shelf-like embankment of earth with a level top and steep or vertical down hill face, constructed along the contour of sloping land to control runoff and erosion.

**Blowout:** An excavation in areas of loose soil, usually sand produced by wind erosion.

**Broad-base terrace:** A ridge type terrace 25 to 50 cm high, and 4.5 to 9.0 m wide with gently sloping sides, a rounded crown, and a dish shaped channel along the upper side constructed to control erosion by diverting runoff along the contour at a non-scouring velocity. It may be level or have a grade toward one or both ends.

**Buffer strips:** Contour strips of grass or other erosion resisting vegetation between or below cultivated strips or fields.
Buffer zone: An area around a forest, national park, or any other conserved place that provides the local community with products that they would otherwise take from the forest, or that provides an opportunity to produce alternative products.

Bund: A barrier on the surface of the soil on sloping land to prevent runoff and soil erosion.

Carrying capacity: Amount of animal life, human life or industry that can be supported indefinitely with available resources on a given area. In wildlife management, the optimum population density that a given environment or range is capable of sustaining permanently.

Catchment area: The land surface on which rain falls. Sometimes called a 'water catchment'. When referring to particular streams or rivers, it is the land surface from which water (rain) flows into them, sometimes through tributaries (feeder streams).

Cavitation: Process of intense erosion due to the surface collapse of air bubbles found in constricted rapid flows of water. Causes the detachment of material from a surface.

Check dam: A small, low dam constructed in a gully or other water course to decrease the velocity of stream flow, for minimizing channel scour and promoting the deposition of eroded material. Usually built of inexpensive and temporary materials where dependence for ultimate protection in placed on vegetative cover.

Chiselling: The breaking or shattering of compacted soil or subsoil layers by use of a chisel.

Clear cutting: Strictly, the removal of an entire standing crop of trees. In practice, may refer to exploitation that leaves much unsaleable material standing. Also termed 'clear felling'. An area from which the entire timber stand has been cut. Removal of the entire stand in one cut. Reproduction is then obtained with or without planting or artificial seeding.

Companion crop: A crop which is grown with another crop.

Concentrated flow: The flowing of a rather large accumulated body of water over, or one which corresponds to a net rain storm of duration longer than one unit period.

Concentration point: The single geographical location at which all surface drainage from a given area comes together as outflow.

Concentration time: The time required for discharge from the most distant point in a drainage area to reach the concentration point.

Conservation tillage: An agricultural system using tillage techniques designed to reduce soil erosion and overland flow. Most conservation tillage techniques involve less manipulation of the soil than conventional techniques, leaving more plant matter on the soil surface.

Contour farming: Conducting field operations, such as ploughing, planting, cultivating and harvesting on the contour or a right angles to the natural direction of slope.

Contour furrows: Furrows ploughed on the contour on pasture or range land to prevent soil loss and allow water to infiltrate. Sometimes used in planting trees or shrubs on the contour.

Contour interval: The vertical distance between contour lines.

Contour ploughing: A soil conservation technique involving ploughing parallel to the contour, across a slope rather than up and down it.

Contour strip cropping: The production of crops in comparatively narrow strips planted on the contour and at right angles to the natural direction of slope. Usually strips of grass or close growing crops are alternated with those in cultivated crops.

Contour: An imaginary line connecting points of equal elevation on the surface of the soil.
Glossary

Cover crop: A close growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production, or between trees and vines in orchards and vineyards.

Cover, ground: Any vegetation production a protecting 'mat on or just above the soil surface. In forestry, low-growing shrubs and herbaceous plants under the trees.

Creep: Slow mass movement of soil and soil material down relatively steep slopes primarily under the influence of gravity, but facilitated by saturation with water and by alternate freezing and thawing.

Crop rotation: The growing of different crops in recurring succession on the same land.

Deciduous forest: A forest composed of trees that shed their leaves at some season of the year. In tropical areas trees may lose their leaves during the hot season to conserve moisture. Trees of a deciduous forest in cool areas shed their leaves during the autumn to protect themselves against the cold and frost of winter. Deciduous forests produce valuable hardwood timber, such as teak and mahogany from the tropics, and oak and beech from the cooler areas.

Deflation: Process where wind erosion creates blowout depressions or deflation hollows by removing and transporting sediment and soil.

Dendrology: The study of trees, that is, a knowledge of the taxonomy, systematic relationships and field recognition of tree species.

Dendrometer: A device for measuring the diameter of the trunk or branch of a tree.

Depression storage: Water in puddles, small ponds and depressions.

Detention dam: A dam constructed for the purpose of temporary storage of stream flow, or surface runoff, and for releasing the stored water at controlled rates.

Dike: An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowland; a levee.

Disperse: To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water.

Diversion dam: A structure or barrier built to divert part or all of the water of a stream to a different course.

Diversion: A diversion is a channel with a supporting ridge on the lower side constructed across the slope to intercept runoff and minimize erosion, or to prevent excess runoff from flowing into lower lying areas. In some areas a series of diversions are constructed across the slope similar to terraces, but with greater horizontal and vertical spacing. Also known as diversion terrace.

Drag: The force retarding the flow of water or wind over the surface of the ground.

Drainage area: An area whose runoff is more or less separate from the runoff of adjacent areas, so that it can be considered a hydrologic unit.

Drainage divide: The boundary line, along a topographic ridge or along a sub-surface formation, separating two adjacent drainage basins.

Drainage: The frequency and duration of periods when the soil is free of saturation with water.

Drift: Material of any sort deposited in one place after having been moved from another. The term is most commonly used when referring to glacial drift.
Drop structure: A dam constructed in a gully or other water course to lower the grade of the water course and thereby decrease the velocity of flow, promote the deposition of sediment, and prevent further channel erosion.

Dryland farming: The practice of crop production in low rainfall areas without irrigation.

Dune: A mound or ridge of loose sand piled up by the wind; common where sand is abundant and wind usually strong as along lake and sea shores and in some desert and semi-desert areas.

Dust mulch: A loose, finely granular, or powdery condition on the surface of the soil usually produced by shallow cultivation.

Edaphic: Of or pertaining to the soil in its ecological relationships. Resulting from, or influenced by, factors inherent in the soil or other substrate rather than by climatic factors.

Effective precipitation: That portion of the total precipitation which becomes available for plant growth.

Eluviation: The transportation of soil material in suspension, or in solution within the soil, by the downward or lateral movement of water.

Energy Farming: The process of using land to grow crops, woody or otherwise, that provide fuel, for example, close-planted, fast-growing tree species such as poplar (temperate) or leucaena (tropical). These may be harvested by hand or mechanically. Hydrocarbon fuels can be extracted from other kinds of plants, for example, from some Euphorbia species.

Enriched fallow: A form of agroforestry in which useful, mainly woody species are sown or planted before cultivation ceases, or at the time it does, so that during the fallow period, or when the land is next cleared for cultivation, products are available for household use or market that would not otherwise have been there (for example, fruits, bamboos, rattans, medicinals).

Entrainment: One of three distinct processes involved in erosion. More specifically, it is the process of particle lifting by an agent of erosion.

Erode: To wear away or remove the land surface by wind, water, or other agents.

Erodibility: Susceptibility to erosion, erosion proneness.

Erodible: Susceptible to erosion.

Erosion pavement: A layer of coarse fragments, such as sand or gravel, remaining on the surface of the ground after the removal of fine particles by erosion.

Erosion: (i) The wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep; (ii) Detachment and movement of soil or rock by water, wind, ice, or gravity.

Erosive: Tending to cause erosion; the term applies to the eroding agent, such as wind or water.

Erosivity: Potential ability of physical dynamic agents such as water, wind or ice to cause erosion.

Estuary: Somewhat enclosed coastal area at the mouth of a river where nutrient rich fresh water meets with salty ocean water.

Eutrophication: Nutrient enrichment of lakes, ponds, and other such waters that stimulates the growth of aquatic organisms, which leads to a deficiency of oxygen in the water body.

Fallow: Allowing crop land to lie idle, either tilled or untilled, during the whole or greater portion of a growing season. Tillage is usually practiced to control weeds and encourage the
storage of moisture in the soil. Land rested from deliberate cropping, not necessarily without cultivation or grazing but without sowing.

**Felling:** Cutting trees for their removal.

**Field border plantings:** Vegetation establishment on field borders to conserve soil and provide cover and food for wildlife.

**Field strip cropping:** A system of strip cropping in which crops are grown in parallel strips laid out across the general slope but which do not follow the contour. Strips of grass or close-growing crops are alternated with those in cultivated crops.

**Filter strip:** A strip of permanent vegetation of sufficient width and vegetative density above farm ponds, diversion terraces and other structures to retard flow of runoff water, causing it to deposit soil, thereby preventing silting of structure or reservoir below.

**Firebreak:** In forestry, an existing barrier, or one constructed before a fire occurs, from which flammable materials have been removed, designed to stop or check creeping or running fires. Also serves as a line from which to work and to facilitate the movement of men and equipment in fire suppression.

**Flood plain:** The land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage.

**Geological erosion:** The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of flood plains, coastal plains, etc.

**Glacial drift:** Rock debris that has been transported by glaciers and deposited, either directly from the ice or from the melt-water. The debris may or may not be heterogeneous.

**Glacier:** A large long lasting accumulation of snow and ice that develops on land. Most glaciers flow along topographic gradients because of their weight and gravity.

**Gley:** Soil with impeded drainage. Used in soil classifications based on profile leaching.

**Graded terrace:** A terrace having a constant or variable grade along its length.

**Grassed waterway:** A natural or constructed waterway, usually broad or shallow, covered with erosion-resistant grasses, used to conduct surface water from crop land.

**Grassland:** Land covered with grasses and other herbaceous species. Woody plants may be present, but if so, they do not cover more than 10% of the ground. There are many different types of grassland designated by ecozone, topography, climate, soil conditions, and so on. Derived grassland is maintained in that condition by regular burning; edaphic grassland arises on particular soil types, for example, those found in or around permanent or seasonal swamps.

**Grazing:** A method of feeding by herbivores characterized by repeated removal of only a part, generally the leaf, of the plant, which is most commonly called herbage.

**Groundwater basin:** A groundwater storage area more or less separate from neighbouring groundwater storage areas, so that it can be considered a hydrologic unit.

**Groundwater:** The general sub-surface water body in the zone of saturation.

**Grubbing:** Felling trees and shrubs by exposing and cutting the roots.
Glossary

**Gully erosion**: The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 30 to 60 cm as much as 22.5 to 30 cm.

**Gully**: A channel resulting from erosion and caused by the concentrated, but intermittent, flow of water usually during and immediately following heavy rains. Deep enough to interfere with, and not to be obliterated by, normal tillage operations.

**Hedge row**: A barrier of bushes, shrubs, or small trees growing close together in a line.

**Infiltration**: The downward entry of water into the soil.

**Interpolated cropping**: A cropping sequence where two or more species are grown on the same unit of land but at least one species has a later sowing (planting) time and an earlier harvest than the other(s). Refers to situations where the crop duration of species is very different.

**Land capability classification**: The arrangement of land units into various categories based upon the properties of the land or its suitability for some particular purpose.

**Land capability**: The suitability of land for use without damage. Land capability involves consideration of (a) the risks of land damage from erosion or other causes and (b) the difficulties in land use owing to physical land characteristics including climate.

**Landscape**: All the natural features such as fields, hills, forests, water etc. which distinguish one part of the earth's surface from another part. Usually that portion of land or territory which the eye can comprehend in a single view, including all its natural characteristics.

**Landslide**: A mass of material which has slipped down hill under the influence of gravity, frequently assisted by water (when the material is saturated).

**Leaching**: The washing out of material from the soil, both in solution and in suspension.

**Level terrace**: A terrace that follows the absolute contour as contrasted with a graded terrace. Used only on permeable soils where conservation of moisture for crop use is particularly important or where outlet channels are impractical.

**Ley farming**: Rotation of arable crops with two or more years of sown pasture.

**Ley pasture**: A temporary pasture grown as a specific phase in a defined crop rotation sequence.

**Loess**: Deposit of wind-transported fine-textured material, uniform and unstratified, mostly silt, but may contain some fine sand and clay.

**Lopping**: Cutting one or more branches of a standing tree, for example, for fuel or fodder.

**Mangroves**: Open or closed stands of trees and bushes occurring in the tropics in intertidal zones, usually around the mouths of rivers, creeks and lagoons where soils are heavy textured and have a fluctuating salt content and soil level.

**Meadow strip**: A sloping field or strip of grassed land which, in addition to yielding a hay crop, acts as a broad shallow water channel during periods of runoff. Often used as a terrace outlet channel and usually much larger in extent than a grassed water way.

**Mulch farming**: A system of farming in which the organic residues are not ploughed into or otherwise mixed with the soil but are left on the surface as a mulch.
Glossary

**Mulch:** Any material such as straw, sawdust, leaves, plastic film, loose soil *etc.* that is spread upon the surface of the soil to protect the soil and plant roots from the effects of rain drops, soil crusting, freezing, evaporation *etc.*

**Multipurpose tree:** A woody perennial purposefully grown to provide more than one significant contribution to the production or service functions (for example, shelter, shade, land sustainability) of the land-use system that it occupies.

**Natural erosion:** Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, *etc.* undisturbed by man.

**Niche:** A place or position adapted to the character, or suited to the merit, of a person or thing. The sum total of adaptations of an organismic unit. In ecology, the total range of conditions under which the individual (or population) lives and replaces itself, or the position or status of an organism within its community and ecosystem resulting from the organism's structural adaptations.

**Normal erosion:** The gradual erosion of land used by man which does not greatly exceed natural erosion.

**Overland flow:** Flow of water over the land surface as sheet flow not in channels.

**Parent material:** The horizon of weathered rock or partly weathered soil material from which the soil is formed.

**Pasture improvement:** Any practice of grazing, moving, fertilizing, liming, seeding, scattering droppings, contour furrowing, or other methods of management designed to improve the vegetation for grazing purposes.

**Pasture:** In U.S. terminology, land on which the natural vegetation is not grass, but which is used primarily for grazing.

**Percolation:** The downward movement of water through soil.

**Productivity:** The capacity of a soil in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. Productivity emphasized the capacity of soil to produce crops and should be expressed in terms of yields.

**Rainforest:** Generally, a forest that grows in a region of heavy annual precipitation. There are both tropical and temperate rainforests.

**Range management:** The scientific management of range land for the continuous production of forage and livestock, consistent with the use of the land for other purposes.

**Range:** Land that produces primarily native forage suitable for grazing by livestock.

**Rangeland:** Land that provides or is capable of providing forage for grazing animals.

**Reach:** A specific portion of the length of a stream channel.

**Reforestation:** Replacing forests after felling.

**Relief:** The relative differences in elevation between the upland summits and the lowlands or valleys of a given region.

**Resilience:** The capacity of a soil (or other ecosystem) to return to its original state after a disturbance.

**Ridge terrace:** A long, low ridge of earth with gently sloping sides, and a shallow channel along the upper side, to control erosion by diverting surface runoff across
the slope instead of permitting it to flow uninterrupted down the slope. Types of ridge terraces include the broad base, drainage, grades level, narrow base etc.

**Rill erosion:** An erosion process in which numerous small channels of only several centimetres in depth are formed; occurs mainly on recently cultivated soils.

**Rill:** A small, intermittent water course with steep sides; usually only a few centimetres to deep and, hence, no obstacle to tillage operations.

**Riparian forest:** Vegetation, with trees and shrubs, growing alongside or close to a watercourse, lake, swamp, or the like, and often dependent on its roots reaching the watertable.

**River wash:** Barren alluvial land, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water. A miscellaneous land type.

**Riverine:** An environment created along permanent and semi-permanent streams because of the increase in soil moisture. This is termed a riverine environment.

**Rotational grazing:** Grazing systems in which the pasture is subdivided into a number of enclosures, with at least one more of these than there are groups of animals. The practice of submitting a grazing area to a regular sequence of grazing alternating with rest.

**Runoff:** Runoff is that part of precipitation, snow or ice melt or irrigation water that flows from the land to the streams or other water surfaces. The portion of the precipitation on an area that is discharged from the area through stream channels. That which is lost without entering the soil is called **surface runoff** and that which enters the soil before reaching the stream is called **groundwater runoff** or **seepage flow** from groundwater. (In soil science **runoff** usually refers to the water lost by surface flow; in geology and hydraulics **runoff** usually includes both surface and subsurface flow).

**Sediment:** Fragmented organic or inorganic material derived from the weathering of soil, alluvial, and rock materials; removed by erosion and transported by water, wind, ice, and gravity.

**Sedimentation:** The deposition of sediment from a state of suspension in water or air.

**Sheet erosion:** The removal of a fairly uniform layer of soil from the land surface by runoff water.

**Shelterbelt:** An extended wind break of living trees and shrubs established and maintained for protection of farm lands over an area larger than a single farm.

**Silting:** The deposition of water-borne sediments in stream channels, lakes, reservoirs, or on flood plains, usually resulting from a decrease in the velocity of the water.

**Slash:** In forestry, the vegetation (branch and other woody and leafy debris) left on the forest floor after trees have been felled or trimmed.

**Slope:** The degree of deviation of a surface from horizontal, measured in a numerical ratio, percent, or degrees.

**Social forestry:** The planting and tending of trees or shrubs for the well-being and betterment of local communities.

**Spillway:** A conduit in or around a dam for the escape of excess water.

**Splash erosion:** The spattering of small soil particles caused by the impact of rain drops on very wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

**Spur terrace:** A short terrace used to collect or divert runoff.
Stream gaging: The collection of stream-flow data by direct measurements of discharge and water surface elevations.

Strip cropping: The practice of growing crops which require different types of tillage, such as row and sod, in alternate strips along contours or across the prevailing direction of wind.

Stubble mulch: The stubble of crops or crop residues left essentially in place on the land as a surface cover before and during the preparation of the seedbed and at least partly during the growing of a succeeding crop.

Surface sealing: The orientation and packing of dispersed soil particles in the immediate surface layer of the soil, rendering it relatively impermeable to water.

Terrace: A raised, more or less level or horizontal strip of earth usually constructed on or nearly on a contour and supported on the downslope side by rocks or other similar barrier and designed to make the land suitable for tillage and to prevent accelerated erosion.

Through fall: The proportion of the gross precipitation that reaches the ground and is not intercepted by, or retained in, the canopy.

Tie ridging: In contour furrowing or trenching, a narrow transverse strip of ground left unexcavated (or ridged).

Wasteland: Land not suitable for, or capable of, producing materials or services of value.

Water harvesting: A general term for any means of collecting and re-distributing runoff water.

Watershed: The total land area, regardless of size, above a given point on a waterway that contributes runoff to the flow at that point.

Waterway: A natural course for the flow of water.

Weir: A dam across a stream for diverting or for measuring the flow.

Windbreak: A planting of trees, shrubs or other vegetation, usually perpendicular or nearly so to the principal wind direction, to protect soil, crops, homesteads, roads etc. against the effects of winds, such as wind erosion and the drifting of soil and snow. A group of trees or shrubs in any arrangement that will afford protection from high winds to animals or crops or both. When the arrangement is in a long line the group is called a shelterbelt. If an associated reason is also to harvest timber at some future date it is sometimes called a 'timberbelt'.

Wind erosion: The detachment, transportation and deposition of soil by the action of wind.

Wind strip cropping: The production of crops in long, relatively narrow strips, placed cross wise of the direction of the prevailing winds without regard to the contour of the land.

Zero-grazing: A method of keeping animals that involves bringing fodder to them rather than letting the animals graze freely.
ABBREVIATIONS

AICRPDA : All India Coordinated Research Project on Dryland Agriculture, Hyderabad
AISSSLUP : All India Soil Survey and Land Use Planning, New Delhi
CADA : Command Area Development Authority
CAZRI : Central Arid Zone Research Institute, Jodhpur
CRIDA : Central Research Institute for Dryland Agriculture, Hyderabad
CSWCRTI : Central Soil & Water Conservation Research & Training Institute, Dehradun
DDP : Desert Development Programme
DPAP : Drought Prone Area Programme
ICARDA : International Centre for Agriculture Research on Dry Areas, Aleppo, Syria
ICRAF : International Centre for Research on Agroforestry, Nairobi, Kenya
ICRISAT : International Crops Research Institute for the Semi-Arid Tropics, Hyderabad
IFOAM : International Federation for Organic Agricultural Movements
IGFRI : Indian Grassland and Fodder Research Institute, Jhansi
IPCC : Intergovernmental Panel on Climate Change
IREP : Integrated Rural Energy Programme
IWDP : Integrated Wasteland Development Project
LCC : Land Capability Class
NBSS & LUP : National Bureau of Soil Survey and Land Use Planning, Nagpur
NRCAF : National Research Centre for Agroforestry, Jhansi
NRSA : National Remote Sensing Agency, Hyderabad
NWDB : National Wasteland Development Board, New Delhi
NWDPRA : National Watershed Development Programme for Rainfed Areas
RADAS : Reclamation & Development of Alkali and Acid Soil
RVP & FPR : River Valley Project & Flood Prone River
UNCED : United Nations Conference on Environment and Development
WALAMTARI : Water and Land Management Training Research Institute
WDF : Watershed Development Fund
WDPSCA : Watershed Development Project for Shifting Cultivation Area
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