

Integrated Water Management

Management of Rainfed Agriculture

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Contents

1. Introduction
 - 1.1 History of rainfed agricultural research
 - 1.2 Dryland vs. rainfed agriculture
2. *Rainwater and Moisture Conservation*
 - 2.1 *Water conservation*
 - 2.1.1 *Agronomic practices*
 - i) Contour farming
 - ii) Cover management
 - iii) Strip cropping
 - iv) Mulching
 - v) Tillage
 - vi) Selection of suitable cropping and alternate land use systems
 - vii) Micro-watersheds
 - viii) Vegetative barrier/Live bund
 - 2.1.2 Mechanical measures of soil and water conservation
 - i) Contour bunding
 - ii) Graded bunding or channel terracing
 - iii) Bench terracing
 - iv) *Puetorican* type bench terracing
 - v) Conservation bench terracing (CBT)
 - vi) Compartmental bunding
 - 2.2 *Moisture conservation*
 - 2.2.1 Measures for moisture conservation
 - 2.3 Water harvesting and recycling
 - 2.4 Factors influencing choice of water and moisture conservation practices
3. *Mulches*
 - 3.1 Types of mulches
 - i) Organic mulching
 - ii) Chemical mulching
 - iii) Soil mulching
 - iv) Vertical mulching
 - 3.2 *Mode of action of mulches*
 - 3.3 Effects of mulches
 - 3.4 Limitations of mulches

- 4. Anti-transpirants
 - 4.1 Scope of using anti-transpirants
 - 4.2 Types of anti-transpirants
 - i) Stomatal closing type
 - ii) Film-forming type
 - iii) Increasing leaf reflectance type
 - iv) Growth retardants
 - 4.3 Effect of anti-transpirants on crop production
 - 4.4 Limitations of anti-transpirants
- 5. Efficient Management of Rainfed Crops
 - 5.1 Land preparation
 - 5.2 Seeding
 - 5.3 Plant population
 - 5.4 *Choice of crops, varieties and cropping systems*
 - 5.5 Alternate cropping and land use strategy
 - 5.6 Soil fertility management and fertilizers use
 - 5.7 Weed control
 - 5.7.1 Weed prevention
 - 5.7.2 Weed control measures
 - 5.8 Contingency crop planning for aberrant weather
- 6. Rainfed Hill Agriculture
- 7. Watershed Management
 - 7.1 Principles of watershed management
 - 7.2 Basic objectives of a watershed management
 - 7.3 Components of watershed treatment plan
 - 7.4 Benefits of watershed management
 - 7.4 Watershed development experiences

List of Tables

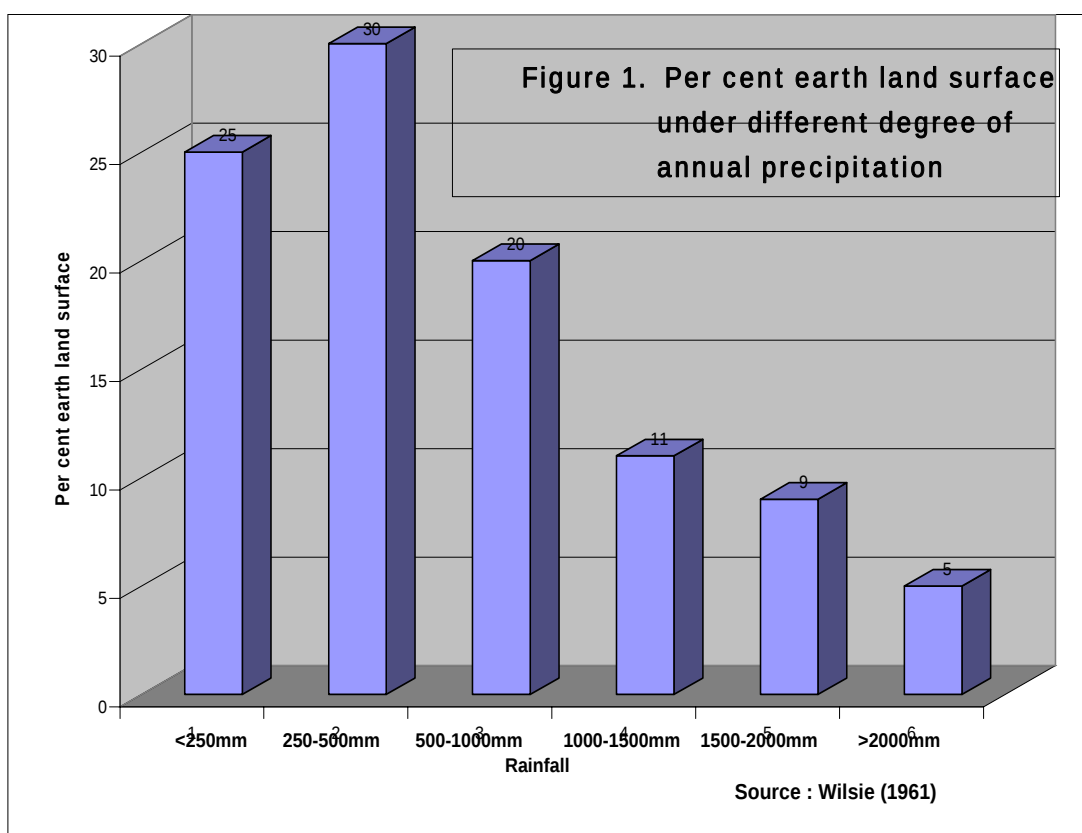
- Table 1. Distribution of dry land area in different rainfall zones in India.
- Table 2. State wise rainfed area (1991-92) in India
- Table 3. Contour strips suitable for crops on different slopes
- Table 4. Estimated water yield into farm ponds and effect of supplemental irrigation (5 cm) on crop yield in different regions
- Table 5. Improved crop varieties suited to rainfed agro-ecosystems
- Table 6. Potential cropping systems for rainfed agro-ecosystems
- Table 7. Cropping system advocated based on the length of growing seasons
- Table 8. Alternate land use system options for different agro-climatic conditions
- Table 9. Potential cropping systems in relation to duration and quantity of rainfall in arid Rajasthan.

List of Figures

- Figure 1. Per cent earth land surface under different degree of annual precipitation
- Figure 2. Geographical area (million ha) in India receiving different degree of rainfall
- Figure 3. Transpiration ratio (gram water transpired/gram dry matter produced) of some dry land weeds and crops

Introduction

Indian agriculture is ‘a gamble in the monsoon’ even today. So, water has been prioritized to be the most crucial resource for sustainable development of agriculture. The life of mankind and almost all the flora and fauna on the earth depends on the availability of fresh water resources. It is an extremely important component of biological systems. The most of the plant cells and tissues contain 80-90 per cent water by weight. Plant water status influences all the physiological processes of plants directly or indirectly. Highly variable global distribution of annual average rainfall of about 1000 mm on the earth surface is responsible for the disparities in agriculture production and socio-economic conditions. Fifty five per cent or more than one-half of the total land surfaces of the earth, receives an annual precipitation of less than 500 mm and must be reclaimed, if at all by dry farming practices. Area with 500-750 mm rainfall, which accounts for 10 per cent of the total land area, also need dry farming measures for successful crop production (**Figure 1**).

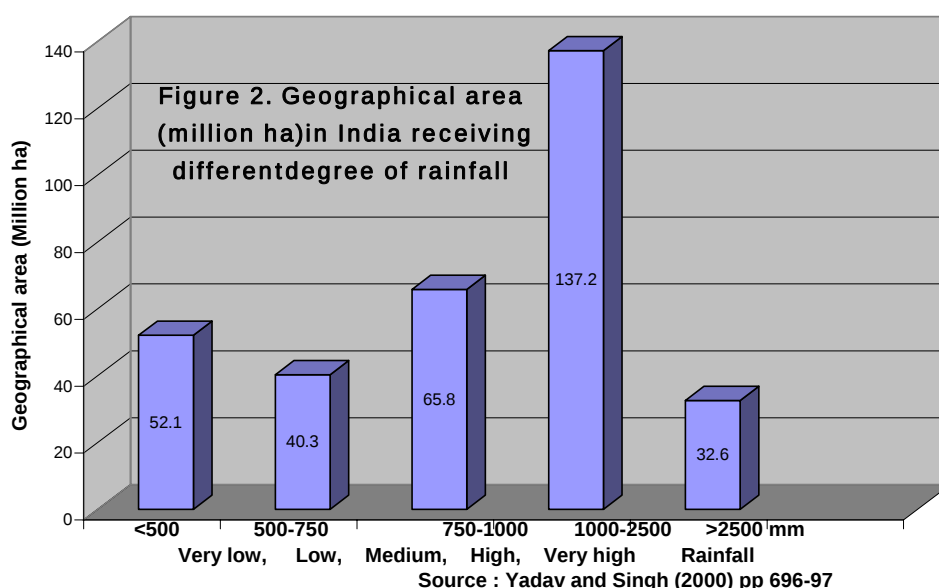


In India also, distribution of the annual average rainfall of about 1200 mm, is highly variable, irregular and undependable with wide spread variations among various meteorological subdivisions in terms of distribution and amount. The spatial distribution of rainfall varies from 100mm/annum in Rajasthan to about 11000 mm/annum in Cherrapunji in Meghalaya. Agriculture uses almost 85 per cent of the total water available in the country. Of the total geographical and net cultivated area about 92 and 33 million hectares receive less than 750 mm rainfall annually respectively (**Table 1 and Figure 2**).

Table 1. Distribution of dryland area in different rainfall zones in India.

Mean annual rainfall (mm)	Climate zone	Dry land area (million ha)
<500	Arid	10.9
500-750	Dry semi-arid	22.2
750-1000	Wet semi-arid	21.2
1000-1250	Sub-humid	19.6
>1250	Humid	27.7

Source : Virmani *et al.* (1991) pp 80-95



Agriculture continues to be mainstay of the Indian economy. It contributes 25 per cent of the national gross product. In this contribution, rainfed lands in India are important today and will continue to be so in future. Currently, about 63 per cent of agriculture in India is rainfed. This area contributes nearly 44 per cent to food production and supports 40 per cent of the human and 60 per cent of the livestock population. Even if the entire irrigation potential of the country is used, still about half of the cultivated land will remain rainfed. About 30 per cent of the country (109 million ha) is drought prone and suffers with critical water shortages. Rainfed agro-ecosystem covers about 90 million ha of net cultivated area, which is distributed unequally among different states. In Assam, Gujarat, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra and Rajasthan more than 70 per cent of the net cultivated area is rainfed (**Table 2**). Besides uncertainties in rainwater availability, the swings in the onset, continuity and withdrawal pattern of monsoon make crop production in rainfed areas a risky proposition. The coefficient of variation in the monsoon rainfall in areas located in the rainfall zones of < 500 mm, 500-700 mm, 700-1000 mm and > 1000 mm is in the range of 50-55, 40-50, 30-40 and 20-30 per cent, respectively.

Table 2. State wise rainfed area (1991-92) in India

State	Net sown area (Lakh ha)	Net irrigated area (Lakh ha)	Cultivated rainfed area (%)
Andhra Pradesh	110.4	66.9	60.6
Assam	27.1	21.3	80.9
Bihar	77.1	43.6	56.6
Gujarat	92.9	69.2	74.5
Haryana	35.1	7.5	21.4
H.P.	5.7	4.7	82.0
J & K	7.3	4.2	57.2
Karnataka	107.1	84.0	78.4
Kerala	22.5	19.2	85.4
M.P.	193.6	147.4	76.1
Maharashtra	177.3	155.6	87.8
Orissa	63.4	44.0	69.4
Punjab	42.1	2.80	6.6
Rajasthan	154.9	115.5	72.0
Tamil Nadu	57.2	31.2	54.5
Uttar Pradesh	173.0	67.6	39.1
West Bengal	53.3	34.2	64.1
Others	13.9	11.2	80.5
Total	1414.1	926.1	65.5

**Source : Natural Resource Management for Agricultural Production in India.
 Edited by J S P Yadav and G B Singh, pp 204**

Water is the most scarce resource in rainfed agriculture. Inefficient use of this scarce resource leads to inefficiency of all other inputs. In water resource management, the focus is not merely on development of new water resources but also on efficient utilization of already developed ones particularly based on indigenous systems. The precipitation reaching the earth surface may be intercepted by vegetation, may infiltrate into the ground, may flow over land surface as run-off or may evaporate. Evaporation may occur over the land surface or free water or from the leaves of the plant through transpiration. Soil acts as a reservoir for the water that enters the soil. Water in the soil is always in transitory storage. Rainfed areas can be made productive and profitable by adopting improved technologies for rainwater conservation and harvesting and commensurate agricultural production technologies. The fundamental problems of dry farming are:-

- Storage in the soil of a small annual rainfall;
- Retention of the moisture in the soil until it is needed by the plants;
- Prevention of direct evaporation of soil moisture during the growing season;
- Regulation of the amount of water drawn from the soil by plants;
- Choice of crops capable of growth under moisture stress conditions and
- Crop management for proper utilization of stored soil moisture.

The relation of crops to the prevailing conditions of arid lands offers another group of important dry farm problems. Some plants are drought resistant and some are drought

tolerant. Some attain maturity in short duration and are suitable for dry farming. Some crops and varieties have deep root system or waxy layer, which aid in their survival under moisture stress. After the selection of crops, skill and knowledge are needed in the proper seeding, tillage, nutrient management, plant population, weed control and mid-season correction for efficient use of conserved moisture.

1.1 History of rainfed agricultural research

Over the years, following efforts have been made to transform rainfed farming into more sustainable and productive systems.

- In 1880, the First Famine Commission was appointed by the then British Empire to suggest ways and means to off-set 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.
- In 1923, the then Imperial Council of Agricultural Research implemented six schemes viz The Bombay Dry Farming Research Scheme at Sholapur; The Madras Dry Farming Research Scheme at Hagari; The Madras Dry Farming Development Research Scheme at Hagari; The Hyderabad Dry Farming Research Scheme at Raichur; The Hyderabad Dry Farming Development Research Scheme at Raichur and The Punjab Dry Farming Research Scheme at Rohtak for different periods at different locations up to 1957.
- Kanitkar, Sirur, Gokhale and others pioneers of rainfed agriculture advocated ways and means for effective soil and water conservation.
- Central Arid Zone Research Institute (CAZRI) was established in 1959 at Jodhpur to tackle the problems of arid agro-ecosystem.
- Renewed efforts were made by the Government of India in mid-fifties to conserve the natural resources and optimising their use by establishing eight Soil Conservation Research Centres at Dehradun, Chandigarh, Udhamandalam, Bellary, Kota, Vasad, Agra and Hyderabad, which were put under the control of Central Soil and Water Conservation Research and Training Institute (CSWCR&TI), Dehradun in 1976.
- All India Coordinated Research Project for Dryland Agriculture (AICRPDA) was initiated in 1970 at 23 centres, selected on agro-climatic basis.
- International Crop Research Institute for Semi-arid Tropics (ICRISAT) in 1972 and Central Research Institute for Dryland Agriculture (CRIDA) in 1985, both at Hyderabad were established to conduct basic, strategic and applied research on rainfed agriculture.
- . All India Coordinated Research Project on Agro-meteorology was started in 1983 to strengthen the location specific weather forecasting.
- State Agricultural Universities and other research institutes of Indian Council of Agricultural Research (ICAR) have contributed a lot to tackle the location specific problems of rainfed agriculture.
- Indian Grassland and Fodder Research Institute at Jhansi in 1962, ICAR Research Complex for North Eastern Hill Region at Barapani in 1975, Central Agricultural Research Institute at Port Blair in 1978, National Research Centre for Agro-forestry at Jhansi in 1988 and National Research Centre for Arid-horticulture at Bikaner in 1990 are conducting basic, strategic and applied research on different aspects of natural resources for sustaining both irrigated and rainfed agro-ecosystems.

1.2 Dryland vs. rainfed agriculture

It is important to distinguish between dryland agriculture in particular and rainfed agriculture in general. Clearly, both of them exclude irrigation. The emphasis for rainfed agriculture, however, is often on disposal of excess water, maximum crop yields, high levels of fertilizer inputs, and water erosion constraints. In dryland agriculture, emphasis is on water conservation, sustainable crop yields, limited inputs of fertilizer, and both wind and water erosion constraints. Drylands receive less than 750 mm of rainfall annually and are arid to semi-arid. However, an absolute value cannot be stated because seasonal rainfall distribution and temperature affect crop water requirements and thus the kind of soil and water management practices. Thus a region with annual rainfall of 750 mm with good monthly distribution in a cool climate might utilize rainfed agriculture type management systems; whereas in a hot climate, a region with poorly distributed rainfall of less than 750 mm per year might appropriately require dryland farming techniques. Available crop growing season is less than 200 days under dryland agriculture. The phrase rainfed has been used in this chapter, which envisages both the situations. Rain water harvesting in storage ponds/ tanks and its recycling to give pre-sowing or life saving irrigation to crops through water saving methods of irrigation such as sprinkler, drip and trickle is now becoming popular in dryland and rainfed agriculture.

2. Rain water and Moisture Conservation

In India, dry lands receive a mean annual rainfall less than 750 mm. Low rain in these areas makes the crop production dependent entirely on the onset, quantity, frequency and distribution of rains. The rainfall in dry land areas is not only scanty but also highly erratic and ill distributed. Besides this, evaporation and transpiration losses of soil moisture are more due to high temperature and low humidity. Rain water and soil losses in dry lands are also more due to run-off and erosion respectively because of the favorable physical and chemical properties of soils. There are always strong links between the measures for soil and water conservation. Mechanical and agronomical practices adopted for soil and water conservation in dry lands attempt to achieve following objectives:

- i) To reduce the length of slope;
- ii) To reduce the degree of slope;
- iii) To increase the rate of infiltration;
- iv) To avoid direct hitting of land surface by rain-drops;
- v) To increase opportunity time for infiltration of water by changing land configuration and
- vi) To increase run-off for water harvesting and *ex-situ* water conservation.

2.1 Water conservation

Water required for plant growth and development is taken from the soil by the roots. Leaves and stem do not absorb appreciable quantities of water. Limited rain water in dryland areas must therefore be made to enter the soil in such a manner as to be readily available as soil-moisture to the roots at the critical periods of plant growth. All the land and crop management practices which improve rainwater storage in the soil profile comprise water conservation. Successful dry farming depends chiefly upon the success with which the rains that fall during any season of the year may be stored and kept in the soil until needed by plant in their growth. The fundamental operation of dry farming includes a soil treatment which enables the maximum possible of the annual precipitation to be stored in the soil. Based on the quantity of rainfall, water conservation may be classified as *in-situ* and *ex-situ* water

conservation. *In-situ* water conservation refers to storage of rain water in the soil profile, where it falls. *In-situ* water conservation is followed and successful in those areas where rain water stored in the soil profile after uncontrollable run-off and other losses is sufficient to meet the crop requirement. In large part of arid region, contemporary precipitation is very low and is not sufficient to meet the crop water requirement even after adopting all *in-situ* moisture conservation measures. In some areas, soil are shallow and water stored in the shallow soil is not sufficient to meet the crop requirement. Under such situations, reducing run-off and increasing infiltration rates are ineffective. In these areas, *ex-situ* water conservation measures are adopted. Under such situation, water conservation consists of using water derived from a catchment area that has been treated to increase run-off of precipitation to supplement soil moisture in the adjacent cropped area, situated at a lower elevation. In these areas, harvested run- off from the catchment plus the rain water falling on the cropped area, using predetermined ratio between catchment and cropped area.

Water conservation technologies broadly fall under two categories, viz. agronomical and mechanical measures:-

2.1.1 Agronomical practices

Agronomical practices involves interception of rain drops to reduce the splash effect; improve intake of water through use of organic matter and crop residue and to bring down run- off and its velocity by adopting contour cultivation, mulches, close and dense planting and strip and mixed cropping.

- i) **Contour farming:** It is a simple water conservation practice which involves ploughing, cultivation and planting across the slope, keeping the same level, as far as possible. Contour farming has many beneficial effects. The ridges and furrows, and the rows of the plants placed across the slope form a continuous layout of miniature reservoirs and barriers to the water moving along the slope. The barriers are small individually, but as these are large in number, their total effect is great in reducing the run-off, soil erosion and loss of plant nutrients. This is non-monetary and simple practice. This practice helps in conserving rain water, reducing erosion and enhancing crop productivity.
- ii) **Cover management:** This practice ensure continuous cover on the soil surface through cultivation of close growing and erosion resisting crops, grasses and shrubs to reduce erosion and improve water conservation. Among the field crops, legumes and forage crops provide better cover for interception of kinetic energy of rain drops and interruption of run-off. Nearness of the canopy to land surface and extent of cover determine the effectiveness of the crop. Mixed cropping systems of low-canopy legumes with widely spaced crops is a most suitable option, which provides a better and continuous cover to ground, protection against beating action of rain drops and ensure at least one crop under adverse climatic conditions, particularly in semi-arid and hilly regions against complete failure of the crops. The cover crops such as greengram, blackgram, groundnut, soybean, sunnhemp and *dhaincha* restore soil fertility, control weeds, conserve rainwater, reduce energy and costs, besides reducing soil erosion and improving soil morphological characters. Intercropping of low canopy legumes such as groundnut, greengram, blackgram, soybean and cowpea in wider inter-row spaces of crops like maize, sorghum, cotton, castor and pigeonpea provide sufficient cover on the ground, thereby reduce erosion hazards apart from biological insurance to increase productivity of rainfed arable lands.

- iii) **Strip cropping:** Strip- cropping is a well-accepted soil and water conservation measure all over the world. It helps in shortening length of slope, reducing velocity of run-off, arresting soil by providing a biological filters/barriers and increasing absorption of rain water in the soil profile. It may be in the form of contour strip cropping, field strip cropping, wind strip cropping, or permanent strip cropping. In the strip cropping, a strip of erosion permitting crop is grown alternatively with strip of soil protecting and erosion resisting crop across the slope. When these strips are grown on contour, it is known as contour strip cropping. Growing of strips across fairly uniform slope but not on exact contour, is known as field strip cropping. Sometime a strip of perennial grasses, legumes or shrubs is planted on steep slopes in the fields, this type of arrangement is termed as buffer strip cropping. Based on the experiments conducted on strip cropping, width of erosion permitting and erosion resisting crops has been standardized for different slopes (**Table 3**).

Table 3. Contour strips suitable for crops on different slopes

Slope	Width of erosion permitting crop (m)	Width of erosion resisting crop (m)
<0.5%	45	9
1-2%	24	6
2-3%	13.5	4.5

Source: Handbook of Agriculture (Fifth Edition)

- iv) **Mulching:** Surface mulches are used to prevent soil from blowing and beating action of rainfall, reduce run-off, increase infiltration, reduce evaporation, keep down weeds, improve soil structure and eventually increase yield. Detail of mulches has been given in respective section in this chapter.
- v) **Tillage:** Tillage is a well known soil and water conservation practice which makes soil surface more permeable to increase infiltration of rain water into the soil, which in turn reduces run-off, 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 rain water. 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 tillage or pre-monsoon tillage also has a marked impact on weed control and rain water 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 under dry land. Conservation tillage is an umbrella term and it envisages stubble mulch tillage, minimum tillage and zero tillage. Low intensity tillage favours consolidation of soils and imparts erosion resistance through better consolidation, structure, infiltration, pores distribution and depression storage.
- vi) **Selection of suitable cropping and alternate land use systems:** Cropping sequence and crop rotation have considerable bearing on production and conservation. Based on the availability of rainfall, soil type, length of growing season and land topography, cropping systems and alternate land use systems

recommended for different agro-climatic conditions have to be exploited for effective conservation of rain water and its utilization. Agro-forestry has become an important technology for resource poor small farmers especially under dry land conditions. Alley cropping is another approach for effective use of limited resources. Putting the land under grasses as per land capability classification and efficient management of existing grazing land may contribute significantly towards efficient utilization of limited natural resources.

- vii) **Micro-watersheds:** Land configurations have been developed in which run-off water from un-cropped area or parts of the field is concentrated in strips or adjoining plots in which crops are planted. The crops are sown in the narrow strips or in the inter-plot between wide strips, which are treated to act as miniature watershed for the cropped areas. The catchment areas are compacted and designed to create slope to increase run-off to the cropped areas. The relative width of water shedding strips and of the crop producing strips depend upon the amount of expected annual precipitation. The usual ratios vary from 2:1 to 4:1. Ground covers of plastic films, rubber and metal sheeting materials and waterproofing and stabilizing soil surfaces by spraying with low cost materials can be used to increase the run-off from the catchment area. Different types of micro watersheds are as follow:-
 - a) **Ridges and furrows:** Ridges and furrows are suitable for 0.2 to 0.4 per cent slope. This type of land configuration is useful in conserving moisture in widely spaced crops like cotton, maize, sorghum, castor and pigeonpea.
 - b) **Ridging and tied ridging:** It involves making ridges and furrows, then tying or damming furrows with small mounds to increase the surface water storage and avoid run-off. The tie act as a barrier for the rain water movement and increases time available for infiltration, thus enhances the availability of soil moisture to the crops.
 - c) **Catch pits or scoop:** In this method, pits of different size are dug at many places in the fields to collect the run-off water along with silt. This will enhance the moisture availability to the crops.
 - d) **Broad bed and furrow system:** This land configurations consists of a relatively raised flat bed of approximately 90 to 150 cm width (depending upon the soil type and crop requirement) followed by shallow furrow of 30 cm width and 15 cm depth. The beds are maintained permanently. The beds function as mini bunds at a grade and help in reducing the velocity of surface run-off and increase infiltration opportunity time. The excess water is removed through the furrow.
- viii) **Vegetative barrier/live bund:** The vegetative hedges and buffers are placed on existing field bunds to conserve soil and water. Dense vegetation raised across the slope, makes a live bund. The live bunds help to reduce the length of field slope, check the run-off velocity, improve the soil moisture, control the soil erosion and trap the silt up to some extent. It is a cheaper and permanent measure. There is need for making a suitable choice of plants for the live bunds. Sachharum munja, Vetiver, jatropha, agave, prosopis etc. can be used for vegetative barrier.

2.1.2 Mechanical measures of soil and water conservation

Mechanical or engineering measures are needed on agricultural lands to supplement agronomical practices when slope becomes steeper or velocity of the run-off and discharge

become high. These measures help in dissipating energy of flowing water by reducing its velocity with permissible limits, increasing the time of concentration to conserve more run-off water into the soil and minimizing soil erosion by reducing length and/or degree of slope. On agricultural land, land configuration measures include contour bunding, graded bunding, bench terracing, conservation bench terracing, conservation ditching, grassed waterways and graded trenching.

- i) **Contour bunding:** Bunding is the most effective and widely practiced field measure for controlling run-off and reducing soil erosion. Contour bunding is defined as series of mechanical barriers across the land slope. Each contour bund acts as a barrier to the flow of water. Thus, the water flow is restricted and there is possibility of impounding water which infiltrate overtime in the soil profile. This type of bunding is recommended for rolling lands with the slope of less than 6 % and flat land with scanty or erratic rainfall. In soil of very shallow depth (< 7.5 cm) contour bunding is not suitable. The design of contour bund involves spacing of bunds, its cross section and surplusing arrangement, which vary with slope, rainfall, soil texture and depth of soil profile. Surplusing arrangements for contour bunds are necessary in high rainfall areas to drain-off excess run-off water safely out of land without causing erosion.
- ii) **Graded bunding or channel terraces:** Graded bunds consist of small bunds constructed with a slope of 0.3 to 0.5 % in order to dispose of excess water through the graded channels which lead to naturally depressed area of the land. These are recommended for area more than 600 mm rainfall having highly impermeable soils. The purpose of graded bunding is to make run-off water to trickle rather than to rush out. Graded bunding is restricted to 6 % slope and in specific cases it may be extended to a slope of 10 %. The height of bund should be at least 45cm and top width may vary with height of the bund. Grassed water ways are necessary to prevent soil erosion down stream and failure of the bunds.
- iii) **Bench terracing:** A terrace is a ridge or embankment of earth constructed across the slope to control run-off and minimize soil erosion. This is one of the most widely adopted mechanical measures of soil moisture conservation suitable for hilly areas with a slope of 6-33%. Bench terracing consist of step like fields or benches constructed along contours by cut and fill method to reduce length as well as degree of slope for either impounding rain water for cultivation or channeling it for safe disposal. In addition, it helps in promoting uniform distribution of soil moisture, irrigation water and controlling soil erosion and there by increasing productivity of land. Depending upon the soil, climate, topography and crop requirements, bench terraces may be of table top or level type, outwardly sloping or inwardly sloping with mild longitudinal grades for run-off disposal. Cultivation is carried out on the leveled field.
- iv) **Puetorican type bench terracing:** *Puetorican* or natural type bench terrace comprises laying an earthen bund (30 to 40 cm height) or a vegetative barrier of 1.0 m width along the contour at 1.0 m vertical interval. The space between barriers is cultivated which results in the formation of terraces through induced deposition of soil along the barriers in about 4 to 5 years. This fairly less costly practice than bench terracing on slopes up to 7-12% and costs 64 to 76% of the conventional cost of bench terracing. The vegetative barriers should be established by staggered planting of 2 to 3 lines of grasses across the slope at appropriate vertical interval. The grass species should be selected as per the agro-climatic condition of the area, their adaptability and preference of farmers. The recommended grass barriers are Guinea grass, Napier, *Bhabar*, *Vetiver*, *Munj* and *Guatemala*.

- v) **Conservation bench terracing (CBT):** The conservation bench terracing has been applied successfully to mildly sloping lands in arid, semi-arid and sub-humid regions for erosion control, water conservation and improvement of crop productivity. The CBT system consists of terrace ridge to impound run-off on a level bench and a donor watershed, which is left in its natural slope and produces run-off that spreads on the level bench. It is suitable for low rainfall condition, for taking assured crop on run-off recipient area. The ratio of run-off donor to run-off recipient area may vary from 1 : 1 to 3 : 1.
- vi) **Compartmental bunding:** This method is one of the cheapest rain water conservation techniques, suitable for rainfed vertisols having slope of less than 1%. By this method the entire field is divided into small sections, which helps in storing the initial rainfall and permitting increased infiltration rate. This method ensures rational moisture distribution as well as optimum moisture for better germination of seeds.
- vii) **Dead furrow:** Instead of bunds, furrows are made across the slope to trap run-off and eroded soil. Water in the furrows slowly infiltrates in the soil profile.

2.2 Moisture conservation

Soil holds water on the surface of soil particles in the form of thin layer with a force. This force vary with amount of water in the soil. Beside this, soil pore space in the form of micro-pores and soil capillaries contain water in varying proportion with air. This water in the soil profile is known as soil moisture. In dry land agriculture, soil moisture is the most limited resource for plant growth. Soil moisture is lost as evaporation from the soil surface and as transpiration from plant surface. For prolonging the use of limited amount of soil moisture by the crop plants, evaporation losses of soil moisture has to be arrested, as these are not related to productivity of the crops, whereas transpiration can be reduced to some extent without affecting productivity of crop plants. This reduction in soil moisture losses for increasing the productivity and water use efficiency through various measures is termed as moisture conservation.

2.2.1 Moisture conservation practices

- i) Mulches
- ii) Anti-transpirants
- iii) Weed control
- iv) Mid-season correction
- v) Optimum plant population
- vi) Wind break and shelterbelts

Role of mulches, anti-transpirants, weed control, mid-season correction and optimum plant population in moisture conservation have been discussed in respective sections under this chapter. Wind break refers to any structure that obstruct-wind flow and reduces wind speed, while shelterbelt is a row of trees planted for protection of crops against wind. Windbreaks and shelterbelts are planted across the direction of wind. Due to reduction in wind speed, evaporation and transpiration losses are reduced and more water is available for plants. Besides this, there is also reduction in soil erosion and damage to crop plants.

2.3 Water harvesting and recycling

The rainfall distribution in the country is highly skewed and variable. Rainfall vary from less than 100 mm annually received in the western-most part and around 11000 mm in eastern most part of the country. About 30 % of the geographical areas of the country receive less than 750 mm rainfall, 42 % of the areas falls in the range of 750 and 1250 mm and 20 %

receives rainfall between 1250 and 2000 mm annually. In terms of temporal distribution, the total rainfall occurs in less than 150 hours and half of it descends in not more than 20-30 hours of heavy spells. Hence, run-off is a prominent feature of the hydrologic cycle of India. The monsoonal run-off flow uncontrolled causes soil erosion, but if used judiciously can be boon for improving crop production in rainfed agro-ecosystem. Rain water harvesting is the collection, storage and recycling of run-off water for irrigation and other uses. The surface run-off water harvesting can be achieved through dugouts ponds, tankas, *khadins*, *havelis*, diversion bunds and roof-top rain water cisterns. Stream flow run-off harvesting is practiced through *nala*-bundling, check-dams, stop dams, percolation tanks/ponds and *nadi*. In dry lands agriculture, water harvesting usually denotes the collection of excess run-off in the farm ponds and using it for providing protective irrigation (pre-sowing irrigation or life saving irrigation or irrigation at most critical stage of crop) and percolation ponds and silt-detention tank to recharge the ground water. People through the ages across the various agro-ecological regions have come up with indigenous and unique water harvesting structure and systems displaying their innovative technical skills. In Rajasthan, people has used the scarce and little rainfall through rainwater harvesting structures such as tankas (dugout and lined circular holes, 3-4 m diameter), *nadi* (small excavated or embanked village ponds), *khadins* (run-off from hilly and wasteland is impounded by constructing earthen bunds and crops are grown) *etc.* *Haveli* system of cultivation is a traditional water harvesting practice in the black soils of Bundelkhand region, where rain water is impounded in banded fields during monsoon and crop is taken on residual moisture during *rabi* season. The most common water harvesting structures are of embankment ponds for hilly and rugged terrains and excavated farm-ponds for flat topography.

The harvested rain water is a scarce resource and therefore should be utilized most judiciously. The supplemental life-saving irrigation given to crops can boost their production tremendously (**Table 4**). For efficient use of stored water, it is necessary to consider conveyance of water, time of irrigation, methods of irrigation, quantity of irrigation water applied and selection of crops and cropping systems. Drip and sprinkler methods of irrigation are recommended to minimize wastage of stored water and to bring more area under command.

Table 4. Estimated water yield into farm ponds and effect of supplemental irrigation (5 cm) on crop yield in different regions.

Region	Rainfall (mm)	Expected water yield (%)	Crop	Yield (tonnes/ha)		
				No irrigation	With irrigation	Increase (%)
Bunga (Haryana)	1116	50	Wheat	0.7	3.40	485
Bellary (Karnataka)	508	20	Sorghum	.43	1.37	318
Hyderabad (AP)	770	10	Sorghum	1.39	1.92	138
Sholapur (Maharashtra)	760	15-20	Sorghum	1.65	2.36	143
Vasad (Gujarat)	850	16.7	<i>Bidi</i> tobacco	1.46	1.75	119

Source: Handbook of Agriculture (Fifth Edition) page 297

For collection of higher amount of rainfall, under arid region, run-off is induced either by compacting the soil surface or using ground cover of plastic films, rubber and metal sheeting

material or using concrete and asphalt, or chemical treatments with soil flocculants (sodium salts) and water repellent (silicone). In the hilly areas, use of low density polyethylene films (250 micron) has been found suitable as a low cost measure for lining of small tanks to check seepage losses

2.4 Factors influencing choice of soil moisture conservation practices

- i) Topography and slope of the land;
- ii) Soil physical properties especially soil texture;
- iii) Soil chemical properties like soil pH and cations exchange capacity;
- iv) Depth of soil which decides the quantity of soil moisture storage;
- v) Weather parameters especially rainfall and temperature and
- vi) Hard-pan in plough layer or beneath the layer.

3. Mulches

About 60-75 per cent of the rainfall is lost through evaporation. Evaporation loss can be reduced by applying mulches. Mulch is any material applied on the soil surface to check evaporation losses, to conserve soil and water and to regulate soil temperature in favour of crop production. Besides this, application of mulches results in additional benefits like reduction in soil salinity, weed control and improvement in soil structure. By way of these benefits, mulches play an important role in improving crop productivity under dryland and rainfed farming. The practice of applying mulches to soil is possibly as old as agriculture itself. Historical evidences indicate that ancient Romans placed stones on the soil surface to conserve water and the Chinese used pebbles from streambeds for similar purposes. These practices were more suitable to areas, where hand labour was readily available, but became less practicable under mechanized agriculture. The current trend under mechanized agriculture is to utilize crop residue as mulches on the areas, where crops are grown or to use transported and manufactured materials as mulches for high value crops. Stubble mulch tillage, minimum tillage, zero tillage and other forms of conservation tillage have inherent ability to retain sufficient crop residue on the soil surface, which is directly or indirectly fulfilling objectives of mulching the soil surface. In general, the yield improvement is greater in low rainfall year as compared to a normal year. Crops residues, leaves, tree waste, manure, paper, plastic films and certain petroleum products are few materials used for mulching.

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

- i) **Organic mulching:** In the organic mulching, crop residues like cereal 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 and moderate soil temperature.
- ii) **Chemical mulching:** In the chemical mulching, aluminum foils, plastic, polythene sheets etc. are spread on the soil surface to moderate soil temperature for controlling weeds, to optimize temperature for germination of seeds and to induce run-off of rain water for *ex-situ* water conservation and harvesting. Besides 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 evaporation.

- iii) Soil or dust mulching:** In soil mulching, surface mulch of dry soil of 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 control further evaporation from sub-soil by breaking the capillaries continuity. 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. Such cracks when penetrate deep, may cause considerable loss of moisture from the root zone. These cracks are filled and covered by the loose layer of dust mulch. It is used as a mid-season correction measure for moisture conservation.
- iv) Vertical mulching:** In heavy black soils, where infiltration of rain water is a great problem, vertical mulching may be practiced keeping straw/stover/stalk/stubbles as vertical mulch in trenches of 40 cm deep, 15 cm wide and protruding 10 cm above the ground level. 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.

3.2 Mode of action of mulches

The amount of rain water taken in by the soil depends on run-off and infiltration. Organic mulches maintain high rate of infiltration as well as reduce the run-off and its velocity, thereby play a significant role in soil and water conservation. Organic mulches trap the kinetic energy of raindrops and thus reduce their impact on the disintegration of soil particles. Reduction in disintegration of soil particles, reduce the clogging of soil pores and thus maintain a high rate of infiltration for longer period. Beside this, organic mulches interrupt the movement of rain water on soil surface and thus reduce the velocity of run-off water, resulting in more opportunity time for rain water to infiltrate. Organic mulches also reduce the rate of evaporation by reducing the amount of energy absorbed by the soil and air movement immediately above the soil surface. Effect of mulches on soil temperature vary with effect of mulching material on albedo, their control on celestial radiation, soil moisture content, evaporative cooling and conduction of heat. White and reflective plastic reduces soil temperature, while black plastic in close contact with soil increases soil temperature. Effects of mulches of plant material on soil temperature vary with the season. In general, during summer soil temperature is lower while in winter it is higher due to mulches when compared to bare soil surface.

3.3 Effects of mulches

- i)** Mulches improve soil water availability to crop plants by reduction in evaporation and run-off, sustaining infiltration rate and controlling weeds.
- ii)** Mulches reduce soil erosion by reducing the velocity of run-off and increasing the rate of infiltration.
- iii)** Soil temperature change due to application of mulches, depend on the type of mulch material. Organic mulches moderate temperature by decreasing it in summer and increasing it in winter. Clear plastic mulch increases the soil temperature. These temperature changes are exploited for early sowing of crops, protecting seedlings from extreme low and high temperature and controlling weeds during summer.
- iv)** Mulches reduce accumulation of salts on the soil surface by increasing infiltration and reducing evaporation.

- v) Organic contribute in improving soil organic carbon content and physical, chemical and biological properties of the soil.
- vi) Organic mulches have smothering effect on the weeds. Plastic mulches during summer affect the viability of weed seeds by raising the soil temperature to lethal level.

3.4 Limitations of mulches

- i) Less availability of material (crop residue, straw and stover) for mulching particularly under dry land conditions.
- ii) Inorganic mulches are very costly and poor farmers of dry land areas can not afford for purchase of synthetic mulches.
- iii) Organic mulches increase the occurrence of insect-pests and diseases.
- iv) Scarcity of crop residue due to its alternate uses.

4. Anti-transpirants

Plants transpire water vapours continuously from all the above ground parts particularly through leaves. This process of evaporation of water from the aerial parts of plants is termed “Transpiration”. Approximately 99 % of the water taken by the plant roots is transpired to the atmosphere. Transpiration occurs through different types of apertures such as cuticles, lenticules and stomata. Among these apertures, stomata accounts for 90-97 % of transpiration. Transpiration is considered an unavoidable evil. Reduction in transpiration may help in maintaining of favorable water balance in dry farming. Any material that is applied to plant surfaces with the aim of reducing or inhibiting water loss from plant surface is called “anti-transpirant”.

4.1 Scope of using anti-transpirants

- i) Under dry land area to reduce water losses through transpiration.
- ii) In costly irrigation for extending the irrigation interval.
- iii) In areas having poor quality of soil water or irrigation water to reduce the uptake of salts.
- iv) For reducing transplanting shock of nursery plants

4.2 Types of anti-transpirants:- Based on the mode of action, anti-transpirants are of four types.

- i) **Stomatal closing type:** Most of the transpiration occurs through stomata on the leaf surface. Spray materials used for various purposes such as certain fungicide (phenylmercuric acetate (PMA), herbicide (atrazine) and metabolic inhibitors have been found to cause the closure of guard cells of the stomata and thereby reduction in transpiration, when sprayed in low concentration on the leaf surface of crop plant. They serve as anti-transpirants by inducing stomatal closing. Complete closure of stomata or reduction in the opening of stomata, contribute in the decrease of water lose through transpiration. The effectiveness of an anti-transpirants is also depends on the coverage of lower surface of leaves, interaction of the anti-transpirants with external environments, surface anatomy of leaves and rate of formation and growth of new leaves.
- ii) **Film-forming type:** Foliar spray of waxy or plastic emulsions such as mobileaf, hexadeconol and silicone produce an external physical barrier outside the stomatal opening to retard the escape of water vapour through stomatal opening. The film so

formed should have more resistance to the passage of water than to that of carbon dioxide. Film type anti-transpirants, which provide selective type of permeability barriers to water vapours and carbon dioxide diffusion in the required directions have not yet been found so far.

- iii) **Increasing leaf reflectance type:** White reflecting materials such as whitewash or kaolinite spray form a coating on the leaves and increase the leaf reflectance (albedo). By reflecting the large amount of radiation, they reduce leaf temperature and vapour pressure gradient from leaf to atmosphere and thus reduce transpiration. Application of 5 % kaolin spray has been found to reduce transpiration losses markedly.
- iv) **Growth retardants:** Foliar application of chemicals such as cycocel reduces shoot growth, increases root growth and induces stomatal closure. Thus, the application of such chemical helps in improving the water status in the plants and soil.

4.3 Effect of anti-transpirants on crop production

Anti-transpirants are used to reduce the losses of water through transpiration, so that limited amount of available soil moisture can be used for completing the life cycle of crop plants. Anti-transpirants along with slowing the rate of transpiration, reduces the photosynthesis efficiency of crop plant due to less uptake of carbon dioxide through narrowed aperture of stomata, relatively less permeability of carbon dioxide through the film and rise in leaf temperature. Reduction in transpiration as well as photosynthesis after treatment with anti-transpirants is well documented in the literature. They are most effective when water losses from leaves are not restricted by natural stomatal closure in response to leaf water deficits (caused by dry soil and/or high evaporative demand or darkness). Thus, an anti-transpirant will be of little benefit to an already wilted plant, but will delay wilting onset if applied when the plant transpiring freely.

4.4 Limitations of anti-transpirants

- i) May reduce the rate of photosynthesis;
- ii) May increase the leaf temperature by reducing evaporative cooling;
- iii) Interaction of climatic factors with anti-transpirants reduces their effectiveness for longer duration;
- iv) Sometime marginal cost is more than marginal returns;
- v) Water uptake and reducing water losses through transpiration and
- vi) May produce toxic effects on leaves.

5. Efficient Management of Rainfed Crops

5.1 Land preparation

Land preparation (preparatory as well as post-harvest tillage operations) influences the infiltration, run-off flow and rate of soil erosion. Deep ploughing or chiseling after crop harvest has been found to increase the infiltration rate especially in soil, where hard pan formation is very common. Minimum tillage (least disturbance to land surface and planting in one operation) is advantageous for soil and water conservation in those areas, where land configuration has been changed in favour of soil and water conservation. Numbers of tillage operation under dry land vary with soil texture and structure, land slope, soil type and requirement of crops. Since soil moisture is the limiting factor of crop production in dry

land, tillage practices should be aimed to fulfill the need of conservation of rain water and moisture.

Major consideration in the land preparation is timeliness and precision of operations. As the rainfall period is very short, the field preparation and sowing have to be completed within short span of time. Any delay in these operations can reduce the availability of soil moisture, which in turn seriously affects the germination stand and yield of the crop. Timeliness of operations is particularly important in areas of double cropping, where available time between the *kharif* harvest and *rabi* sowing is pretty short. There is urgent need to go for mechanization for timeliness in land preparation under dry land.

5.2 Seeding

In arid and semi-arid regions, the choice of an appropriate planting date may have a considerable affect on water use efficiency. Sowing of dry land crops with the onset of monsoon is an important practice that can significantly improve the yield of crops across location. Timely sowing helps in optimum utilization of seasonal rainfall, reduces the incidence of pests/diseases and is an escaping mechanism from terminal drought. The most important requirement for obtaining higher productivity in dry land crops is to attain good germination and uniform plant population under field conditions. In the post-rainy season, seeding should be done after considering the soil moisture storage and prevailing temperature. Ridge seeder can also be utilized for placement of fertilizer in the moist zone below seed and seeding of dry land crops along with making ridge and furrow. Rainy season crops sown at the edge of ridge and furrow system provide good crop stand due to reduced soil crusting. Sowing at right time does not cost more to sowing the crop late, so it is the most effective way of reducing per unit cost of production. Optimum time of sowing wheat in India is the first fortnight of November. Wheat sowing beyond 15 December, results a decline in yield @ 100 kg/day approximately.

In dry regions, pre-monsoon dry seeding is a common practice, which ensures timely and early sowing. Dry sowing enables full utilization of pre-monsoon showers for better germination, optimum crop stand and growth. Early sowing avoids pressure on bullock and human labour for field preparation and sowing. Dry sowing also ensures protection of crops against pests and diseases incidence. Cotton, sorghum, greengram, blackgram and pigeonpea are extensively sown under pre-monsoon dry seeding condition. Dry seeding under dry land condition based on the probability of occurrence of rainfall, which is obtained on the analysis of long term rainfall using conditional probability. In dry seeding, shallow seeding ensures quick germination with the receipt of meager rainfall. Generally, seeds are sown at optimum and uniform depth (5-7 cm) using seed drill.

5.3 Plant population

In dry land ecology, moisture is the most limiting factor. Therefore, plant population must be adjusted to available soil moisture levels, either within rows or between rows. Under rainfed system, especially in the post-monsoon season, the optimum plant density is usually less than recommended under irrigated agriculture. The excessive foliage results in quicker loss of soil moisture through transpiration and higher plant density becomes counter productive if conserved moisture exhausted before the seed formation and development or rainless period prolongs during critical stages of crop growth and development. Moreover, added soil fertility in rainfed conditions is not high and relatively a higher plant density would have individual plant under nutrient stress, leading to lower grain yield. Under dry land, sometime plant population is also adjusted through thinning during the lateral stages of crop growth to match with available moisture supply as discussed under the section 'mid season correlation' of this chapter.

It is well known that optimum density for a crop has to be lower than normal under conditions of limited water supply. Plant population must be adjusted to available moisture levels, either within rows or between rows. Beside this, there is a need to go for rational planting geometry for the rational use of available soil moisture. Wider row-to-row spacing and very closer plant-to-plant spacing may defeat the purpose of optimum use of soil moisture. Based on the results of experiments conducted in different parts of the country, optimum-planting geometry has been recommended for different soil moisture regimes. Under dry land conditions, evaporation is influenced more by the moisture supply at the soil surface than by radiation. Therefore, once the upper soil layer has dried, further moisture losses by evaporation become negligible. Under these conditions, wide row are not more conducive to greater water loss by evaporation than are narrow rows.

5.4 Choice of crops, varieties and cropping systems

It is important to choose appropriate crops and their varieties and cropping systems to suit available moisture and aberrant weather situations under rainfed ecology. Many of the existing crops and their varieties are of longer duration, photosensitive, inefficient user of available moisture and often have poor response to applied nutrients. The average yield of many important crops in dry land is as less as 700 kg/ha. Thus, the guiding principle of choice of crops, varieties and suitable cropping systems for dry lands should fit with the rainfall and its behaviour of a particular region.

The farmers used to grow crops and varieties of long duration and slow growing nature till recently and therefore the scope for increasing the crop productivity in these lands was less. Introduction of high yielding, drought resistant/tolerant varieties under dry land condition now hold the promise for getting higher yields. It is imperative to select the crops and varieties, which possess wider adaptability, short duration and evade or tolerate insufficient moisture periods by virtue of their ability to maintain high internal water content with deep root system and less transpiration. The crops and varieties suitable for dry land condition should have following characteristics:-

- i) Short duration and early vigour;
- ii) Deep root system with ramified roots;
- iii) Dwarf plants with erect leaves and stem;
- iv) Moderate tillering in case of tillering crops and varieties;
- v) Resistance/tolerance to biotic stresses;
- vi) Lesser period between flowering and maturity so that the grain filling is least affected by adverse weather;
- vii) Resistance/tolerance to abiotic stresses;
- viii) Low rate of transpiration;
- ix) Less sensitive to photo-period and
- x) Wider adaptability.

Among the crops, pulses and oilseeds are preferred over cereals with respect to water requirement and for delayed *kharif* sowing. In the pulses, clusterbean, mothbean and horsegram are better choice for low rainfall areas as compared to other *kharif* season pulses. For cultivation on conserved soil moisture during *rabi* season, chickpea and lentil are preferred over peas and Frenchbean. Similarly in oilseeds crops, groundnut, castor sesame and niger performed well under rainfed during *kharif* season. In the rapeseed-mustard group of

crops, *taramira* is the best choice for light soil with low moisture storage capacity, followed by Indian mustard. In the *kharif* cereals, coarse cereals (millets and sorghum) is a better choice over maize and rice. Similarly in *rabi* seasons, barley does well under conserved soil moisture than wheat. Among the millets, setaria is most suited for late sown condition without any serious effect on productivity. Some important crops and their varieties recommended for dry land conditions are given in **table 5**.

Table 5. Improved crop varieties suited to rainfed agro-ecosystems

Serial No.	Crop	Variety
1	Sorghum	CSH 1, CSH 2, CSH 5, CSH 6, M 35-1, JS- 20
2	Maize	Ganga 2, Ganga 2, Ganga 5, Chandra 3, Vikram
3	Pearlmillet	PHB10, Manupur, HHB 67, HC 4, HHB 45, HHB 50, WCC 75, HHB 76, HHB 60, Pusa 23, Pusa 322, Pusa 444, BK 560
4	Wheat	Pratap, C 306, K 65, WH 410, VL 804, VL 738, VL 421, VL 829, Kundan, PBW 396, K 8027, HDR 77, Amar, HI 1500
5.	Lentil	Pusa vaibhav, Shivalik, Pant L 4, Pant L 406, Pant L 639, DPL 15, Noori, , Arun, K 75, Ranjan, JL 1, JL 2, Sapna, Priya
6.	Pigeon pea	Pusa Ageti, Sharda, Prabhat, T 21, C 11, ICPL 87, UPAS 120, Basant, Khargaon 2,
7.	Black gram	T 9, Krishna, Mash 48, Mash 1-1
8.	Green gram	Pusa Baisakhi, S 5, S 8, Jawhar 45, RS 4, K851, Jalgaon 781
9.	Chick pea	Ujjain 21, G 24, G 130, Phule G5, K 850, Vijay, RSG 4, RSG 936, Pant G 114, Pusa 1053, Pusa 256, Pusa 372, Pusa 362
10.	Cluster bean	Durgapura, Safed, FS 277, Maru guar, HG75, G 1, Suvidha, Navin
11.	Taramira	T 27, RTM 314, RTM 1, RTM 2
12.	Sesame	T 13, N 32, PB Till, RT 124, RT 142
13	Groundnut	TMV 1, M 13, T 64, S 206, TG 26, TG 30, K134, ICGS 92234
14.	Castor	Aruna, GCH 3, Jyoti, GCH 4, PCH 1, Bhagya, TMV 5, TMV6
15	Safflower	JSF 10, A 300, N 62-8, N 7, Tara, NARI 6, Bhima, Sharda
16.	Soybean	JS72-44, Ankur, Bragg
17.	Sunflower	EC 68414, EC 68415, MSFH 17, KBSH 1, Morden
18.	Indian mustard	RH30, RH 8133, Pusa Bold, RH 819, RN 393, Varuna, Kranti
19.	Moth Bean	Maru Moth 1, Jadia, Jwala, T 18, AKMO 33, AKMO 35, Moth 880, RMO 40
20.	Horse gram	Maru Kulth 1, Solapur, TPK 2, PHG 9
21	Barley	Ratna, DL 3, Azad, Ambar, R S 6, Kailash, Karan 795, Vijaya

Choice of cropping systems, for rainfed agro-ecosystem depends upon the rainfall, soil characteristics, moisture availability period and other meteorological parameter. Based on these parameters different potential cropping systems have been identified for various rainfall region of the country as per detail in **table 6**. Mixed-cropping and its modified version intercropping ensure conservation of soil and water, optimum use of conserved water and other resources and increased productivity of rainfed arable land. Important intercropping systems for dryland during *kharif* season are sorghum + cowpea, pearlmillet + cowpea, cotton + groundnut, sorghum + greengram/pigeonpea/blackgram, maize + soybean, cotton +

blackgram, maize + blackgram, sorghum + pulses, pearl millet + sunflower, castor + cowpea, pearl millet + clusterbean etc. In the winter season, rapeseed mustard + wheat/chickpea/linseed/lentil/sugarcane, wheat + chickpea/pea/linseed, chickpea + safflower, barley + safflower etc. are recommended for different agro-climatic situations.

Table 6. Potential cropping systems for rainfed agro-ecosystems

Annual rainfall (mm)	Soil type	Water availability period in days	Potential cropping systems suggested
350-600	Alfisols Aridisols Vertisols	<140 <140 <140	Single <i>kharif</i> crop Single crop either <i>kharif</i> or <i>rabi</i> Single <i>rabi</i> crop
600-750	Alfisols Vertisols Entisols	140-210	Double cropping with sufficient moisture conservation practices or intercropping
750-900	Entisols Vertisols Alfisols Inceptisols	>210	Double cropping with moisture conservation and monitoring
>900	Vertisols Inceptisols	>210	Double cropping

Source : Yadav and Singh (2000)

5.5 Alternate cropping and land use strategy

The choice of alternate land use systems viz. mono-cropping, double cropping, mixed cropping, mixed farming, agro-forestry, agro-horticulture and silvi-pastoral and their success under dry land mainly depend up on the rainfall, soil type and temperature. Based on the available soil moisture and length of available growing season, choice of crops, varieties, cropping system and other alternate land uses are made (**Table 6 & 7**). Beside rainfall, the depth of water holding capacity of the soil, play a significant role in deciding the selection of crops and alternate land use system (**Table 8**). A careful analysis of data over 75 years from Rajasthan suggests land use strategy mainly based on rainfall (**Table 9**).

Table 7. Cropping system advocated based on the length of growing seasons.

Length of the growing period	Cropping system to be adopted
<75 days	Mono-cropping of short duration pulses, perennial vegetations.
75-140 days	Mono-cropping with short duration pulses, pearl millet, sorghum, castor, sesame Or mono-cropping during post-rainy season with safflower, chickpea etc.
140-180 days	Intercropping
>180 days	Double cropping with winter sorghum chickpea, safflower, barley, lentil, mustard

Source : Singh (1995)

Table 8. Alternate land use system options for different agro-climatic conditions

Rainfall (mm)	Soil type	Land use system
<500	Shallow (<30 cm)	Tree farming
	Medium (30-45 cm)	Pasture management
500-750	Shallow (< 30 cm)	Silvi-pastoral system
	Medium (30-45 cm)	Horti-pastoral system
>750	Shallow (<30 cm)	Ley farming or silvi- pastoral system
		Ley farming or horti-pastoral system
	Medium (30-45 cm)	Agri-silvi or Agri-horti system
	Deep (> 45 cm)	

Source : Yadav and Singh (2000)

Table 9. Potential cropping systems in relation to duration and quantity of rainfall in arid Rajasthan.

Rainfall range (mm)	Growing season (weeks)	Cropping system
<150	<6	Only tree and shrubs
150-250	6-8	Grasses
250-300	8-10	Short duration pulses
300-400	10-12	Pearl millet and short duration pulses

Source : Yadav and Singh (2000)

The choice of post-rainy season crops is related to thermal regime during winter season in the northern parts of the country, whereas it is still the moisture regime which plays a major role in the southern peninsular parts, which receive seasonal rains during north-east monsoon. The cultivation of wheat, chickpea and field pea has been advocated with conserved moisture above 300 mm in the soil profile, while with soil moisture ranging from 120-150 mm barley, chickpea and mustard are the obvious choice. At the moisture range of 50 to 75 mm, *taramira* (*Eruca sativa*) is the only choice. In an agro-ecological zone, where length of growing season is longer than for a single crop but not long enough for sequential cropping, intercropping is the best choice. Based on the soil depth of vertisols, 100-150 mm available moisture is suitable for mono-cropping (sorghum, maize), 150-200 mm for intercropping and more than 200 mm for double cropping (maize-sunflower, soybean-chickpea, sorghum-chickpea).

5.6 Soil fertility management and fertilizers use

Indian dry lands are not only thirsty but also hungry. Small and poor farmers of dry land areas can not afford external inputs like fertilizers, improved seed and pesticides. The fertilizer consumption is approximately 15-18 kg/ha under dry farming conditions as against the average consumption of more than 100kg NPK/ha. Dry land soils are mostly deficient in nitrogen, often deficient in phosphorus and medium in potassium. A great scope for increasing the productivity exists under dry land conditions through efficient nutrient management practices. Crops in dry land areas suffer not only from moisture stress but also from nutrient stress. Addition of fertilizer is meaningless, unless sufficient water is available to support a response. Similarly, increasing plant available water is futile unless the soil fertility problems are attended with a view to ensure adequate fertility. Fertilizer use efficiency under low soil moisture condition decreases with application of higher dose of fertilizer. On the contrary, fertilizer use efficiency under high soil moisture condition increases with addition of fertilizers.

In arid and semi-arid agriculture, the basic problem in plant nutrition is that of adjusting fertilizer application to the moisture regime under which the plants are expected to grow. Even under condition of limited moisture, nutrients deficiency will reduce WUE, therefore a moderate amount of suitable fertilizers, adjusted to soil moisture level, may increase WUE. If, however, the fertilizers application increases water use excessively in the early stages of growth, severe water stress occurs at the critical stages resulting in adverse affect on yield. Basically, the problem is one of nutrient-soil moisture interactions. Under conditions of sparse rainfall, there is a need to limit fertilizer application rates, which will not promote more growth than the available soil moisture can sustain until harvest or in other words, to prevent upsetting the very delicate and critical balance between vegetative and reproductive growth under condition of limited moisture.

Fertilizer recommendations in dry land crop production emphasize on conjunctive use of chemical, organic, legume based cropping system and bio-fertilizers. Inclusion of legumes in the cropping systems can supplement fertilizer N to the extent of 20 to 40 kg N/ha. In order to reverse the adverse effects of fertilizer nutrients under moisture stress, it has been recommended to substitute 50 per cent requirement of the fertilizer nutrients with organic sources. The method and time of application of fertilizer dose is another important recommendation to optimize the use of nutrients and available water. As the quantum and distribution of rainfall are highly unpredictable, fertilizer dose and timing have to match with rainfall events. Two to three splits have been recommended depending on the crop duration and rainfall pattern. Basal dose of nutrient should be placed below the seed at appropriate distance for their efficient use.

Important recommendations to improve the fertilizer use efficiency in rained dry farming are:-

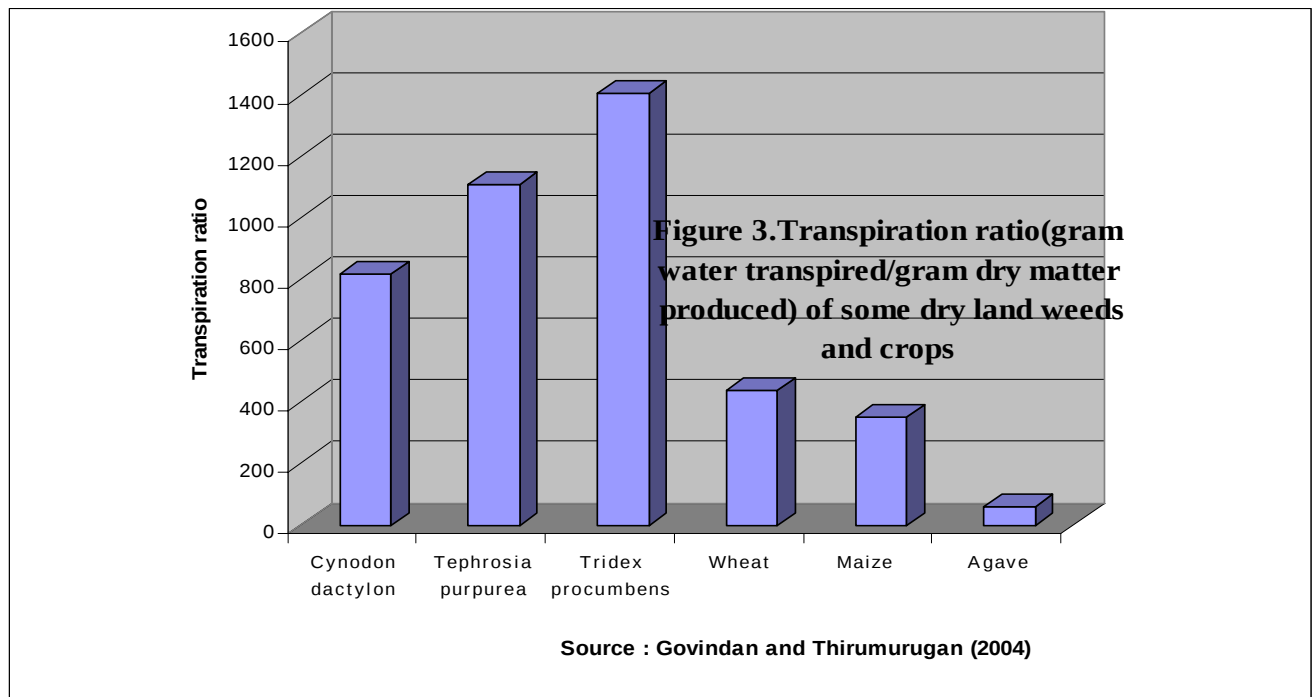
- i) Scheduling the fertilizer application based on soil test;
- ii) Selecting the type of fertilizer based on soil reaction;
- iii) Placing the fertilizer at 3 to 4 cm by the side or below the seed zone;
- iv) Adjust N dose depending upon moisture availability;
- v) Spraying of fertilizer nutrients on need basis;
- vi) Adding organic manure/green manure at least once in three years;
- vii) Including leguminous crops either in rotation or as an intercrop;
- viii) Application of bio-fertilizers like *Rhizobium*, *Azospirillum*, *Azotobactor*, PSB and VAM as a component of integrated nutrient management;
- ix) Integrated nutrient management and
- x) Water and moisture conservation to enhance soil moisture availability.

5.7 Weed control

Weed is a plant, which grows out of place. Weeds are unwanted, useless, prolific, competitive and often harmful to the environment. They interfere with agricultural operations, compete with crop plants for water, nutrients, space and light and thus reduce their production potential. The effects of weed competition are mainly felt in the young crop. Rapid rate of growth of both aerial parts and roots of many weeds give them a considerable advantage of depressing the crop plants among which they are growing. Most of weeds have luxuriant growth in term of leaf area, so they have relatively more demand for soil moisture as well as on the amount of radiant energy intercepted by the weeds. Leaf area of single plant of *Sinapis arvensis* at blooming stage was found to be 7300 sq cm compared to 140 sq cm of a single wheat plant.

Weeds can cause yield reduction up to 90 per cent in many crops. The reduction in yield is mainly due to the weed competition with crop plants for nutrients, moisture, space and sunlight. Critical period of crop weed competition is the period from the time of sowing to the time to which the crop is to be maintained in the weed free environment to get the highest yield. Critical period vary with the crop, variety and growing condition. For efficient use of resources and higher production, crop should be kept free from weeds during the critical period for crop weed competition. Critical weed free periods of 30 days for short duration crops and 45-60 days for long duration crops are observed for higher yield.

Since time immemorial, controlling weeds has been known to be one of the most effective means of increasing the amount of water and nutrients available to the crops and therefore, of increasing water and nutrient use efficiency. Weeds frequently transpire greater amounts of water per unit of dry matter produced than do the crop plants with which they grow in association (**Figure 3**). Weeds can remove more quantity of soil moisture and they can survive better than crops under drought conditions. Weeds growing under dry land conditions have some special adaptation like thicker and fleshy leaves with waxy coating, mucilaginous nature of stem and spines, which make them to withstand better than crop plant under drought.



Weed management practices under dry land include weed prevention and control measures:-

5.7.1 Weed prevention: It includes prevention of weed seeds spread, growing crops and varieties which grow faster than weeds (cowpea, mungbean), checking weed seed production, adjusting plant population to suppress weed, using weed seed free crop seed, using well decomposed farm yard manure and compost etc.

5.7.2 Weed control measures:

- i) Cultural control envisages inter/mixed cropping, mulching, selection of suitable variety/crop, proper crop rotation, adjusting time of sowing etc.
- ii) Physical methods include hand weeding, tillage, hoeing and other inter-culture operations
- iii) Chemical weed control measures include application of selective and non-selective herbicide for the control of weeds on cropped and non-cropped land. Crop specific herbicides are available for effective and economical weed control under dry farming *e.g.* Fluchloralin and Alachlor for pulses and most of oilseed crops. Atrazine for maize, sorghum and pearl millet, 2, 4-D Na salt and isoproturon for wheat and number of other crop specific herbicides are available, which kill the weeds on the cropped land.
- iv) Biological control includes the use of insects, animals and pathogens to control or limit weed infestation.

5.8 Contingency crop planning for aberrant weather

Dry lands are characterized by uncertainty of rainfall in quantity, arrival and distribution. Under situation of undesirable behaviour of monsoon and weather aberration, the crop growth and yield will be affected. Certain specific practices are adopted to encounter aberrant weather conditions for producing some food, feed and fodder and to make use of favourable

weather conditions to increase productivity. These practices are collectively termed as contingency crop planning or alternate crop production and mid-season correction.

Crop production in the rainfed area is affected by the aberrant weather in following ways. Delayed onset of monsoon, short or long dry spell during the growing season either in mid-season or late season, withdrawal of rain before the crop completes its lifecycles and water logging and floods due to heavy rains. For developing a contingency plan to an area a detailed study of the rainfall data and analysis for a longer period will be necessary, as this information would help in understanding the general pattern of rainfall in a particular area and also the crops and varieties suitable for cultivation.

To meet the possible weather aberration, a few alternate crop production strategies are recommended:-

- i)** Dry seeding of crop like cotton, sorghum, maize, pearl millet and pigeonpea, in case monsoon set is delayed but expected within week or ten days.
- ii)** Raise nursery of rice, millets *etc.* for transplanting after onset of monsoon.
- iii)** Closer spacing under delayed sowing.
- iv)** Intercropping to cope up with the weather aberration during crop season.
- v)** Selecting short duration crops (pulses and oilseeds) and varieties in the event of delayed monsoon, e.g. Sesame in place of transplanted rice. In minor millet, *Setaria* is most suited for late sown condition.

Mid-season corrections are carried out at any stage of the crop. Some of the mid-season correction measures are given below:-

- i)** Re-sowing of the same crop and variety, short duration variety or some other crop with subsequent rains, if crop failure occurs within 7-10 days after sowing.
- ii)** Thinning of crop within the row or removing alternate rows or one row after every third rows, in case of occurrence of drought at 40 to 50 days of sowing. This is done in case of maize, pearl millet, sorghum, pulses oilseeds *etc.* Plants removed are used as fodder.
- iii)** Removing basal three to four leaves of the crop at the later stages, in case of early stoppage of rain or terminal drought.
- iv)** Mulching of soil surface with agricultural waste and/or weeding in case of a brief-break in the monsoon.
- v)** Soil mulching to conserve soil moisture.
- vi)** Water harvesting and its recycling for supplemental irrigation to save the crop.
- vii)** Harvesting at physiological maturity stage, if there is moisture stress at very late stage.
- viii)** Application of 20-25 kg N/ha on release of drought with subsequent rains to take advantage of favourable soil moisture.
- ix)** Spraying 2 to 3 per cent urea and recommended concentration of other plant nutrients to take advantage of favourable conditions.
- x)** Ratooning of drought affected crops (sorghum, pearl millet) with subsequent rains, if possible.

6. Rainfed Hill Agriculture

The hilly and mountainous areas in India are vastly distributed all over the country with a large area located in the Himalayas. The development of hilly and mountainous areas and protection of hill ecology have become a matter of nation concern, as these areas are recognized climate makers and repository of rich biodiversity. The hilly and mountainous areas differ from the plains in topography, elevation, physio-graphic and socio-economic conditions. Hills in general, offer a vast scope for cultivation of diverse mix of crops. Animal husbandry is the integral part of farming systems. Temperate climatic conditions support some fruits and vegetable crops, which otherwise cannot be cultivated in plains. Traditional agriculture in hilly areas combines crop production with livestock, horticulture and farm forestry or agro-forestry in an integrated fashion. Inaccessibility, fragility, marginality heterogeneity, natural instability and human adaptation mechanism are six mountains specific problems, which have been identified to be key factors to be addressed for sustainable agricultural development in hills. Crop production, livestock, horticulture and agro-forestry are recognized four major components of hill-agro-systems.

Basic problem of hilly and mountainous areas is soil erosion, which is responsible for land degradation, silting of water reservoirs in plains and loss of biodiversity. Various location specific soil and moisture conservation measures and technologies, which are the part of recommendation, should be adopted (For detail see relevant section in this Chapter). Low cost technologies such as agro-forestry, agro-horticulture, silvi-pastoral, alley cropping and grass barriers are very effective for soil and water conservation in hilly areas. Regenerative technologies for soil and water conservation should be adopted as alternative to terracing.

Denudation of forest vegetation covering vast tract in the hills of NEH region has attained an alarming magnitude. It is causing recurring floods in the valleys. Adoption of alternate land use systems with perennial horticultural crops and livestock as major components could make hill farming in the NEH region sustainable and profitable. In spite of the fact that most mountains regions are located in regions with high rainfall, at times these are the areas, which suffer most from the water shortage. The problem of water management in the hilly areas is further aggravated with small and scattered land holdings. The extent of irrigated areas is small and on an average about 80 per cent of cultivated area is rainfed. Harvesting of run-off at micro-level for storage and recycling is necessary and possible due to suitable land topography for water harvesting. Water harvesting on large scale ensures better utilization of rain water, control of erosion and providing some essential and life saving irrigation to the crop during the dry spells or to grow a second crop during the *rabi* season.

7. Watershed Management

The Government of India in its Seventh Five Year Plan had launched a national development programme of rainfed agriculture on watershed basis. The work initiated in 47 model watersheds under the technical guidance of Indian Council of Agricultural Research. Watershed is a geo-hydrological unit draining at a common point by a system of streams. The watershed represents a hydrological unit of area, but can also be described as bio-physical, socio-economic and sometimes a political unit for planning and management of natural resources. A good watershed management, therefore must consider the social, economic and environmental sustainability and institutional factors operating in and outside the watershed area. The basic concept of watershed is to conserve all the basic natural resources and plan for their optimal utilization. The major concern of watershed approach in dry lands is conservation of soil and water. The approach and strategy of watershed management are mainly based on the concepts of integrated water management and sustainable farming systems. Development of dry land agriculture on watershed basis has been the national

strategy for the sustained productivity and rational utilization of natural resources. It relates to soil and water conservation measures in watershed which includes proper land use, land protection from degradation, management of surface and ground water, flood protection and increasing land productivity.

7.1 Principles of watershed management:-The main principles of watershed management based on resource conservation, resource generation and resource utilization, are

- i) Utilizing the land according to its capability;
- ii) Protecting productive top soil;
- iii) Reducing siltation hazards in storage tanks and reservoirs;
- iv) Maintaining adequate vegetation cover on soil surface through out the year;
- v) *In-situ* conservation of rain water;
- vi) Safe diversion of excess water to storage points through vegetative waterways;
- vii) Stabilization of gullies by providing checks at specified intervals and thereby increasing ground water recharge;
- viii) Increasing cropping intensity and land equivalent ratio through intercropping and double cropping;
- ix) Safe utilization of marginal land through alternate land use systems with agriculture-horticulture-forestry-pasture systems with varied option and combinations;
- x) Water harvesting for supplemental and off-season irrigation;
- xi) Maximizing agricultural productivity per unit area per unit time and per unit of water;
- xii) Ensuring sustainability of the eco-system befitting the man-animal-plant-water complex;
- xiii) Maximizing the combined income from inter related and dynamic crop-livestock-tree-labour complex over years;
- xiv) Stabilizing total income and to cut down risk during aberrant weather situations;
- xv) Improving infra-structural facilities;
- xvi) Setting up of small scale industries and
- xvii) Improving the socio-economic status of the farmers

7.2 Basic objectives of a watershed management

1. Promote the economic development of village community, which is directly or indirectly dependent on watershed through
 - a. Optimum utilization of natural resources for mitigating drought and ecological degradation.
 - b. Generation of employment opportunities and development in villages.
2. Encourage the restoration of ecological balance through
 - a. Sustained community action and development of natural resources
 - b. Affordable technical solutions and use of technical knowledge and available materials.

3. Improve the socio-economic conditions of the resource poor farmers through
 - a. Equitable distribution of benefits from natural resources
 - b. Income generation activities.

7.3 Components of watershed treatment plan

Agronomical measures in agricultural lands (mixed-farming, strip cropping, mixed-cropping, run-off farming, contour farming, residue management, land management practices etc.)

- i) Mechanical measure in agricultural lands (contour and graded bunds, bench terracing, contour cultivation etc.)
- ii) Erosion control measures on non-agricultural lands (contour trenches, gully control measures, *nalla* bunds etc.)
- iii) Water conservation and harvesting structures (Farm ponds, earthen embankments etc.)
- iv) Ground water recharge and management (Percolation tanks, dykes etc.)
- v) Nursery raising and community plantation of fuel, fodder, fruits and small timber species.
- vi) Grassland development.
- vii) Horticultural development.
- viii) Agro-forestry.
- ix) Protection, conservation and enrichment of degraded forest in watershed through Joint Forest Management.

7.4 Benefits of watershed management

The watershed approach benefits the farmers through improved soil health, better drainage and more efficient use of rain water with the possibility of excess water being stored in suitable structures for use during scarcity periods. With voluntary farmer's participation, sustainable improvement in crops and animals production is possible. The society benefits from floods to downstream farmlands and human habitation, reduced siltation of expensive irrigation structures and protection of natural resources.

7.5 Watershed development experiences

Under Indian conditions, several watershed development programmes have been or being implemented in different parts of the country. The overall impact of 31 watershed development programmes reviewed in 2003 in the NATP programme. As a results of development activities taken in different watershed projects based on the principles and practices of watershed management, on an average cropped area increased from 12 to 53 % , water level in the dug wells increased from 1.0 to 7.0 metres and cropping intensity increased from 115 to 157 %. The consumption of fertilizer nutrients in most of the areas has gone up substantially. Crop yield increases in watershed ranges from 51% for mustard to 91 % in pearl millet and to maximum to 206 % in sorghum. There has been enhanced employment generation by 13 to 100% depending upon the stage of development. The increase in per capita income is 16 to 649 % as results of development activities. In the watershed areas, percentage of irrigated area increased from 38.2 in non-watershed areas to 52.4 in watershed areas. All socio-economic indicators showed marked improvement in watersheds over non-watershed areas. Among the farmers, large and medium farmers were more benefited in the programme, because the programme was land based. In crop production, cereal production was more with small farmers. In the watershed

areas, there was also marked increase in milk production compared to non-watershed areas. There was also increase in ground water level. There was also saving of time to the tune of 18%, in fetching water and fuel for household purposes in watershed areas.

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