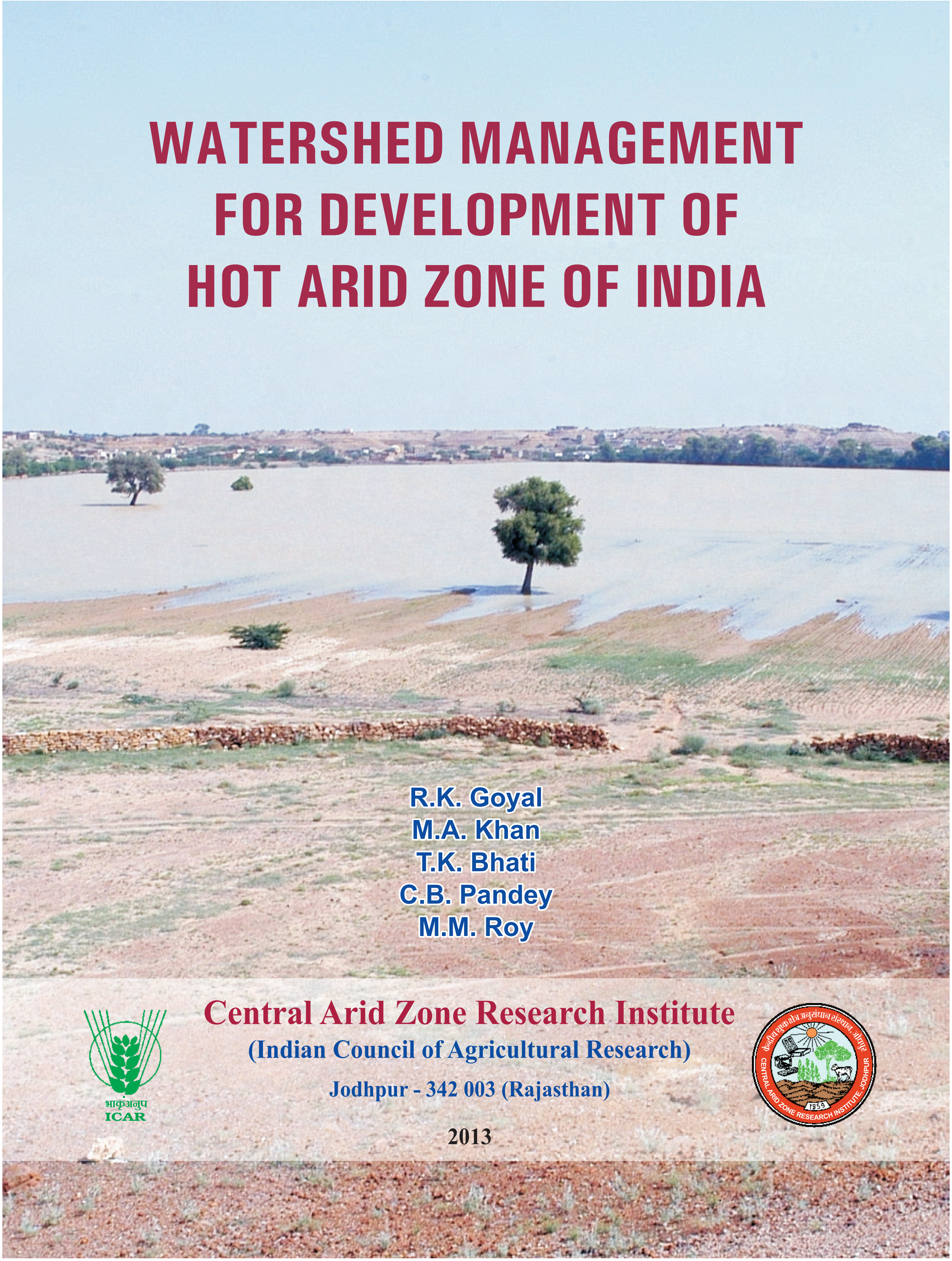

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Central Arid Zone Research Institute
(Indian Council of Agricultural Research)
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Foreword

Ecosystems in the arid environment are fragile in nature owing to periodic droughts and over-exploitation of natural resources. Arid environments are also diverse in terms of land forms, soils, fauna, flora, and water, which calls for location specific technologies for management of natural resources. Indeed, the Indian hot arid zone, spread over 31.7 Mha, is capable of supporting a very high population of livestock and human, provided the natural resources like soil and water are managed properly. As a basic unit of land and water management, watershed offers immense scope to improve soil and water productivity. The concept of integrated watershed development and management has emerged as a foundation for rural development in the rainfed and arid regions of the world, and it marks a paradigm shift from earlier plot-based approaches. Watershed impact assessment studies have shown that location specificity is an extremely important aspect for the success of any watershed project.

Watershed technologies like rainwater harvesting through *tanka* and *khadins* are unique to the hot arid areas of western Rajasthan. Windbreak/shelterbelt is a specific measure to control wind erosion in sandy areas. Alternate land use systems like agroforestry, horticulture, fuel wood plantation, medicinal plant plays an important role in sustaining production in this region. In view of frequent droughts especially the mid season droughts, selection of appropriate crops and contingency planning are key to survival in this zone. All these aspects are well covered in this bulletin. Furthermore, conservation measures specific to the hot arid areas for arable and non-arable lands are presented in detail, beside, production technologies for arable and non-arable lands.

Many of the methods and techniques described in this bulletin have potential for wider use in other areas with similar problems. This bulletin is intended as a reference material to guide to those involved in the development of arid areas on watershed basis.

(Alok K SIKKA)

September, 2013

CONTENTS

Foreword	
Introduction	1
Arid zone climate	1
Water resources	3
Challenges for arid lands	4
Watershed definition	5
Watershed approach	6
Watershed planning	6
Indicators of erosion in watershed area	7
Components of watershed management for arid areas	9
Conservation measures for arable lands	11
Conservation measures for non –arable lands	16
Gully control measures	18
Rainwater harvesting for arid lands	21
Agronomic practices	27
Production practices for arable and non-arable lands	29
Alternate land use systems	31
Contingency planning	39
Recommended farm implements	40
Conclusions	41
References	41

INTRODUCTION

Soil and water are two essential natural resources for sustaining life and environment. Since advent of human race on the earth these resources are being used for various purposes. The prosperity of mankind on the earth depends to a great extent on these resources and their management. In nature, soil and water resources are often in a fine balance. However, with unprecedented increase in human and livestock population in the arid region of the country demand for food and fodder have increased tremendously. The imbalances in natural resources have resulted in reduction in productivity of land.

Arid ecosystems are among the world's most fragile ecosystems made more so by periodic droughts and increasing over-exploitation of meager resources. Arid environments are extremely diverse in terms of their land forms, soils, fauna, flora, water balances, and human activities. Because of this diversity, no practical definition of arid environments can be derived. However, the one binding element to all arid regions is aridity. Aridity is usually expressed as ratio of mean annual precipitation (P) to the mean annual potential evapotranspiration (EPT). UNEP (1997) has recognized four main classes of aridity: hyper-arid ($P/EPT < 0.03$), arid ($0.03 < P/EPT < 0.20$), semi-arid ($0.20 < P/EPT < 0.50$), and dry subhumid ($0.50 < P/EPT < 0.65$). The term "arid zone" is used here to collectively represent the hyper-arid, arid, semi-arid, and sub-humid zones. Of the total land area of the world, the hyper-arid zone covers 4.2 per cent, the arid zone 14.6 per cent, and the semi-arid zone 12.2 per cent (FAO, 1989). Therefore, almost one-third of the total area of the world is arid land and is inhabited by about one billion people, a large proportion of whom are among the poorest in the world (*Malagnoux et al., 2007)*.

ARID ZONE CLIMATE

The arid region of India is spread in 38.7 million hectare (Mha) area out of which 31.7 Mha is under hot arid zone and 7 Mha under cold arid zone (Fig.1). The hot arid region occupies major part of north-western India (28.57 Mha) between 22°30' and 32°05' N latitudes and from 68°05' to 75°45' E longitudes, covering western part of Rajasthan (19.6 Mha, 69%), north-western Gujarat (6.22 Mha, 21%) and 2.75 Mha in south-western part of Haryana and Punjab (Faroda *et al.,* 1999). The climate of Indian hot arid zone is characterized by an abundance of solar energy from cloud-less sky, high diurnal and seasonal temperature variations and annual and inter-annual irregular rainfall with long dry seasons associated with strong winds. The incoming radiation ranges from 15.12 to 26.50 MJ m^{-2} day^{-1} with very little cloud for most of the year. Annual rainfall is approximately in the range 100-500 mm, with a coefficient of variation varying from 40 to 80 per cent (Rao and Singh, 1998). The rainfall results largely from convective cloud mechanisms and is characterized by a relatively high intensity, short duration and limited aerial extent. The distribution of rainfall in space is very much influenced by the local terrain. With low ground level and little topographic relief, it is common to see rain evaporating before reaching the ground. The rainy season varies from 50 days in the western part to 80 days in the eastern part of arid Rajasthan. A small quantum of rainfall of about 7-10 per cent of the annual is received during the winter season under the influence of western disturbances.

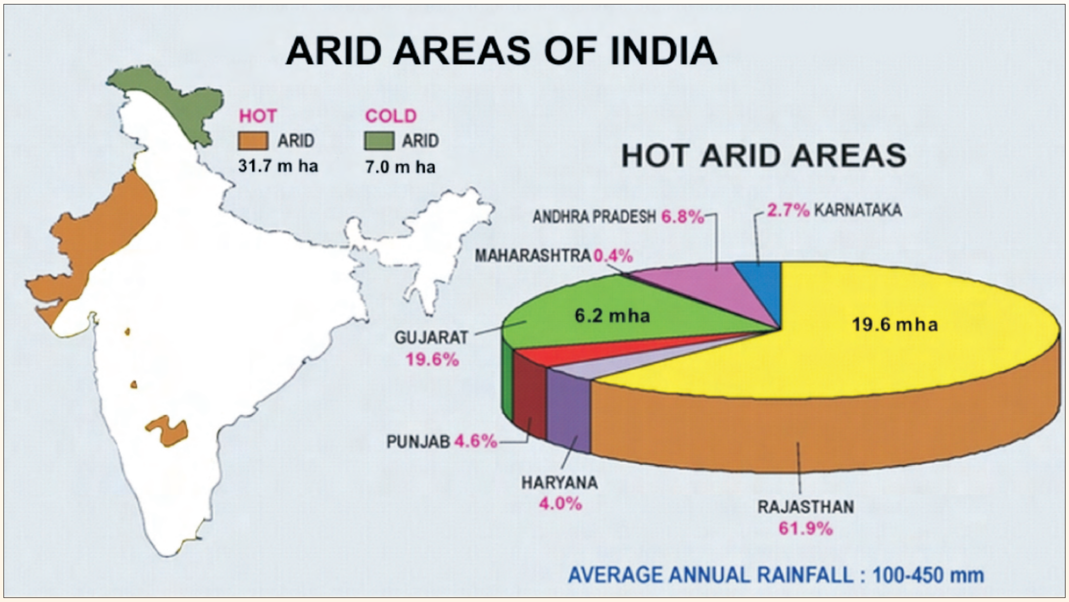

Fig-1. Distribution of arid areas of India

Rainfall distribution models of Jodhpur indicate that out of 97 years (1901-97), 52 years at Jodhpur recorded average to above average (350 to more than 400 mm) rainfall which indicates that one in two years, Jodhpur region receives substantial rainfall. About 19 years recorded a rainfall of 250-350 mm. Appropriate crop production technologies can stabilize yield levels in such years. The rest 26 years received less than 250 mm implying specific technology to overcome deficit rainfall situations. The studies on water harvesting potentials of Jodhpur and Nagaur revealed that eastern part of the two districts have better potential to practice water harvesting for successful crop production (Sastri *et al*., 1980). In these regions, the average surplus water obtained from water balance studies varied from 50 to 100 mm in Jodhpur district and above 100 mm in Nagaur district.

WATER RESOURCES

The water resources of the arid region are scarce and because of low and erratic rainfall, replenishment is also very poor. The quantity and quality of water available from various sources such as surface water and ground water is not adequate even for drinking purposes. Apart from insufficient quantity, the ground water is moderate to highly saline over large area. A dominantly sandy terrain, the disorganized drainage network (drainage density is as low as 0.3 km^{-1}) and high annual potential evapotranspiration (1400-2000 mm $year^{-1}$) leads to a permanent negative water balance (Rao, 2009). Recurring droughts and consequent crop failures are regular events in this zone. Yet the demand for water is increasing steadily, as human and livestock population is increasing and newer industries are being setup. Table-1 presents the estimated water demand for the arid Rajasthan.

Table-1. Estimated present water demand of arid Rajasthan (mcm)#

Demand	Year				
	1981	1991	1995	2001	2011
Human consumption @ 40 lpd*	196.85	236.00	261.82	289.00	349.02
Livestock consumption @ 30 lpd	249.00	290.00	308.00	332.00	376.00
Irrigation @ 0.30 m ha^{-1}	5178.00	5696.00	5900.00	6265.00	6892.00
Industry	16.00	17.00	17.50	18.00	21.00

*Lpd: litres per day # mcm: million cubic meter
(Source: Water: 2000 AD, The Scenario for Arid Rajasthan, CAZRI monograph, 1990)

Since the water is limited, such trend is forcing people to use even 'marginal' quality water in some areas. This again triggers off a chain of degradation processes and also affects human and animal health.

The people in the arid areas by and large, reside in scattered settlements (*dhani's*) where sand dune and interdunal plains and undulating plains are the dominant landforms. Under such conditions it is inconceivable that organized water supply will be feasible proposition to fully meet the demand of thirsty land, human and livestock. Experience has shown that effort to bring water by artificial means such as canal etc. are very expensive and they are associated with some other problems like water logging by way of seepage from canal and excessive irrigation, misuse of water, high maintenance cost etc. Over and above, it is not possible by any artificial means to provide water in every corner of arid zone. Under such circumstance the only feasible solution is to make best use of resources available locally.

The soils in arid regions are characterized by large variations in soil moisture, ground-water storage and high infiltration rates. A dominant feature of these soils is their susceptibility to erosion and degradation by wind, water and human activities. There are frequent dust and sand storms. The surface water resources are meager and directly dependant on rainfall and dry up during the rainless season. Groundwater is deep and often brackish. During the twentieth century, the region has experienced agricultural drought once in three years to every alternate year in one or the other part of the region. The overall probability of drought is 47 per cent. The weather condition, even in average years, for most part of the year remains too dry and inhospitable for successful growth of crops. Under such conditions of uncertainty, conventional cropping is risky and is essentially for sustenance only (Goyal and Vittal, 2008).

CHALLENGES FOR ARID LANDS

Desertification is the single and perhaps the most important hazard that is threatening the low rainfall areas of the world today. Vast areas of low rainfall zone are being inundated and lain waste by advancing deserts. Furthermore, many marginal lands of the arid world that otherwise could become productive to serve the needs of the people are now essentially wastelands as the result of exploitative human activities. The UNCCD defines desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The most commonly cited forms of unsustainable land use are over-cultivation, overgrazing, deforestation, and ill-considered irrigation practices. Soils are being mined of nutrients at an alarming rate (Smaling, 1997; Van der Pol, 1992). Periodic droughts debilitate and destabilize poor societies, and contribute to land degradation by reducing vegetative cover and water supplies, triggering a desperate exploitation of the remaining resources in order to survive. The major physical manifestation of desertification in hot arid zone of India is wind erosion/deposition, followed by water erosion, as well as water logging and salinity (Ghose *et al.,* 1977). Wind erosion is a major problem in arid sandy tract of north-western India, especially in west Rajasthan (Fig-2). About 76 per cent area of western Rajasthan is affected by wind erosion, encompassing all major land uses, followed by vegetation degradation (3%), water erosion (2%), salinization (2%) and about 0.10 per cent area by mined spoiled degradation (Kar *et al.,* 2009). Despite the present state of land degradation, Indian hot arid region supports 22 million human and 29 million livestock population over 19.6 mha geographical area. The human: animal ratio ranges from 1:1.3 to 1:5 in hyper arid regions against a national average of 1: 0.5

(Narain and Goyal, 2009). Acute human and biotic pressure has put tremendous pressure on the fragile water and land resources of this region. Desertification, manifested in different forms of degradation has been a challenging issue to the arid zone of India. The adoption of dryland conservation technologies can significantly increase productivity and profitability in these areas (Halvin and Schlegel, 1997).

Fig-2. Wind erosion is a severe problem in western Rajasthan

The Central Arid Zone Research Institute, Jodhpur was established in 1959 to combat desertification and evolve sustainable land management technologies. Over five decades of research the Institute has evolved watershed management technologies of soil and water conservation for the management and sustainable development of the arid lands.

WATERSHED DEFINITION

The term 'watershed' implies to an area which has well defined hydrological as well as geographical boundaries from where the entire runoff drains towards a single outlet. A watershed captures precipitation, filters and stores water and determines its release. A watershed also includes groundwater aquifers that discharge to and receive discharge from other streams. Watershed management is defined as “Rational utilization of land and water resources for optimum and sustained production with minimum hazard to natural resources. It essentially relates to soil and water conservation in the watershed which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of water for drainage, flood protection, sediment reduction and increasing productivity from all land uses." Watershed management programs can be developed to provide monetary benefits as well as positive environmental/ecological and social/cultural impacts. Upland development, if carried out using sound watershed management principles, can offer an array of economic benefits to both upland watershed inhabitants and down-stream communities.

Watershed Characteristics

- Watersheds divide the landscape into hydrological defined geographic areas
- Watersheds integrate all environmental functions
- Physical, chemical, biological, human use, and management determine water quality and water flow
- Each watershed has a unique combination of inherent conditions, use, and management, thus response to water quality and flow is variable and complex

WATERSHED APPROACH

Till recently, conservation programs used to be carried out on individual holdings on the basis of the particular problem of the land. In this patchwork approach often the upper reaches of the fields were left untreated and runoff from uplands used to damage the conservation work laid out in the individual holdings at downlands. To overcome such situations it is essential to treat the whole area as single hydrological unit known as watershed. Only in a watershed can all resources be controlled from highest ridge to the lowest land, without outside forces preventing the essential maintenance or re-establishment of the ecological balance. Though no two watersheds are identical, their characteristics have common parameters, which can be judiciously used for obtaining the required results. The watershed approach helps in integrated development of different parts of the watershed in accordance with their nature, problems and potential with the best amount of interference. The planning commission while emphasizing the role of local level planning in VIII Five Year Plan, highlighted the role of drought prone and dryland areas in augmenting the food production level of the country by way of adopting the watershed approach.

WATERSHED PLANNING

The following requirement must be met for planning watershed

(i) Reconnaissance survey of the watershed area for delineating nature of soil-water conservation and its related problems, their probable remedial measure and requirements for its overall development. It should be followed by preliminary and detailed survey for basic resources. Land area map should be prepared on suitable scales for carrying out these surveys.

(ii) Preparation of soil map and classification of land for uses according to capability for agriculture, horticulture, forestry, pasture development, rearing of cattle/sheep, etc.

(iii) Preparation of inventory of existing land uses, farm sizes and fragmentation.

(iv) Appraisal of agricultural production pattern and potentials.

(v) Topographic features and hydrology of the watershed area.

(vi) Geophysical and geo-hydrological surveys to delineate areas suitable for ground water development.

(vii) Information on rainfall intensity, amount and pattern, on weekly and daily basis.

(viii) Formulation of an integrated time based plan.

(ix) Fixation of priorities for the implementation of the program.

(x) Assessment of benefit cost ratio.

(xi) Social and political forces and their involvement in the watershed development program.

INDICATORS OF EROSION IN WATERSHED AREA

It is extremely important to recognize watersheds damaged by active erosion so that timely steps can be taken to adjust land use and to initiate corrective vegetative and engineering measures. Detailed and precise methodologies including long term surveys i.e. reservoir sedimentation, plot studies, sediment runoff monitoring etc. are available to assess the severity of erosion. However, when such an information is not available it is necessary to rely upon observations and signs of erosion. Following are the some of the quick indicators of erosion which are best observed during or shortly after storm.

(i) Rills are small channels formed by water, especially near upper slope, roadside, or in furrowed fields. When enlarged by the concentration of excess runoff, the rills become gullies.

(ii) Muddy water and mud flows during and shortly after storm may indicate that, there is a considerable amount of movement of soil from the slope.

(iii) Gullies of all kind, small or large, normally show an erosion problem.

(iv) Erosion pedestals are soil column left beneath stones, where erosion has removed the surrounding soil. These columns may be a fraction of a centimeter or several centimeters high.

(v) Erosion pavements are gravel and stones left on the soil surface after the fine soil particles have been washed away. They can be observed in many ploughed fields and rangelands.

(vi) Mounds of residual soil with perched clumps of grass often are signs of erosion.

(vii) Soil accumulation above trees, stones, fences and hedges indicates erosion particularly on sloping lands.

(viii) Exposed roots of trees and shrubs also are a result of soil washing or blowing away.

(ix) Deposits of soils on gentle slopes, sometimes difficult to observe, are evidence of erosion.

(x) Exposed parent material is usually a sign of severe erosion.

(xi) Bare spots in grassland and pasture may indicate a downward trend of range condition, most probably the result of overgrazing. Erosion may occur or likely to occur.

(xii) Uneven top soil on sloping and rolling fields may easily detected from a distance by observing light and dark colored patches of soils

(xiii) Deposits of gravel, sand and silt in stream channels may indicate erosion upstream.

(xiv) Trampling displacement is the result of soil being moved down-slope by grazing animals walking along cow paths on the contour.

(xv) Vegetation species changed as a result of overgrazing often are accompanied by erosion.

Technological Issues

What are the available technological options and research needs in various development sectors considering the requirements of watershed projects?

What should be the mechanism of integrating the traditional and modern technologies for making them more easily adaptable?

How to quicken the process of technology generation?

Peoples Participation

Before starting the actual planning and management, it is essential to fix targets to be achieved through consultations with experts, policy makers and representatives of farming community. These initial consultations are of utmost importance especially those with representatives of farming community who should be partners in the decision making process. If the individual and communities have to co-operate for the sake of common good and they are not active and willing partners in the decision making process, then development schemes are from very start at a disadvantage and doomed to fail. Techniques like Participatory Rural Appraisal (PRA) is very useful in learning very quickly from the farming community about the important problems and opportunity in a given area in an informal way. Hence, the understanding of agro-ecosystem, social organization and total involvement of the local people is very important for comprehensive area development plan.

COMPONENTS OF WATERSHED MANAGEMENT FOR ARID AREAS

Resource Conservation

Soil and water are the two basic resources, needed for crop production. Measures for soil and water conservation can be divided in two main categories i.e. physical/engineering and biological. Physical measures consist of construction of mechanical barriers across the direction of flow of water to retard/retain the runoff and thereby reduce soil and water losses. Contour bunds, contour cultivation, trenching, sub-surface barrier etc. are some of the physical measures which are found to be useful in arid areas. Biological measures like vegetative barrier, windbreak/shelter belt and stubble mulching are very effective for moisture conservation and controlling soil erosion due to wind and water.

Resource Utilization

Efficient utilization of available resources is of paramount importance for successful crop production. Improved agronomic practices i.e. inter cropping, improved crops and seed varieties, crop rotation, minimum tillage etc. plays vital role in ensuring risk distribution. For aberrant weather situation contingency planning like life saving irrigation, integrated insect-pest management, differential fertilizer application etc. are important tools to minimize loss of seed, crop and fertilizer (Fig-3). The land which is unfit for conventional farming as per land capability classification may be used for alternative landuses. Agro-forestry and agro-horticulture has started finding favor among farming community in recent years.

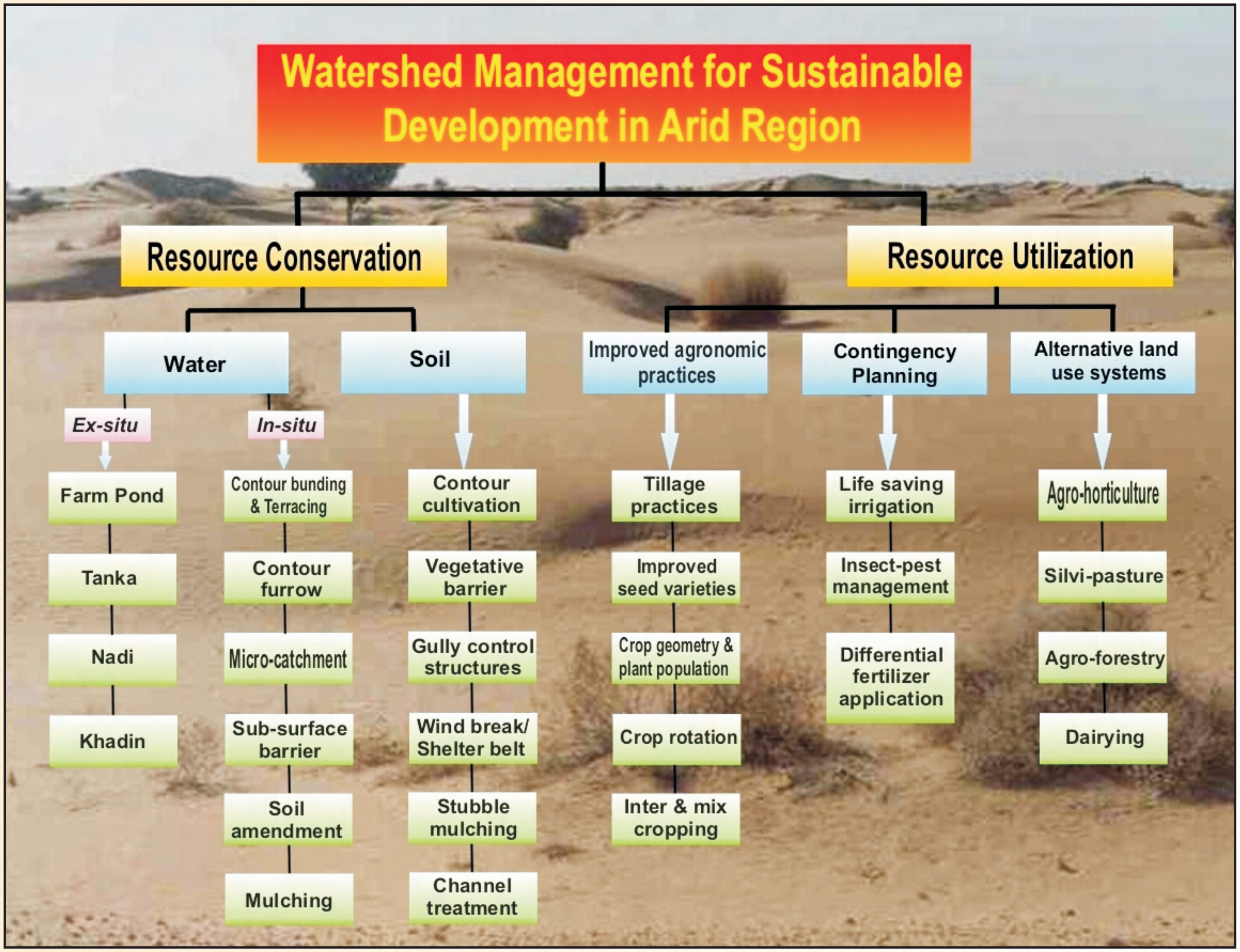

Fig- 3. Various components of watershed management in arid eco-system

CONSERVATION MEASURES FOR ARABLE LANDS

Contour Farming

Contour farming is beneficial on all slopes where line sowing is adopted (Fig-4). All ridges and rows of plants are placed across the slope to form continual series of miniature barriers to water and offer maximum opportunity for infiltration.

Fig-4. Contour farming for soil and water conservation

Contour operations reduce the power of the water to erode, suspend and carry away soil particles and increase the moisture storage. Increased uniform moisture storage can boost up the yield above 10 per cent. Contour farming alone cannot control runoff volume from higher sloppy lands which may need bunding and grass waterways in natural drainage. For small fields with uniform slopes, one contour guideline is enough and where slopes are irregular two to three guidelines may be enough for farming operation. Contour farming is most effective on moderate slopes of 2 to 7 per cent. Contour farming is reported to reduce soil loss upto 60 per cent in comparison to up and down farming on 1 per cent slope (Smith and Wischmeier, 1962).

Contour Bunding

Contour bunds are narrow base trapezoidal earthen embankment on contour, 1.5 to 2 m wide, constructed across the slope to act as barriers to runoff, to form water storage area on their upslope side and to break up a long slope into short segments. Contour bunds are recommended upto 6 per cent slope and rainfall of upto 600 mm. Contour bunds are not suitable for shallow soils having depth less than 7.5 cm. Spacing between contour bunds is usually expressed in terms of vertical interval (VI), which is the difference in elevation between two similar points on two consecutive bunds. The principle involved in fixing the spacing between two bunds is to keep the velocity of water below critical value in order to avoid scour. Vertical interval is generally expressed as a function of per cent slope(s)

$$VI \quad 0.305 \quad \frac{s}{a} \quad b$$

where, V I = vertical interval between consecutive bunds in m

S = land slope in per cent

'a' and 'b' are constant specific to particular region

For soils having good infiltration rates value of 'a' and 'b' are 3 and 2 respectively. For soils with low infiltration rate the value of 'a' and 'b' may be taken as 4 and 2, respectively. The horizontal interval (HI) is related to vertical interval (VI) by following equation

$$HI \quad \frac{VI}{s} x100$$

Depth of impounding in calculated on the basis of maximum rainfall of 24 hours for 10 years recurrence interval as follows

$$h \quad \sqrt{\frac{Re x VI}{50}}$$

where 'h' is height of impounding (m) 'Re' is 24 hours maximum rainfall (cm) for 10 years recurrence interval. Total height of bund H can be find out by adding 20-25 per cent freeboard to height of impoundment. For light red loam and sandy loam soils, the side slope of both the sides is taken as 1.5: 1 whereas for sandy soils it is taken as 2:1. The line of seepage should not cross the bottom of the bund while deciding the other dimension of the bund. On average, contour bunds had 27 per cent higher soil moisture and 14 to 181 per cent higher fodder yield than flat surfaces on grasslands of western Rajasthan (Wasi-Ullah *et al.,* 1972).

Contour Vegetative Barriers

Contour vegetative barriers are hedgerows of perennial grasses or shrubs planted at a regular interval on contours for conserving soil and water in sloping lands. Suitable grass species are grown along contours at suitable vertical interval to intercept part of runoff and to control erosion in agricultural fields having flat to slight undulating topography. The contour vegetative barrier moderates the velocity of overland flow and traps silt at low cost, and augment production of food, fuel and fodder or fibre from lands by growing suitable vegetation species. In recent years, contour vegetative barriers have found acceptability among the farmers as these are cheaper over mechanical measures and are protective while being productive. Contour vegetative barriers can be easily established across a wide spectrum of soil-climatic conditions. Selection of species depends upon purpose of barrier, site-specific conditions, particularly soil and climatic variables. The spacing between plant-to-plant and row-to-row is governed by vegetation species to be planted as barrier. In general the plant-to-plant spacing of 20 to 30 cm at predetermined or 50 to 100 cm vertical interval between the barriers has been found effective for soil and water conservation. Generally, paired row of barrier planted in staggered form across the slope proves more effective.

Generally, dominant grass or shrub species of the region should be preferred for vegetative barrier. Among grasses *Cenchrus ciliaris, Cenchrus setigerus, Saccharum bengalense, Vetiveria zizanioides, Lasiurus sindicus, Panicum antidotale and Panicum turgidum can* be effectively used for soil and water conservation in arid areas. Shrubs like *Leptadenia pyrotechnica, Ipomoea carnea and Euphorbia antisyphylitica* can also provide good protection against water and wind erosion. Contour vegetative barriers of *C. jwarancusa, C. ciliaris and C. setigerus* transplanted at 0.30 m apart on contours at 0.6 to 1.0 m vertical interval in sandy loam soil of Jodhpur (Rajasthan) have performed well and formed effective barriers in reducing soil erosion and increasing soil moisture storage. In a study conducted during 1992-1994 at 19 farmers' fields near Jodhpur, rooted slips of local eight species of perennial grasses (*C. ciliaris, C. setigerus, C. jwarancusa, L. sindicus, P. antidotale, P.turgidum, S. bengalense* and *V. zizanioides*) and seedling of six species of shrubs (*Agave americana, Aloe barbadensis, Barleria prionitis, E. antisyphylitica, I. carnea* and *L. pyrotechnica*) were transplanted at 1 m vertical interval on contours across the slope. Result indicated that perennial grass species performed the best and formed effective barrier against soil erosion. Runoff volume and specific peak discharge were reduced by 28 to 97 per cent and 22 to 96 per cent, respectively (Sharma *et al.,* 1999; Tiwari and Kurothe, 2006). In another study conducted at Kalyanpur (Barmer district) during 1998, vegetative barrier of *L. sindicus, Saccharum munja* and

Cassia angustifolia were established at horizontal interval of 30 m. The moisture data revealed 36.5, 72 and 54.2 per cent higher moisture storage as compared to control in *C. angustifolia*, *L. sindicus* and *S. munja* respectively (Gupta and Rathore, 2002).

Graded Bunds

Graded bunds are used to dispose off safely the excess water from the agricultural fields to avoid water stagnation. Graded bunds are suitable in areas where annual rainfall is 500 mm and if the soils are highly impermeable. Graded bunds usually have wide and shallow channels and earthen bund laid along a predetermined longitudinal slope. As graded bunds are essentially means for the safe disposal of excess water from cropped lands, suitable outlets are required to be constructed on graded bund. Draining of excess water from one plot to another through outlets provided in the bund require special attention since considerable amount of soil may be lost through these outlets. Provision should be made to arrest the silt and allow only clear water to flow away. The vegetated watercourse strengthens the system. In areas with high rainfall where the volume of water to be disposed from one plot to the next lower level plot is large and the vertical interval between the plots is reasonably high, a site specific outlet design like a pipe outlet, drop structure etc. must be provided for safe disposal of the excess water. Graded bund is reported to reduce the run-off from 20 to 4.8 per cent and soil loss from 24 to 4.12 t ha^{-1} yr^{-1}. Besides other benefits, intercropping on contour resulted in 48 per cent higher grain yield (Singh *et al.,* 1997).

Grass Waterways

Grass waterways are developed for safe disposal of excess water from agricultural fields. These may be natural or man made courses protected against erosion by suitable grass cover. Grass waterways are also used for channalising and regulating runoff flows for water harvesting purposes. The best location for waterways is a natural depression or along valley line. These may also be constructed along field boundaries for safe disposal of excess rainfall from agricultural fields. Vegetative waterways may be located in all classes of lands except hard rocks, where construction may be difficult. The cross section of waterways may be trapezoidal, triangular or parabolic with shallow depth and flat side slope to facilitate easy movement of man, animal and machinery. The depth of waterways may be kept within 20 to 50 cm and side slope more than 4:1. The channel should have free board of 15 cm. The channel cross-section and bed slope should be such that the computed velocity is within permissible limit (Singh *et al.,* 1990). Cost of construction of grass waterways depends upon type of soil, channel cross-section, length of channel and grass plantation technique.

Shelterbelts

In arid zones, the harsh conditions of climate and the shortage of water are intensified by the strong winds. Living conditions and agricultural production can often be improved by planting trees and shrubs in protective shelterbelts (Fig-5) which reduce wind velocity and provide shade. Shelterbelts are barriers of trees or shrubs that are planted to reduce wind velocities and, as a result, reduce evapotranspiration and prevent wind erosion; they frequently provide direct benefits to agricultural crops, resulting in higher yields, and provide shelter to livestock, grazing lands, and farms. Shelterbelt when planted across and on the margins of agricultural fields effectively protect crops and control sand drifting (Ganguli and Kaul, 1969). The effectiveness of shelterbelt in reducing wind velocity depends on wind velocity itself, direction, shape, width, tree height and density etc.

Trees for shelterbelt are planted at right angles to the prevailing wind direction. If the wind direction changes frequently a checkerboard pattern of plantings is required. Otherwise only parallel lines are needed. From 2-5 rows of fast growing trees of different heights should be planted to prevent any possible breaks in single rows, which would create a tunneling action with high and dangerous wind velocities. The shape of shelterbelt should be pyramidal in structure, i.e., tallest trees should be in centre followed by flank rows of medium height trees and lateral rows should be of bushy plants or shrubs. Windbreaks should be partly permeable to prevent turbulence. A permeability of 30-40 per cent is considered the optimum. The distance between shelterbelts should be about 20 times the expected height of trees after 5-7 years of growth. No cutting for firewood should be permitted in shelterbelts. In an experiment a three rows shelterbelt in which *P. juliflora* shrubby thicket was used as outer rows with central row of *Albizzia lebbek* reduced wind speed from 12 per cent at 10H (height) distance from shelterbelt to 33 per cent at 2H distance during summer season (Gupta *et al*., 1984). The following trees/shrub species are recommended for shelterbelt plantation in arid areas.

Flank rows : *Prosopis juliflora, Zizyphus nummularia, Acacia bevinosa, Calligonum polygonoides*

Lateral rows : *Cassia siamea, Tamarix articulata, Acacia tortilis, Parkinsonia aculeata*

Central rows : *Azadiranchta indica, Albizzia lebbek, Acacia nilotica, Ailanthus excelsa, Hardwickia binnata, Eucalyptus camaldulensis*

Fig-5. Shelterbelt plantation for wind erosion control, CAZRI Farm, Jodhpur

CONSERVATION MEASURES FOR NON-ARABLE LANDS

Non-arable lands are those lands, which do not fulfill life sustaining potential. These can result from inherent / imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints. In arid zone of western Rajasthan alone, about 7 million hectares area is classified as wasteland. The area under wasteland is further increasing because of over-exploitation and improper land use, to meet increasing demand for food, fodder and fuel. Also, cultivable area is decreasing because of increasing urbanization, mining and other economic activities. So there is need to develop these wastelands appropriately for sustained and improved fodder production. The adoption of dryland conservation technologies can significantly increase productivity and profitability in these areas (Halvin and Schlegel, 1997).

Contour Furrowing

Contour furrowing is the most effective measure to reduce runoff and soil loss, increase yield and is commonly adopted in grasslands and forestlands. However, in very sandy soils or soils with heavy clay pan area, their benefit is limited. Contour furrows varying from 30-60 cm wide and 10-25 cm deep can be used. The shape varies from "V" to square, rectangular, or parabolic. The cross section and depth of furrows mainly depend on soil and equipment used for making them. Furrows spaced 8-10 m apart give a better distribution of runoff water and higher yield of fodder. The effectiveness of contour furrows to hold water depends upon the degree of slope smoothness of the surface and accuracy in following contours and its life depends upon stability of soil and water storage capacity of the furrow, which can be estimated by following equation:

$$Q \quad \frac{WxD}{100\,HI}$$

where, Q = Depth of runoff water stored in cm from unit area

W = width of furrow, cm

D = depth of furrow, cm

HI = horizontal spacing, m

Construction of contour furrow is always started from the ridge and progressively extended towards the valley. In a study conducted in arid part of Iran it was found that contour furrow and pitting significantly helped in controlling soil erosion, increasing water penetration and soil moisture content and promoted propagation of *Hammada saliconica* species, a desirable plant species for both soil conservation and livestock grazing in the region (Jahantigh and Pessarakli, 2009).

Contour Trenches

A contour trench is a useful practice in forestry areas. This practice can be adopted in area which is unsuitable for cultivation but suitable for forestry. Normal standard size of a trench is 60 cm x 30 cm x 60 cm depth with an unexcavated portion 1.5 m after every 50-75 cm. Length spacing or vertical interval depends on the slope of land. Spacing may vary from 30-60 m. After the trenches are excavated to correct size, they are refilled partially, and stocking the remaining excavated material as a small bund on the down stream side. The storage capacity of trench is be estimated by the following equation.

$$Q \quad \frac{WxD}{100\,HI \quad 1 \quad \frac{X}{L}}$$

where, Q = depth of runoff from area in cm

W = width of trench in cm

D = depth of trench in cm

HI = horizontal interval in meters

X = gap between the trenches in m

L = length of trench in m

Mane *et al.* (2009) reported effectiveness of continuous contour trench for runoff control and recommended as best soil conservation practice on area having 7 to 8 per cent slope in konkan region of India.

Gradonies

Gradonies are steeply inward-sloping narrow bench terraces constructed on contours (Fig-6). Usually, gradonies are suitable for afforestation in uniformly steep sloping lands. Based on the steepness of slope, vertical interval is kept from 1.0 to 1.5 m. The width of gradonies also varies from 1.0 to 1.5 m. The material dug from the inner side is heaped on the outer edge in order to make a berm of about 20 to 30 cm high with an inward slope of 7.5:1. In the middle of the gradonies, pits of 50 cm x 50 cm x 50 cm are made at spacing of about 3 m. On an average 1000 trees are planted within the gradonies and interspaces in one hectare area (Mahnot and Singh, 1993).

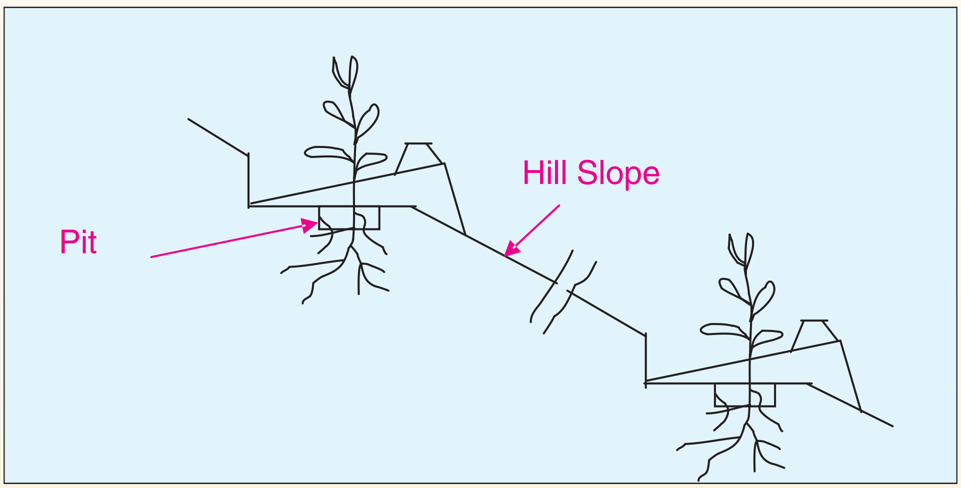

Fig-6. Gradoni

GULLY CONTROL MEASURES

About 4 million hectares in India are affected by gullies and ravines that threaten another 4-6 million hectares of productive tablelands. On marginal farmland, gully erosion is major source of soil and associated nitrogen and phosphorous losses (Sharpley *et al.,* 1996). However, with proper management, the gullies can be utilized to store runoff for groundwater recharge and human and livestock consumption. In western countries, construction of gully control works was initiated as far back as 1900. However, in India, such works have been taken up on an extensive scale since 1960 in Gujarat, Maharashtra, Madhya Pradesh and Rajasthan.

Anicut/Check-dams

Check-dams are masonry overflow barriers (weirs) constructed across seasonal streams (Fig-7). A check-dam as such has a relatively limited storage capacity but a large volume of water can still be pumped from such storage as the stream continues to flow and the check-dam serves the purpose of an ideal intake structure. A check-dam, by storing the base flow, maintains a supply of water for recharge as well as for direct use beyond the monsoon period (Goyal and Narain, 2006). It creates flooding of upstream area, which requires surplusing arrangements at suitable intervals to drain water. Check-dam should be avoided in isolation. The number of check-dams primarily depends upon the slope of the gully and the quantity of runoff. It may not be advisable to construct check-dams on bigger streams with high gradient and where runoff is very high. The bigger streams should be treated with drainage line treatment like gabionic structures and boulder checks with masonry work to curtail the runoff.

Fig-7. Check-dam at Beriganga research farm of CAZRI, Jodhpur

Gabionic Check-dams

Gabionic check-dams are useful in a locality where stones are readily available and their irregular shape makes them unsuitable for making loose stone check-dams. If the expected water velocity is very high, gabion is recommended in place of loose rock dams. A gabion is rectangular shaped cage made of galvanized wire, which is filled with locally available boulders, rocks or stones. The gabion may be conveyed flat and are folded to shape at the construction site. Usually, gabions are 1 m wide and 0.75-12 m high with varying lengths ranging between 2-10 m. The gabionic check-dams are constructed by connecting several gabions in horizontal and vertical direction. The gabionic check-dams are very stable and semi-permanent in nature. These structures are flexible; they may even change shape automatically according to the streambed, even when the bed shape changes due to erosion, without losing stability.

Loose Stone/Dry Stone Masonry Check-dams (LSCD)

These structures are effective for checking runoff velocity in steep and broad gullies. These are suitable at upper reaches of the catchment. They have a relatively longer life and, usually require less maintenance. The bed of the gully is excavated to a uniform depth of about 0.3 m. Stones are then hand packed from the foundation level. Flat stones of size 20-30 cm are the best for construction and laid in such a way that all the stones are keyed together. Large size stones are placed at the center of the dam and gaps between stones may be filled with small piece stones. The dam should go up to 0.3 to 0.6 m into the stable portion of the sides of the gully to prevent end cutting. In the center of the dam, sufficient spillway is provided to allow maximum runoff to discharge. LSCD constructed at 1 m V.L. in Jhanwar watershed (Fig-8) area on 17 gullies proved to be very effective in controlling further extension of gullies (Goyal *et al*., 2007). Vangani *et al*. (1998) reported sediment deposition of 3.86 t ha^{-1} yr^{-1} against loose stone check-dam in Osian-Bigmi watershed (Jodhpur district).

Fig-8. A series of Loose stone check-dams (LSCD) at gully in Jhanwar Watershed (Jodhpur)

Brushwood Check-dams

These check-dams are constructed by using locally available brushwood and supported by wooden stakes and used in the small gully heads not deeper than 1 m. These check-dam are of two types; single row post brush dam and double row post brush dam. Brushwood check-dams are constructed in areas where wooden posts, brushwood, etc. are available in plenty. These check-dams can only be used in the small gully heads not deeper than 1m. Single row post brush dam are made of single row of wood stakes to which long branches of trees are tied length wise along gully with their butt ends facing upstream while in double row post brush dam, the straw and brushwood are laid across the gully between two rows of wooden posts, the distance between the rows being not more than 0.9 m. The longest branches are laid at the bottom and the shorter length branches are laid above it till the required dam height (0.3 to 0.7 m) is obtained.

RAINWATER HARVESTING FOR ARID LANDS

Since primary source of water in arid zone is rainwater, so for any improvement in availability of water, catchment conditions become crucial. Catchment is the base for harvesting rainwater in form of runoff. Runoff is highly dependent on catchment's shape, size, slope, and type etc. beside rainfall characteristics. Goyal and Issac (2009) have estimated runoff coefficients for different catchments characteristics for hot arid zone of India. Some general modifications can greatly help in enhancing the runoff percentage from catchments.

Techniques for Enhancing Runoff from Catchments

1. Simple earth smoothing and compaction helps increasing runoff from catchment areas. Success is generally greater on loam or clay loam soils. Care must be taken to reduce the slope and/or the length of slope to lessen runoff velocity and thereby reducing runoff.
2. Small amounts of sodium salts - particularly NaCl, $NaHCO_3$ applied to desert soils where vegetation has been removed - causes dispersion of the surface soil, reducing infiltration and increases runoff. However, this type of treatment requires a minimum amount of expanding clays in the soil.
3. Removal of stones and boulders and unproductive vegetation from catchment helps in uninterrupted flow, enhances runoff to collection site.
4. Land shaping into roads and collection of water in channels.
5. Sandy soils have low water holding capacity. Spreading of clay blanket to the soil surface reduces the infiltration and consequently accelerates runoff.

6. Chemical treatments like wax, asphalt, bitumen and bentonite prevent downward movement of water, which augments runoff.

Rainwater Harvesting through *Tanka*

Tankas (small tanks) are underground tanks, found traditionally in most part of western Rajasthan. They are generally built in the main house or in the courtyard. *Tanka* is a circular hole made in the ground, lined with fine polished lime for collection of rainwater primarily from rooftop of individual house. The water collected in small *tankas* is generally used for drinking purposes, however bigger *tanka* can be used for providing supplemental/life saving irrigation to horticultural plants. During subnormal rainfall when *tanka* does not get adequate rainwater, water is hauled in camel/bullock cart from nearby wells/*nadis* to fill the household *tankas*. For rainwater management, CAZRI has designed underground *tanka* of 10 m^3 to 600 m^3 capacities for different rainfall and catchment conditions. These *tankas* were successfully constructed in Jhanwar, Sar, Baorali-Bambore (Jodhpur district) and Kalyanpur (Barmer district) villages. Harvested water of these *tankas* was used to provide life saving irrigation to plants. The Benefit cost ratio of *tanka* ranged from 1.25 to 1.40 under different uses (Goyal *et al*., 1995, 1997; Goyal and Sharma, 2000). The improved design of tanka has provision for inlet and outlet with silt-trap for control of silt inflow with runoff (Fig-9). The catchment of a *tanka* is made by

Fig-9. Improved *tanka* of 21 m^3 capacity at Baorali village (Jodhpur district)

spreading the excavated material around the structure. With a view to inducing the runoff, the catchment may be treated either with asphalt or sodium carbonate spray on soil surface. A uniform slope of 2-3 per cent towards *tanka* is provided for harvesting maximum possible runoff. The improved design of *tankas* have a lifespan of more than 20 years. The improved *tanka* design developed at CAZRI has wide acceptability in the region, which has been widely replicated in large numbers under Rajeev Gandhi National drinking Water Mission.

Rainwater Harvesting through *Nadi*

Nadis are village ponds used to store runoff water from adjoining natural catchments during the rainy season. In arid Rajasthan *nadi* system of water harvesting is the oldest practice and still the principal source of water supplies for human and livestock consumption. Across Rajasthan, most nadis have a capacity of between 1,200 to 15,000 m^3. Water availability in *nadi* ranged from 2-12 months after the rains. Since *nadis* received runoff from sandy and eroded rocky basins, large amounts of sediments used to deposit regularly in them, resulting in quick siltation. High evaporation and seepage losses through porous sides and bottom, heavy sedimentation due to biotic interference in the catchment and contamination are major bottlenecks. Evaporation losses ranged from 55 to 80 per cent of the total losses in various environments. Seepage losses are greatest during the rainy season (July-September) when *nadi* is completely filled. To overcome these problems, CAZRI has developed design for improved *nadis* with LDPE lining on sides and bottom keeping surface to volume ratio 0.28 and provision of silt trap at inlet (Khan, 1989).

Fig-10. Improved *nadi* with inlet and outlet

The site selection of *nadi* is based on availability of natural catchment and its runoff potential (Fig-10). The location of the *nadi* had a strong bearing on its storage capacity due to catchment and runoff characteristics. *Nadis* are 1.5 to 4.0 m deep in dune areas and those in sandy plains vary from 3 to 12 m. In addition, planting suitable tree species around the nadi creates an oasis in the desert and improves the local environment.

Rainwater Harvesting through *Khadin* for Crop Production

Khadin is a unique practice of water harvesting, moisture conservation and utilization in hyper arid region of Rajasthan. This system was designed and developed by the Paliwal Brahmins of Jaisalmer (Rajasthan) in the 15th century. This system has great similarity with the irrigation methods of the people of Iraq around 4500 BC and later of the Nabateans in the Middle East. A similar system is also reported to have been practiced 4,000 years ago in the Negev desert, and in southwestern Colorado 500 years ago. The main feature of *khadin* 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. The *khadin* system is based on the principle of harvesting rainwater on farmland and subsequent use of this water-saturated land for crop production. The ratio of farmland and catchment areas is regulated to be about 1:10 so that a suitable moisture supply is uniformly maintained. It is suitable for deep soil surrounded by some natural rock outcrops constituting catchment area. CAZRI has developed *khadin* of 20 ha areas in Baorali-Bambore watershed with surplussing arrangements (Fig-11). Before construction

Fig-11. *Khadin* with wastewier at Baorali-Bambore watershed (Jodhpur)

of *khadin*, uncontrolled runoff from upper catchment used to wash away seeds, fertilizers, and standing crops besides loss of valuable water. After construction of *Khadin*, farmer could take excellent *kharif* and *rabi* crops (Narain and Goyal, 2005). Collecting water in a *khadin* aids the continuous recharge of groundwater aquifers. Studies of groundwater recharge through *khadins* in different morphological settings suggest that 11 to 48 per cent of the stored water contributed to groundwater in a single season. This replenishment of aquifers means that subsurface water can be extracted through bore wells dug downstream from the *khadin.* The average water-level rise in wells bored into sandstone and deep alluvium was 0.8 m and 2.2 m, respectively (Khan, 1996).

Design Package and Guidelines for *Khadin* Construction

Central Arid Zone Research Institute, Jodhpur has prepared the design package and guidelines for construction of *khadin* by users agencies;

1. *Khadin* may be defined as a water harvesting system used for runoff farming on stored soil profile moisture.
2. The catchment may be classified on the basis of infiltration rate. In the areas where infiltration rate is less than 5 cm hr^{-1} may be considered as good catchment, 5-12 cm hr^{-1} as bad catchment. The delineation of catchment should be done on the cadestal/village map or G.T. sheet through reconnaissance survey.
3. The average rainfall of over 30 years available at the nearest rain gauging stations should be considered for working out the catchment yield. Log Pearson III method or strange table should be used.
4. For calculation of flood discharge upto 480 ha area Rational Formula and above 480 ha Dicken's Formula may be used.
5. *Khadin* may be constructed in a area where soil is fine textured, medium to deep with high soil moisture retention capacity. Soil should be free from salinity.
6. In order to have economic design the ponding depth over sill level at the *khadin* bund may vary from 0.65 to 1.10 m with overall average of 0.60 m.
7. The flood lift may be adopted as 0.3 m.
8. During the ponding period from July-October there will be wave action therefore, a free board of 0.5 m may be considered.
9. The side slopes of the bunds may be generally kept 2.5:1 (D/S) and 2:1 (U/S). However, these would be governed by the type of soil, angle of repose, bund cross section and its safety factor.

10. The top width of *khadin* bund may be calculated by appropriate formula and not for constructing inspection road.

11. A *murrum* capping of 7.5 cm thick layer be provided over the bund section for protection against wind and rain erosion.

12. The head outlet sluice of appropriate size may be provided in the *khadin* bund for the release of the standing water if any before the *rabi* sowing.

Rainwater Harvesting thorough Micro-catchment for Tree Establishment

Micro-catchment technique is particularly suitable for establishment of trees. In this technique a circular catchment of 1 to 1.5 m radius is constructed around the tree (Fig-12). The catchment is compacted by roller or any other heavy machine. A slope of 5-10 per cent is provided in catchment towards tree for directing flow of water. The catchment can also be lined with locally available materials such as polythene sheets, lime mortar, stone pieces, grasses, etc. for higher runoff generation. It is reported that the plants with micro-catchment have better chances of establishment in rainfed conditions as compared to conventional plantation technique (Ojasvi *et al.,* 1999). In another study Sharma *et al.* (1986) suggested that conversion of canopy area into runoff catchment may be just sufficient for improving its soil moisture profile.

Fig-12. Circular micro-catchment for tree establishment

AGRONOMIC PRACTICES

All operations carried out in the field, from land preparation to crop harvesting, with the aim of increasing the crop yield are included under agronomical practices. Certain simple agronomical practices like optimum tillage, administration of organic manure, suitable cropping pattern, and strip cropping have been found to be effective in retaining soil fertility as well as giving satisfactory crop yield.

Tillage Operation

Tillage (Ploughing) is the practice of breaking and working the soil to the desired depth prior to sowing. Tillage makes soil loose and hence prone to erosion. Timing and depth of tillage are the two important factors, which need special attention. Tillage should be done immediately before the crop season to take advantage of one or two early showers for land preparation. In arid region, land tilled into ridges and furrows across the wind direction has been found to reduce the effects of wind erosion during the summer months. However excessive tillage before the monsoon lowers the percentage of clods and accelerated the wind erosion (Gupta, 1993). Therefore proper tillage is very important to take advantage of moisture conservation during rain and at same time should avoid soil erosion by wind.

Crop Management

Row crops that are widely spaced are generally erosion-permitting. To reduce the erosion, the plants should be spaced in such away as to obstruct the flow of water downhill by crop itself. A proper combination of raw to raw and plant to plant spacing goes in long in reducing the soil erosion beside enhancement in yield. For same plant population increase in raw spacing and corresponding decrease in plant to plant spacing help in creating mini barrier to control erosion by water and wind without adversely affecting the yield. Weeds consume water at much faster rate than crop because of smaller life cycle. Elimination of weed at proper time greatly reduces the competitions for water for the crop. Crops of moth and gaur when kept weed free till maturity produces higher seed yield where as weed infestation after 30 to 40 days of sowing, resulted significant reduction in yield (Singh, 1984). Optimum plant population is important aspect of crop production in arid areas. Higher plant density enhances evapotranspiration losses relative to non-growth parameter of plant. Higher plant densities do not allow deep percolation of soil moisture as observed in vegetables grown under drip irrigation (Singh, 1978). In arid region, particularly rainfed condition, larger canopy growth may be disadvantageous as it may exhaust the available soil moisture from root zone during drought (Singh, 1977). So in such areas, one has to be more cautious in deciding optimal plant population and row spacing for sustainable crop production. Crop rotation is another practice to maintain the fertility of soil. Crop rotation not only helps to increase the crop productivity and soil fertility, but also improves the water and nutrients use efficiency by reducing weeds, providing conductive micro-climate for plant growth and development.

Strip Cropping

Strip cropping for wind erosion control consists of alternate plantation of erosion susceptible and erosion resistant crop against prevailing wind direction preferably across the slope. In this system soil eroded from one strip is retained by the next strip and the overall fertility of the land is maintained. Narrow strips are more effective in reducing wind erosion in lighter soils. The width of the strip varies from 6 m in sand to 30 m in sandy loam. Establishment of strips of perennials like *Lasiurus sindicus* and *Ricinus communis* at right angle to the prevailing wind direction at CAZRI Farm, Jodhpur, reduced the impact and threshold velocity of wind to the minimum and checked the erosion. Consequently, crop grown in between the protective strips recorded increased production (Mishra, 1971). Reduction in sand drift due to protective strips of grass at Bikaner and Hingoli (Jodhpur) was also reported by Singh (1989). In another study the productivity and quality of fodder was increased by strip cropping of *C. ciliaris* or *L. sindicus* with *L. purpureus* in association with *C. mopane* or *H. binata* under silivi-pastoral system in arid zone (Patidar *et al.,* 2008). Another advantage of strip cropping is that it helps in the prevention of pest attack on the crops. Since pests are mostly crop specific, one particular strip affected by one particular pest remains confined within that strip itself and does not spread to the next strip, thus preventing the spreading of the diseases to the entire field.

Mulching

Mulching of open land surface is achieved by spreading stubble, trash or any other vegetation. The objectives of mulching are to minimize splash influence of rain drops on base surface; reduce evaporation; increase absorption of the rainfall; obstruct surface flow thereby retarding erosion and allow microbiological changes to occur at optimum temperature (Fig-13). Sometimes, spreading of organic residues, instead of mixing can help in reduction of soil and water loss to a considerable extent. Polyethylene mulches have also been utilized for water harvesting and control of seepage. Trash farming, in which crop remains are cut, chopped and partly mixed in ground and partly left on land surface, is also a form of mulching. Studies conducted at CAZRI have shown that use of organic mulches reduced the maximum soil temperature at 10 cm depth by 1 to 6°C with suppressed weed growth and increase in soil moisture status. Similarly application of grass mulch at the rate of 6 t ha^{-1} resulted in reduced mean maximum soil temperature, reduced evapotranspiration and consequently increase of 40 per cent yield of green gram (Gupta, 1978, 1980).

Fig-13. Grass mulch for evaporation control

PRODUCTION PRACTICES FOR ARABLE AND NON-ARABLE LANDS

Crop Production Based System

In Indian arid zone, more than 95 per cent of the total cultivated area is rainfed. Even after completion of Indira Gandhi Canal Project, crop production in more than 85 per cent of land continues to depend on vagaries of monsoon. Crop productivity from rainfed areas in general low and unstable due to low and erratic rainfall, hostile climatic condition, low fertility and poor water holding capacity of sandy soils, scarce and poor quality of groundwater, limited choice of crops, traditional and unscientific methods of cultivation, irrational land use system and poor economic base. In order to enhance and stabilize crop production in rainfed regions, due importance is necessary to be placed on rainwater management and its use, improved agricultural practices, improved crop variety and timely sowing. To overcome moisture deficiency during dry spells, it is imperative to maximize soil moisture regime through in-situ moisture conservation, harvesting excess rainfall and recycling for crop improvement.

Main Cropping Season

In arid regions crops are grown in monsoon season (*kharif*), and to a smaller extent in winter season (*rabi*). However, in 95 per cent area crops are grown in *kharif* season. *Rabi* crops are taken in pockets where limited water is available for irrigation. In good rainfall years, at few locations post monsoon crops such as chick pea and mustard are grown on stored soil profile moisture particularly where *khadin* cultivation in vogue.

Major Crops

In Indian arid regions crops such as pear millet, mungbean, clusterbean, moth bean, sesame and caster are grown in various proportions. Among these crops pear millet is the most important. Monoculture of pearl millet or pearl millet-fallow rotation is common. Clusterbean, moth bean and green gram are legume crops of *kharif* season which usually show better performance. Wheat crop is possible through irrigation. Silvi-pastoral cultivation with production of pearl millet, moth bean, sesame, barley and chickpea can pay dividends and stabilize crop production in this region provided recommended tree spacing is adopted. Some of the promising crops and their recommended varieties tested at CAZRI are presented in Table-2.

Table-2. Important crops varieties recommended for arid region

Cereals	Pearl millet	HHB-60, HHB 67, MH 179, WCC 75
	Sorghum	CSH-1, CSH-5, SPV-96
Grain legumes	Green gram	S-8, S-9, K-851, PS-16
	Dew gram	Jadia, T-2, T-18, Maru moth, Jwala
	Cow pea	FS-68, K-11, Charodi-1, HFC-75, FS-277 HFC-42-1 (fodder)
	Clusterbean	Durgapura Safed, Maru guar, HG-75, FS-77
Oilseeds	Sesame	T-13, TC-25, RT-46
	Castor	Aruna, Bhagya, Gauch-1
	Mustard	T-59 (Varuna), Pusa bold

Source: Bhati, 1997

Improved Agronomic Practices

Mixed cropping and inter-cropping system also plays a vital role in ensuring risk distribution (Table-3). Instead of full dose of nitrogenous fertilizers half dose at sowing time should be applied. Remaining half dose, could be withheld if the prevailing soil moisture conditions are not favorable or weeding has not been done till that time. This is another way of risk distribution, wherein investment for costly input like fertilizer can be saved. Timely weeding contributes significantly in increasing crop production.

Table- 3. Promising Intercrop systems and their yield potentials

Region	Intercrop systems
Hissar	Pearl millet + Fodder cowpea (paired rows 30:60 cm)
Jodhpur	Green gram + Pearl millet (3:1) Clusterbean (30:60) + Pearl millet *Cenchrus ciliaris* + Green gram (paired row) *Cenchrus ciliaris* + Moth bean (paired row) *Cenchrus ciliaris* + Clusterbean (paired row)
Rajkot	Groundnut + Pigeonpea (6:1) Groundnut + Castor (6:1) Pearl millet + Pigeonpea (1:1) Pearl millet + Pigeonpea (4:1) Pearl millet + Clusterbean(1:1)
Dantiwada/Anand	Pearl millet + Pigeonpea Pearl millet + Castor

ALTERNATE LANDUSE SYSTEMS

Agroforestry

In arid eco-system agriculture alone would not be stable system and should incorporate other systems like forestry into farming system in order to impart stability and generate assured income. Agro-forestry in the arid ecosystem envisages a sustainable land management system which helps in augmenting overall production from land, combines the production of crops and forest plants simultaneously or sequentially on the same unit of land. With this system neither crops sown in between the trees harm them nor the trees cause any harm to the agricultural crops. There is rather a symbiotic action between these two and higher yields has been reported from both crops and trees under certain conditions.

In arid areas the farmer has been traditionally protecting Khejri (*Prosopis cineraria),* Bordi (*Zizyphus rotundifolia*) and Babul (*Acacia nilotica*) trees in their farmlands. These trees besides conserving moisture add to the fertility and overall productivity of soil. These species are drought hardy and well adapted to the climatic conditions of the desert. Saxena (1977) reported that 'Khejri' forms climatic climax of western Rajasthan and dominate the alluvial flats while 'Bordi' is one of the main co-dominant on the flat plains of arid and semi-arid zones. Mann and Saxena (1980) reported the effect of different densities of 'Khejri' on the major crops grown in different habitats. The data showed not much variations in crop yields due to tree densities. Even as high a tree density as 80 tree ha^{-1} showed an improvement in crop production in sandy plains. The increase in yield beside other factors could be due to build up of soil fertility. Khejri and 'Bordi' trees besides improving productivity supply 20-30 kg and 2-3 kg air dried leaves *Loong* and *Pala* as fodder respectively (Saxena, 1984).

Besides 'Khejri' and 'Bordi' there are also other trees and shrubs used in different traditional agroforestry system prevalent in western Rajasthan. In Pali *Acacia nilotica* (Babul) and *A. nilotica* var. *cupressiformis* (Khajoor) are the two main species which grow along Jawai and Sukri tributaries of Luni. These trees are generally found in the density of 40-50 trees ha^{-1}. Khajoor babul is a tall, conical shaped tree with little shade and does not interfere with crops and field operations. There is very little scope of lopping for this tree and does not compete with crops. In *Acacia nilotica* (Babul) however, lopping is practiced.

In Nagaur, Churu, Jhunujunu and Sikar region (deep older alluvial plains), *Prosopis cineraria* (Khejri) predominates. The trees are lopped in November and December for fodder and fuel wood purposes and the practice also helps the *rabi* crops of wheat and mustard. *Ailanthus excelsa* (Ardu) is grown in Sikar. It is a fast growing erect fodder tree and its leaves are fed to goat and sheep. Although *Prosopis cineraria, Acacia nilotica* and *Zizyphus nummularia* are the trees commonly grown in traditional agroforestry, some of the other exotic species introduced for agroforestry purposes are *Acacia albida, Acacia tortilis, Tecomella undulata, Hardwickia binata, D. nutan and C. mopane*. These trees have fodder, fuel wood and other economic benefits and could be tried for agroforestry purposes.

Acacia tortilis is a very fast growing tree and grows in almost all types of habitats. Harsh *et al.* (1992) reported increased production of mungbean, clusterbean and forage sorghum in association with established trees of *Acacia tortilis* but with pruning of roots by digging trenches to avoid competition.

Fodder Development

Pasture management techniques for forage production and utilization vary from region to region and place to place depending upon climate, soil, and availability of inputs. An ideal pasture management technique provides the maximum output of digestible nutrients per hectare or maximum livestock products from a unit area. Straws and other crop residues constitute an important source of fodder in our country. The straws and agricultural residues are obtained as a byproduct of the agricultural crops and the production techniques adopted aim at maximizing grain production. Other important sources of fodder in the country are grasses growing in pastures, forest areas and fallow lands. The grass lands are mostly in degraded condition as a result of continuous over grazing and soil erosion. As a result of continuous over grazing the proportion of palatable and nutritious grasses has decreased and that of less nutritious and coarse grasses has increased. The productivity of such grass lands is consequently very low. Extensive areas have been invaded by noxious weeds and bushes. Many grasslands are, as a results, occupied by such weeds and bushes which yield no fodder. The productive area of pastures has consequently shrunk and the availability of grasses from such areas has decreased. Therefore, there is need to improve pastureland to optimize production from such area's. In many areas, particularly in the hills, suitable soil and water conservation measures are required. The most important step required in the direction of restoration and improvement of the grassland is the controlled grazing. The grazing in these area should not exceed their carrying capacity. Some areas will have to be closed to grazing for a few years for reseeding with suitable grasses which have disappeared from these areas as a result of continuous grazing. Various methods have been tried to replace inferior annual grasses by improved high yielding varieties. The techniques will vary with the type of soil, climate and the species of grasses already existing and to be introduced.

Optimum time and frequency of grass cutting are important factors determining the yield and quality of fodder obtainable from pastures. Optimum time of harvesting the grasses is normally the pre-flowering stage and the nutritive value and digestibility decreases as the maturity advances after flowering. The harvesting of grasses at this stage with the adoption of proper methods for drying and hay making results in rotting of the grasses. The hay and silage making is normally not adopted by the villagers and the harvesting of grasses is done normally after the monsoon rains. Harvesting of such dry grass after seed shedding, provides only fodder of very low nutritive value and poor digestibility. But in some areas harvesting of grass is delayed to allow the grasses to shed the seeds so that the pastures may regenerate. Solution of these problems is necessary in order to ensure optimum grass yield of better quality from degraded pasture lands. The productivity of grasses in rangeland is given in Table-4.

Table-4. Productivity of grasses in rangelands of Indian arid zone

Condition of rangelands	Forage production (kg ha^{-1}) during normal years	Carrying capacity of adult cattle (300 kg body wt. 100 days ha^{-1} year)
Excellent	1500 and above	25-30
Good	1000 and above	20
Fair	750	17
Poor	500	13
Very Poor	200 or even less	0-6

Silvi-pasture systems ensures higher forage yield; better quality of forage and maintenance of the productivity of the pasture land. The trees introduced in the silvi-pastoral system provide a sizeable quality of nutritious fodder and ensure better growth of grasses and legumes. The trees tap the lower layers of the soil which otherwise could not be tapped by the grasses and thus ensure better utilization of the site.

The trees suitable for particular site and climate should be selected for silvi-pastoral practices. The fodder trees suitable for different zones in western Rajasthan have been identified through experiments conducted at CAZRI. The grasses and legumes capable of growing with these trees have also been identified (Table-5).

Table-5. Suitable species of trees/shrubs, grasses and legumes for silvi-pastoral system in arid areas

Trees	*Acacia tortilis, Prosopis cineraria, Albizzia amara, A. lebbeck, Dicharostachys nutans, Colophospermum mopane*
Grasses	*Cenchrus ciliaris, C. setigerus, Lasiurus sindicus, Panicum turgidum*
Legumes	*Macroptelium atropureum* (Siratro), *Stylosanthes hamata, S. scabra, Atylosia scarrabaeoides, Desmanthus virgutus* etc.

Grassland forage production is closely associated with soil-water availability which is limited by rainfall amounts and run off. The moisture conservation measures suitable for different grasslands for enhancing grass land productivity have been identified through research conducted at CAZRI, Jodhpur.

Fuel Wood Plantation

The fuel shortage of western Rajasthan is worse than other parts of Rajasthan because in western Rajasthan only 1 per cent land is under forest cover whereas, in the other parts of Rajasthan the forest cover is about 10 per cent. The poor forest cover in western Rajasthan is due to the harsh climatic conditions, poor soils and high biotic stress. The vegetation of this region is thorny scrub type (Champion and Seth, 1968). The tree species are very few in number, sparsely distributed and they are very slow growing. In rural areas of Rajasthan 70 per cent dependency for fuel is on fire wood (Table-6).

Table-6. Pattern of use of various types of fuel in Rajasthan

Type of fuel	% contribution
Fire wood	70.0
Dung	24.0
Charcoal	0.1
Vegetable waste	4.0
Soft coke etc.	1.0
Kerosene	0.9

Source: Soni, 1984

For improving the fuel availability, CAZRI, Jodhpur has introduced number of the tree species from iso-climatic regions of the world as well as from different parts of India. Since 1956 approximately 120 sp. of *Eucalyptus*, 64 species of *Acacia* and 85 miscellaneous of species of different genera have been introduced.

Promising Fuel Species

The species identified for fuel purpose are presented in Table-7. Out of the many exotic species the most promising tree species are *Acacia tortilis* and *Prosopis juliflora.*

Increasing the Fuel Wood Production

About 5.6 million hectare area in this region is identified as wasteland which could be put under forest tree plantations. Beside wastelands, grasslands or agricultural fields can also be utilized for introduction of trees. These tree can be introduced in the following manners

1. Block planting - as fuel wood plantation
2. Bund plantations - i.e. on the boundaries of agricultural fields

Table-7. Promising fuel yielding species and their calorific values

Promising species	Calorific values (BTU/lb)
Acacia tortilis	7,800
Prosopis juliflora	8,050
Calligonum polygonoides	7,590
Acacia nilotica	7,680
Prosopis cineraria	7,640
Albizia lebbek	7,530
Butea monosperma	7,340
Anogeisus rotundifolia	7,660
Eucalyptus camadulensis	7,730

3. Silvi-pastoral, in which fuel trees should be planted in between the grasses
4. Agri-silvicultural system: in which fuel tree should be planted in between the agricultural crops
5. Shelter belt plantation
6. Block rotational planting: In this system the rotation between tree/crop should be done

Horticultural Development Techniques

Horticulture has special significance in arid zone especially in drought prone areas because fruit crops once established, become permanent source of income and impart stability to uncertain agriculture in arid zone. Horticulture crops constitute a significant component of the total agricultural production in the country. These crops cover nearly 11.6 million hectares area with a total production of over 91 million tones (Prasad and Vashishtha, 1998). The estimated production of fruits and vegetables is much below the annual requirement of population if the recommended level of per capita consumption of 85g of fruit and 280g of vegetables is taken as base (Chadha, 1993). To meet this gap in production, the emphasis now is given to utilize the arid and semi-arid lands, which have so far remained as "land reserves".

At present most of the arid zones of India has animal husbandry based economy which is not sufficient to provide the required stability in the income of people and therefore, people at large in this region are nomadic in habits. Provision of sustained and stable income to these people shall be sufficient incentive for them to grow fruits. We are now aware that there are a number of fruit crops which have great capacity to stand drought and salinity and still provide good income to the growers. For example, the ber which was considered to be a wild fruit a decade back has gained commercial importance in the states of Rajasthan, Gujarat, Haryana and Punjab. Like wise, pomegranate, *aonla* and *bael* can also provide considerable income to the growers. CAZRI has developed the propagation techniques for fruit trees (CAZRI, 1989).

Propagation

Ber: In propagation techniques standardized at this Institute, the seedlings are ready for budding in 90 days and buddings are ready for out planting in 120 days. The seedlings are raised in Polythene tubes (open at both ends) and budded in the nursery. A poly-pack method of bare root buddling in sphagnum mass soaked in nutrient solution has also been developed which reduces the weight of plant (70 g as against 1.5 kg in Polythene tube with soil), found to be useful for export of buddings (Pareek and Vashishtha, 1980).

Pomegranate: Pomegranate is propagated by stem cutting (semi-hard wood). Research conducted at CAZRI revealed that treatment of cutting with 1000 ppm IBA, for 30 seconds gave 60-80 per cent success in rooting. The third week of February to first week of March is the optimum time for planting. After six months the rooted cuttings are ready for transplanting in the field.

Datepalm: Datepalm is propagated through suckers. Treating datepalm suckers with 2000 ppm IBA and with any copper fungicide before planting increased the establishment percentage. Use of bentonite as sub-soil barrier was also found to be useful in the establishment of suckers.

Sitaphal: The rooting of cutting was obtained about 26 per cent with 2500 ppm IBA. The veneer grafting gave about 78 per cent success. The 'T' budding resulted in about 70 to 75 per cent success. The best time of budding is in the month of March (Bankar, 1989).

Gonda: T budding has been found to be successful. The seedlings are grown in the nursery and can be budded after 100 days.

Karonda: The cuttings are difficult to root. Budding (T) in the month of November and March gives about 60 to 80 per cent success. The one year old rootstock raised from wild seedlings is suitable for budding (Bankar and Prasad, 1994).

Aonla: 'T' budding was found most successful in the region. 5-6 month old seedlings are suitable for rootstock and the best time of budding is July-August. Propagation by 'T' budding in the month of July-August gives 80 per cent success.

Bael: In *bael*, 'T' budding was found best. 'T' budding gives 60-70 per cent success. Bael seedlings also take about 6-7 months to be ready as rootstock. July-August is the optimum time for budding.

Ker: The seedling population in *Ker* is quite variable. Therefore, hard wood and semi-hardwood cuttings were treated with Indole butyric acid (1000 to 5000 ppni) and planted every month except December and January. The best results (30 to 40% success) were obtained by treating with I000 ppm IBA and planting in July and August when the atmospheric humidity was high (Vashishtha, 1987).

Table-8. Fruit Crops based on rainfall

Rainfall zone	Fruit crop	Cultivar
< 350 mm	Ber (*Zizyphus mauritiana*)	Seb, Gola, Mundia
	Gonda or Lasora (*Cordia myxa*) Ker (*Capparis decidua*) Pilu (*Salvadora oleoides*)	Local seedlings
350-500 mm	Ber (*Zizyphus mauritiana*)	Katha, Maharwali, Bagwani, Seb, Gola, Mundia
	Anola (*Emblica officinalis*)	Banarsi, Hathijhool, Chakaiya
	Mulbery (*Morus alba*) Khirni (*Manilkara hexandra*) Jamun (*Syzygium cumini*)	Seedling local strain
600-700 mm	Bael (*Aegle marmelos*) Aonla (*Emblica officinalis*) Ber (*Zizyphus mauritiana*) Mango (*Mangifera indica*) Phalsa (*Grewia subinaequalis*) Karonda (*Carissa carandus*)	
	Bael (*Aegle marmelos*)	Faizabad selection
	Sourlime (*Citrus aurantifolia*)	Baramasi
	Custard apple(*Annona* sp.)	Balangar, Mammoth

Medicinal and Aromatic Plants

Arid land plants have developed adaptations to survive the extremes of environmental conditions. These adoptions are in the form of having alkaloid, glycosides, gums, resins, oils, mucilage and tannins. The secondary metabolites are the constituents of many medicines of importance, some of these are: *Withania somnifera* (Ashwa gandha), *Emblica officinalis* (Aonla), *Glycyrrhiza glabra* (Mulethi), *Tinospora cordifolia* (Guduchi), *Pedalium murex* (Gokshru), *Tribulus terrestris* (Gokshru), *Cassia angustifolia* (Sanai), *Aegle marmelos* (Bael), *Boerhavia diffusa* (Punarnava), *Plantago ovata* (Isabgol), *Lawsonia inermis* (Mehndi), *Cathranthus roseus* (Periwinkle), *Commiphora wightii* (Guggal), *Aloe barbadens* (Ghrit Kumari), *Psoralea corylifolia* (Babchi), *Vetiveria zizanioides* (Khas), *Citrullus colocynthis (Colocynth)*, *Peganum harmala* (harma), *Cymbopogan martinii* (Citronella oil grass), *Andrographis paniculata* (Kalmegh) and finally *Salvadora oleoides, S. persica and Tecomella undulata.* The species could be grown as per local habitat situations (Kumar, 1998).

CONTINGENCY PLANNING

The principal source of water for crops in arid areas is monsoon rains. Monsoon rains are highly unreliable having *breaks and bursts*. As result of concerted research efforts contingency plans including the choice of alternate crops and varieties are now available for aberrant weather situations. The following alternate strategies are useful in arid areas.

(a) Delayed onset of monsoon late in July

- Transplanting of pearl millet
- Diversion of major area earmarked for pearl millet to planting of *kharif* pulses

(b) Delayed onset of monsoon upto first week of August

- Planting of traditional grain legumes- guar and moth

(c) Occurrence of drought early in the season

- Gap filling of pearl millet by transplanting
- Complete removal of weeds

(d) Occurrence of drought late in season

- Reducing plant population
- Protective irrigation from harvested water

If the moisture stress is of short duration (10-15 days), thinning of plants in rows will be helpful. If the moisture stress is of longer duration (20-25 days) removal of alternate rows bringing down the plant population to 2/3rd or even 1/2 of the normal plant population should be resorted to ensure moderate productivity.

Life Saving Irrigation

Moisture storage, *in-situ* (in soil profile) and *ex-situ* (in dug out ponds) imparts stability to crops and is a good insurance against total crop failure. A 'Life Saving Irrigation' of 5-7 cm from stored water during dry spell or at critical growth stage of crop stabilizes yields. The pay-off could be higher in case of high value crops.

RECOMMENDED FARM IMPLEMENTS

The farm machinery plays an important role in timeliness of various farming operations particularly in arid areas where rainfall is very low and erratic and moisture remains for a very short period where important activities like seedbed preparation, sowing etc. needs to be completed within a short time. The farm machinery also plays a important role in overall productivity of crops in terms its precision in tillage and various operations. Following machinery is recommended for arid regions for various farming operations (Singh *et al.,* 1998).

Seedbed preparation: Mould board plow, disc plow, disc harrow, bund former, buckscraper, clod crusher

Sowing: Seed-cum-fertilizer drill, different kind of planters as per crops.

Interculture operation: Cultivator with duck foot shovel, ridger, *bukhar*, wheel hoe, *kudali*

Irrigation: Diesel pump set, electric pumping set, submersible pumping set

Plant protection equipment: Sprayers and dusters

Harvesting: Reaper binder, combine harvester, sickle

Threshing: Multi crop threshers, winnowing fan

Drying: Solar cabinet dryer, solar batch and bin dryer

Processing: Hand and power operated chaff cutter

CONCLUSIONS

Worldwide arid zones have witnessed increase in human and livestock populations like any other region as a result of natural increase. The increased population pressure has stressed the limited natural resources of this fragile eco-system. Since good lands are already under intense cultivation so focus has shifted towards arid zone all over the world for the crop production. The scientific approach towards understanding the problems and constraints of arid region and adoption of proper watershed management technology can greatly help in achieving the goal of meeting the aspiration of its dwellers on sustainable basis.

A successful application of any soil and water conservation measures for improving production requires an integrated watershed approach. In arid areas, conditions vary too much soil, climate, social factors and the list is endless so no two areas are identical, and therefore proper selection of technology for area specific is essential. While designing any structure for area specific its cost-effectiveness should be kept in mind. It is generally cheap to repair a structure rather than designing a robust costly structure for extreme events of 100 years. All the watershed technologies discussed above are essentially site specific and different components need to be integrated as a holistic approach to maximize production on sustainable basis. These technologies are time tested and are of proven soundness for extreme conditions such as of arid.

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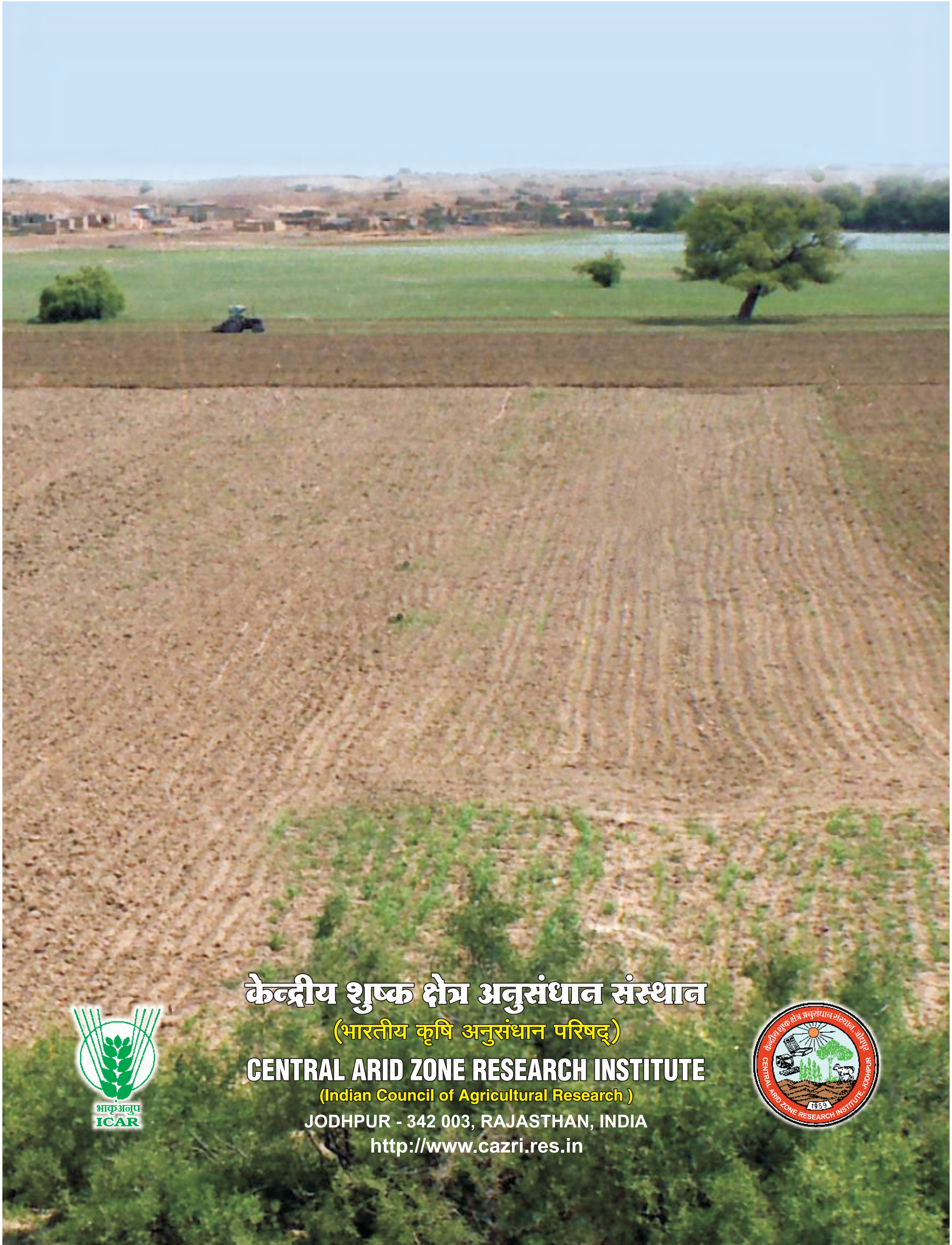
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