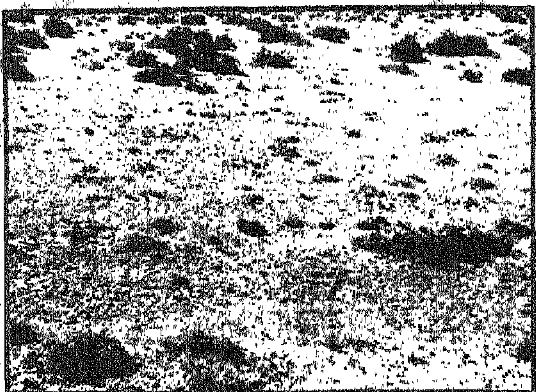
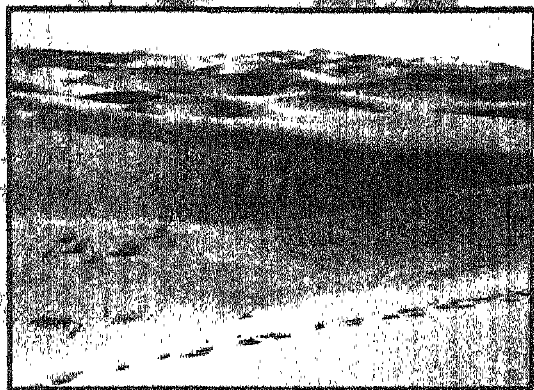
TECHNOLOGY APPROACH FOR GREENING DEGRADED ARID LANDS

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PREFACE

According to United Nations estimates about one-third geographical area of the world supporting a population of about 80 million people suffers from aridity. In India about 13% geographical area is under aridity. These areas are environmentally very harsh, less productive and therefore neglected and economically backward since centuries. Ironically many of these areas have tremendous pressure of human beings and livestock for grain, fuel wood and fodder leading, thereby, to indiscriminate and over exploitation of already meager resources. The net result is desertification and the creation of wastelands.

During the last two decades lot of work has been done and awareness created throughout the world to ameliorate the conditions of arid and semi arid areas. Central Arid Zone Research Institute, Jodhpur (India) has generated wealth of information on desert resources (soil, water, vegetation etc.) and their utilization. Significant achievements have been made and technologies developed for soil and water conservation, improved crop production, afforestation, pasture land management and livestock production. Some of these technologies are already being used by various agencies for desert development. Efforts are also made for updating these technologies and making site-specific corrections.

This publication is an attempt to put together the available information and the technologies developed for rehabilitation of the arid areas and sand dunes. It is hoped that the publication will be of great interest and help to agriculturists, foresters, extension workers and all others engaged in desert development work.

March, 2000

(J.P. Gupta)
Head of Division
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1. INTRODUCTION

The arid zone of India occupies an area of 3.2 lakhs km^2 which is about 13% of the geographical area of the country. It is spread over Rajasthan (62%), Gujrat (19%), Punjab and Haryana (9%) and Andhra Pradesh and Karnataka (10%). The main problems of these areas are low availability of rainfall, irrigation water and high frequency of droughts, adversely affecting the growth of vegetation. Also there is continuos increase of human and animal population in these areas. It has almost doubled up during the last one decade. This has therefore increased the grain, fodder and fuel wood requirements leading to denudation and over exploitation of the meager resources. There is a large scale cutting of trees, shrubs and even roots to meet fuel wood and fodder needs. Pasture lands have been degraded due to over and indiscriminate grazing. This has accelerated erosion processes and converted productive lands to wastelands. There is also continuos exploitation of the ground water leading to lowering of the water table and deterioration of its quality. Introduction of irrigation through canals without proper drainage system has created water logging and salinity.

Mining is another most important economic activity of the arid areas particularly of western Rajasthan. It is reducing the cultivated and the catchment areas so important for ground water recharge and vegetation production. In the absence of the vegetating over burdens it is creating more wastelands. It is also seriously affecting water bodies, so essential for meeting drinking water needs of animals and human beings.

Sand dunes and their movement is a problem which seriously affects the production of agricultural lands, road ways, railway tracks, water courses and other economic establishments in many parts of arid western Rajasthan. About 68% area of western Rajasthan is affected by this problem.

In view of this there is an urgent need for halting these trends and rehabilitating the wastelands with the available technology.

2. CLIMATIC FEATURES

The annual rainfall of the arid areas in general and the western Rajasthan in particular varies in general and the western Rajasthan in particular varies from 200-400 mm with a coefficient of variation as high as 40-60% table 2.1. The distribution of rainfall is generally erratic occurring mostly during the period from July to September which is the main cropping season. During the summer mean maximum daily temperature is around 40°C and during winter it is 22-28°C. The maximum temperature recorded during summer is as high as 52°C. The minimum daily temperature varies from 24-26°C during summer and from 4-10°C during winter. During the monsoon period maximum day temperature varies from 36-39°C with a diurnal variation of 10°C. Soil temperature at 5 cm depth ranges from 35 to 45°C during the monsoon period. The mean relative humidity in the afternoon during summer ranges from 20-35% and during monsoon from 48-60%. The mean evaporation rate during summer exceeds 10mm/day.

Table 2.1: Mean annual rainfall, moisture index, their coefficient of variation and frequencies of drought in the zone (1971-80).

Districts	Annual Rainfall (%)	C.V. of Annual (%)	Mean Moisture index	C.V. of moisture index	*Freq. of moderate to severe drought
Barmer	248.5	63.5	-79.0	10.0	3
Bikaner	323.4	49.0	-81.2	10.0	4
Churu	408.6	42.6	-75.1	12.1	3
Jaisalmer	214.1	66.1	-88.9	6.6	3
Jodhpur	361.4	60.7	-75.4	13.1	2

Source: Ramakrishna et al., (1988)
*Number of drought years in decade.

Aridity defined

Thornthwaite and Mather (1955) described moisture regime of a region in terms of moisture index (Im) and defined it as

$$Im = \frac{\text{Annual water surplus} - \text{Annual water deficit}}{\text{Annual water need}} \times 100$$

Which in simple form is expressed as

$$Im = \frac{P - PE}{PE} \times 100$$

Where P is the annual precipitation in mm and PE is the annual potential evapotranspiration in mm.

Variations in moisture index

Variations in moisture index described the variations in moisture regime and thus determine the crop production levels of arid area. Ramakrishna et al. (1988) pointed out that coefficient of variation of moisture index decreases with decrease in moisture index showing thereby that regions with low moisture index will have large fluctuations in climatic pattern. On the basis of moisture index they classified the moisture conditions as follows:

Value of Im	Moisture regime
-33 to –66.6	Partly dry
-66.7 to –80.0	Dry
-80.1 or less	Extremely dry

The probability analysis by these authors revealed that probability of occurrence of dry conditions is generally high in the region with mean moisture index of – 75.0.

3. MAJOR LAND TYPES, SOILS AND THEIR CHARACTERSTICS

About 7.00 Mha area of the arid Rajasthan is occupied by wastelands of different types like sandy, shallow gravelly, rocky and gravelly etc. (Table 3.1). Because of gravelly and stony nature and poor soil depth, these lands are unproductive unless treated otherwise. Sandy soils and the sand dunes are dominating features of arid areas and occupy about 64.9% of the area in western Rajasthan predominantly in the districts of Jaisalmer, Barmer, Bikaner and Ganganagar (Dhir, 1977 b). The major soil groups and their extent of distribution is as under

Soil groups	**% extent**
Light brown sandy soils	34.3
Dunes and interdunal plains	30.6
Gray brown loam soils	13.6
Others	15.7

Table 3.1: Wastelands of western Rajasthan.

Wasteland category	Area (million ha)	% of total area of western Rajasthan
Sandy waste	3.43	48.7
Saline waste	0.20	2.8
Stony waste	0.15	2.1
Gravelly	0.29	4.1
Rocky	0.02	3.1
Rocky and stony	0.11	1.6
Stone and gravelly	0.06	0.8
Rocky and gravelly	0.67	9.4
Sandy with open scrubs	1.00	14.1
Rocky and gravelly with open scrubs	0.93	13.1

Source: A.K. Sen (Personal Communication)

The sandy soils generally contain 3 to 10% clay, 3 to 6% silt, 60-75% fine sand and 10 to 15% coarse sand. The soils are generally single grained, loose, structure less and are highly vulnerable to wind erosion. Available water capacity of these soils is very low and ranges from 50 to 100 mm of water per meter of soil profile. Because of high infiltration rate and low moisture retention and storage capacity of these soils, about 30 to 50% of the water percolates down the profile after each heavy rainfall shower (Gupta, 1986). Though water retention at field capacity (0.01 MPa tension) is very low and ranges from 6 to 9% moisture on weight basis, it is held very loosely and is freely available as 50% of it is released just upto 0.1 MPa tension. As the major part of the pore space is made up of non capillary pore space, therefore the saturated hydraulic conductivity of these soils is very high ranges from 32.0 to 35.4 cm/h. Unsaturated conductivity, however, is very low and is of the order of 5.7×10^{-2} to 9.9×10^{-3} cm/h at 0.01 MPa tension (Gupta et al., 1986). *This property helps in conservation of moisture during periods of great* atmospheric demand. Gupta (1979) reported that most of the sand dunes remain near field capacity below 30 to 60 cm depth throughout the year if kept free of vegetation. The water movement during most of the period takes place in vapour phase. Though low unsaturated conductivity values restrict water movement towards roots, the low mechanical impedance values of these soils help in deep penetration and proliferation of roots for sustained availability of water for plant growth.

The fertility status particularly the available nutrient status is an important parameter for raising arable and perennial crops. It has been reported (Dhir, 1991) that the nutrient availability status of these soils is generally adequate for sustaining the existing vegetative cover. However, for raising arable crops, addition of chemical fertilizers is necessary depending upon the availability of rainwater. The soils are very low in organic carbon content (Table 3.2). Nitrogen content is adequate to sustain natural vegetation. Though the phosphorus status seems to be low but generally low response to applied phosphorus has been observed for most of the crops. Potassium is generally adequate and ranges from 138 to 230kg/ha. The micro-nutrient (Fe, Mn, Zn, Cu) status of these soils has also been reported high inspite of the fact that there is little biomass addition by way of crop residues. This shows that these soils are reasonable fertile and it is through rainwater conservation/management that the efficiency of utilization of these nutrient can be enhanced.

Table 3.2: Mean value of organic carbon and available nutrient content in some arid zone soils.

Soil series/types	Org.C (%)	P_2O_5 (kg/ha)	K (kg/ha)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Stable dunes (150-250)	0.08	13.0	158	6.1	5.0	0.65	0.45
Stable dunes (250-450)	0.11	16.7	176	8.3	5.8	0.70	0.50
Shifting dune	0.02	15.4	153	5.7	4.8	0.63	0.48
Chirai	0.13	13.0	138	6.6	9.8	0.88	0.58
Modasar	0.12	16.6	189	10.1	14.9	0.97	0.76
Pal	0.20	17.2	230	7.2	10.4	0.76	0.63

Source: Dhir (1977 b)

4. PRESENT LAND USE PATTERN AND FUTURE NEEDS

In arid zone of western Rajasthan, the most spectacular land forms are sand dunes over 58% of the area of the region (Raheja and Sen, 1964). These dunes are coalesced parabolic, longitudinal, transverse, brachan and obstacle. Out of these, parabolic and coalesced parabolic dunes are the dominant ones (Ghose et al., 1977) and are variable in height. Though these sand dunes have been put in class VI of land capability classification, barring the bigger ones, these are cultivated during the rainy season. Pearlmillet, clusterbean, mothbean and sesame are the main crops of the region. Interdunal plains contain more of silt and clay and retain higher amount of water harvested from partially or fully stabilized sand dunes and thus produce higher crop yields.

Arable farming often with fallow system and open grazing are by far the most common land uses. It is a matter of fact that over a period of several decades more and more fresh land has been brought under farming in arid tract. The present land use pattern in the arid zone and its comparison with the rest of the state is presented in table 4.1. The total geographic area in arid western plains is 12.4 mha, out of which 32.6% is sown every year. The whole of cultivated area is mono cropped with pearlmillet as the main crop. Mixed cropping is also practiced as an insurance against delayed or monsoon failures and also to provide economic stability. Also useful top feed species of *Khejri* and *Zizyphus* are maintained in the agricultural fields to meet the fuel and fodder requirements of the farmer. Another land use system most common in the arid areas of western Rajasthan especially in Jaisalmer area is 'Khadin' system of cultivation. It is a system of in-situ water harvesting where generally rabi crop is taken with the harvested water.

Table 4.1: Land utilization in the zone and Rajasthan (1982-85).

Class	Total area (mha)		Percent of the total area	
	State	Zone	State	Zone
Total geographical area	34.2	12.4	100.0	100.0
Forest	2.1	0.1	6.1	0.8
Land put to non agricultural use and barren and uncultivated	4.5	9.7	13.1	7.9
Permanent pasture and other grazing land, land under miscellaneous tree crops and grasses and cultivable waste	8.1	5.1	23.7	41.0
Current fallow and other fallow land	4.0	2.2	11.8	17.6
New area sown	15.6	4.0	45.5	32.5

Source: A.K. Sen (Personal communication)

Area sown more than once is very little and is around 1% only. Permanent pasture and grazing land including culturable waste is major group spread over 5.08 mha which constitutes 62% of the total area of the state. Area under forest in the state is low, around 6% of the total area. In arid zone the situation is still worse and the area under forest is only 0.8%.

Human and livestock population

Inspite of low productivity of land and the hostile environment, arid areas have shown increase in human and livestock population. The human population in western Rajasthan increased from 9.81 m in 1971 to 13.50 m in 1981. As regards livestock, every farm family keeps a herd of 15-20 animals which sustains on crop resides and grazing on fallow lands. The livestock population also showed an increase from 10.34 million in 1951 to 23.33 million in 1983 (Bharara, 1988). In terms of "adult cattle" the pressure on the land has increased from 54.7 units/100 ha in 1961 to 86.6 cattle units in 1981 against optimum desirable density of 20 adult cattle units/100 ha of permanent pasture and other grazing lands (Ahuja, 1977). This increase in livestock population has increased the fodder requirement from 17.2 million tonnes to 23.3 million tones. The availability of forage from all the sources (grass, crops, top feed) however, ranges from 10-14 million tonnes. To meet this requirement not only marginal or sub-marginal lands are cultivated but are also overgrazed leading thereby to degradation and dersertification.

5. IMPROVED TECHNOLOGY FOR CROP PRODUCTION

Inspite of harsh climatic conditions, the arid zone farmer had been growing crop since ancient times though with low yields and frequent crop failures. He had been following mixed cropping involving millets, legumes, pulses, oil seeds and livestock raising as measures for economic stability against adverse climatic conditions. Though the farmer has been using some conservation measures like growing crops down the slope and in depression with adequate moisture storage capacity of soil, but still the yields are poor because of the use of traditional crop varieties and poor soil and water management and crop planning. Research efforts of about four decades have shown that a certain amount of stability of crop production could be achieved through improved technology discussed as under.

Appropriate crop planning

Crop production plans should be formed only for the area with adequate rainfall, soil depth and water retention and storage capacity. On the basis of rainfall arid areas of western Rajasthan have been divided into three zones: Zone-I (Jaisalmer, Barmer, Bikaner with rainfall below 300 mm), Zone-II (Jodhpur, Nagaur, Jalore and Churu with 300-400 mm rainfall) and Zone-III (Jhunjjhunu, Pali, Sikar with more than 400 mm rainfall).

The probability of drought has been found much higher in Zone-I (80%) than Zone-II (50%) and Zone-III (25%) with higher stability of crop production in the latter. The latter zones therefore, should only be considered for crop production. Marginal and sub-marginal areas should be avoided for crop cultivation.

Choice of crops and varieties

Choice of crops and varieties to be grown depends upon the time of onset of rainfall and the length of the available growing period. Usually short duration and efficient water utilization crops should be preferred. In case of early to normal rainfall (1^{st} to 2^{nd} week of July), the natural choice should be pearlmillet. In case of late onset of monsoon (4^{th} week of July to 2^{nd} week of August) grain legumes like clusterbean, mungbean, mothbean and cowpea etc. should be grown. For better results the critical stages of the crop should coincide with the moist period. Bajra varieties WCC-75, RHB-30, MH-179, Maru gaur, Maru moth, RMO-40 moth, S-8 Moong, FS-68, Cowpea and Til T-13 are some of the established drought resistant varieties most suitable for the arid areas.

Conservation tillage

Tillage for soil preparation before sowing is an important practice for opening up the soil and killing weeds. It has, however, been observed (Gupta, 1987) that loamy sand and sandy loam soil need minimum tillage (once disking) for soil preparation before kharif sowing. Sand soils (more than 90% sand), however, do not need soil preparation before sowing. These soils are highly vulnerable to wind erosion. No tillage and stubble mulching are ideal practices for such soils. Crop stubbbles not only add organic matter to the soil after decay but also act as barriers to the moving sand. Post sowing soil compaction due to rain showers and weeds adversely affect the seedling emergence, subsequent growth and crop stand. The results presented in table 5.1 show that one post sowing cultivation after 20-25 days of emergence was found highly effective in controlling weeds, improving soil environment, growth, yield and water use efficiency of the crops grown on loamy sand and sandy loam soils (Gupta and Gupta, 1982).

Table 5.1: Effect of post emergence cultivation on the weed production and the yield of pearlmillet.

Treatments	Weed production (kg/ha)	Water use (mm)	Grain yield (kg/ha)	Crop water use efficiency (kg/mm/ha)
No cultivation	1720	310	0050	0.16
One post sowing cultivation	0060	292	1140	3.90

Source: Gupta and Gupta (1982)

Wind strip cropping

Wind strip cropping is a useful practice in the areas having soil prone to wind erosion (sand soils), low rainfall and high wind regime. Under this practice erosion resistant crops like grasses are alternated with erosion susceptible crops like bajra and the grain legumes perpendicular to the prevailing wind direction. Misra (1964) reported that protective strips of *Lasiurus sindicus* and *Ricinus communis* established at right angle to the general direction of the prevailing wind, reduced the impact and threshold velocity of the wind, minimized erosion and increased the yield of *Phaseolus radiatus* and *Phaseolus aconitifolius* crops by raising 0.5 to 1.5% moisture in the protected plots. Daulay (1990) showed that intercropping of grain legumes like mungbean, mothbean and gaur with grasses (*Cenchrus ciliaris* in areas above 300 mm rainfall and *Lasirus sindicus* in areas below 300 mm) in strips of 1:2 ratios (grass 2.5 to 5.0 m and crops 5.0 to 10.0 m) was highly useful in checking wind erosion and for the productivity of soil. This practice, therefore, could be used in highly vulnerable areas like Bikaner, Barmer and Jaisalmer.

Water harvesting and recycling

Water harvesting is an age old practice of collecting water in low lying areas, depressions, ponds and tanks for agriculture, ground water recharge and for drinking purposes in the arid areas of western Rajasthan. Jawai, Hemawas, Kharada, Jaswant sagar, Sardar samad are some of the examples of water harvesting system built by ancient kings for drinking and agricultural purposes. Even in Negev desert water harvesting has been in use since ancient times for agriculture, drinking purposes and for the establishment of trees and fruit crops particularly figs, grape vines, pomegranate and olive etc. (Evenari et al., 1971). The formation of network of water harvesting structures and micro-catchments helped the dwellers of the Negev desert to survive and prospers as a nation.

Studies conducted at Central Arid Zone Research Institute, Jodhpur for over two decades showed the usefulness of on farm water harvesting technology for field and orchard crops. Inter row, inter plot and micro-catchment techniques were evolved and perfected for different soil, topographic and rainfall situations. Runoff from micro-catchments was generally found to depend upon rainfall characteristics (amount, intensity, and distribution), micro-catchment characteristics (size, slope, length and nature of the surface and antecedent moisture conditions) and water spreading properties of soil. The result of the seven years field studies showed (Sharma et al., 1986) that micro-catchments produced 13 to 32% of rainfall as runoff at 0.5% slope; and even higher amount at 5% (36 to 45%) and 10% (16 to 44%) slopes. Runoff generally increased with decreasing slope length; runoff for 5 and 10% slopes were nearly equal but greater than for 0.5% slope (Sharma, 1986). Apparently there is a critical slope beyond which runoff is not affected by slope increases. On the average runoff volume decreased with increasing slope length. This effect was more apparent for 0.5% slope and was hardly observed for 5% and 10% slope.

Studies conducted with different catchment to cropped areas ratios revealed 0.5 ratio to be optimum with about 25 to 100 mm of additional water supply depending upon rainfall conditions. Though no significant differences in yield of various crops were observed during normal rainfall years, the yields were generally higher with water harvesting system particularly during drought years. A significant increase in yield of pearlmillet and mungbean crops with higher water use efficiency was recorded during low rainfall years from 1982-1985 (Gupta, 1989). Pearlmillet, mungbean and cowpea were generally found to be the best users of harvested water. Though the system was found highly useful, it has some of the inherent limitations like use of 1/3 of land in constructing catchments, soil disturbance and earth movement etc. In view of this a micro-catchment technique involving 50 cm wide compacted catchment with 50 cm wide cultivated strip having paired rows of crop, was evolved. The technique was found to generate 20 to 80%, runoff depending upon the rainfall conditions. As a result of increased water availability, 50-100% increased in yield of pearlmillet, mungbean and clusterbean was recorded over control without water harvesting.

Zizyphus mauritiana locally called 'ber' is an important horticultural plant which supplies fruit, fodder and fuel wood and could be raised under arid conditions. However, due to low rainfall and other harsh climatic conditions, it gives low fruit yield, bears stunted growth and its survival rate after planting is low. Also established of other tree seedlings without irrigation water is problem because of high mortality rate.

Therefore, a circular catchment technique was specifically evolved for making more rain water available for successful establishment, growth and yield of the transplanted plants (Gupta, 1984). The technique involves the construction of compacted circular catchment of 1.5 m radius with 5-10% slope around the transplanted plants. The result of field trials show that even during low rainfall years from 1986 to 1988, circular catchment technique increased the mean soil profile moisture storage by 10-30 mm/m profile and improved the growth (Fig. 5.1) and fruit yield of ber plants. Also tree seedlings of *Acacia nilotica* (babul) and *Prosopis cineraria* (khejri) were successfully established with this technique.

A large part of the rainfall is absorbed by the sandy soil of the catchment, thereby reducing the total amount of runoff/harvested water. Various surface covers and sealants were therefore, tried during 1985 and 1986 for determining their relative efficiency for runoff generation. Plastic covered catchments were found to generate 95% runoff while Janta emulsion (asphalt), pond sediment and compacted catchments yielded 91%, 88% and 66% runoff respectively. While the coefficient of correlation between precipitation and runoff was near unity (0.99 to 0.999), the threshold retention was 0.06 to 0.76 in plastic, 0.29 to 0.71 in Janta emulsion, 1.98 to 3.09 in pond sediment and 1.23 to 2.75 in earth compacted catchments (Singh et al., 1988). Uncompacted earth catchments were found prone to crust formation. As a result of this after 7 years of formation of these catchments, the threshold rainfall was found to decrease from 4.7-6.00 mm to 2.3 mm, thereby increasing the runoff efficiency from 22-36% to 52-56%.

Construction of farm ponds and tanks and 'nadis' with appropriate catchment area help in runoff collection during periods of high intensity rainfall (Fig. 5.2). The water thus collected is used for supplemental irrigation during periods of drought, for the establishment of nursery plants and orchards trees and for drinking purposes. Though the construction of cement concrete tanks by each farmer may be expensive, yet it could be done with the support of government agencies and nationalized banks etc.

Use of manure and fertilizers

Sandy soils are less productive because of their inherent characteristics of low fertility and poor moisture retention and storage characteristics. The productivity of such soils could be increased by the combined use of fertilizers and manure's (Gupta et al. 1983). The main constraints in the use of fertilizers and manure's is however, uncertain rainfall conditions, high cost of fertilizers and the low availability of manure for this purpose. Arid zone farmers hardly uses fertilizers for crop production under rainfed conditions. He feels the use of fertilizers to be extremely risky and non-remunerative. The results for four years field trials however, showed (Table 5.2) that an application of 10-20 kg N/ha along with 1-2 tons of manure at the time of soil preparation and sowing improved soil environment and resulted in better establishment, growth and higher yield of pearlmillet particularly under normal and low rainfall situations. A further split does of 10-20 kg N/ha could be considered if the subsequent rainfall conditions permit so (Aggarwal and Venkateswarlu, 1989).

Table 5.2: Effect of organic manure and fertilizer on the yield of pearlmillet (bajra).

Treatment	Grain yield (kg/ha)		
	Above normal	Normal 220-260 mm	Below normal· 220 mm
Control	1340	750	250
10 kg N + FYM	2020	1500	680
20 kg N/ha	2070	1180	450

Source: Aggarwal and Venkateswarlu (1989)

Mulching

Mulching is a practice of covering the surface of soil with organic materials, plastics, stones etc. to check evaporative loss from soil, modify soil thermal regime, check weed population and their growth and improve the availability of water and nutrients to the plants. The studies conducted at CAZRI for over ten years show (Gupta, 1980; Gupta and Gupta 1983; Gupta and Gupta, 1985) that post sowing mulch application in inter row spaces with locally available plant materials like weeds, grass and other waster materials at the rate of 2 to 5 tons/ha depending upon the availability reduced the maximum soil temperature by 1 to 12°C and increased the profile moisture status by 5 to 15 mm. The magnitude of reduction of soil temperature and increase in moisture status by mulching was however, found to depend upon the rainfall distribution, atmospheric conditions and type and stage of crop. It was generally higher during the period of frequent droughts and also with less crop canopy. Mulching also suppressed weed growth and weed population, increased nitrogenous activity and thus increased the production of grain legumes grown during monsoon season by 70-80% (Table 5.3, Fig. 5.3). Mulching has also been found useful against crust formation by absorbing rain drop impact and also check the growth of fungus macro-phomina phaseolina which seriously affects growth and establishment of seedlings of legumes (Gupta and Gupta, 1986; Gupta, 1987; Gupta, 1989).

Table 5.3: Effect of grass mulching on weed production and yield of pulse crops.

Treatments	Weed dry matter production			Mean grain yield		
	Green gram	Mothbean	Clusterbean	Green gram	Mothbean	Clusterbean
Control	1130	440	360	140	210	380
Mulching	680	440	300	390	400	650

Source: Gupta and Gupta (1983).

Conservation of irrigation water

Irrigation water is a precious resource in the arid areas. About 5% area of arid Rajasthan is under irrigation. Now with the coming of Indira Gandhi Canal, more area is being brought under irrigation. Excessive of this water leads to heavy percolation and evaporation losses and has created problems of water logging and salinity at many places. In view of this it has become essential to adopt conservation irrigation like drip and sprinkler systems of irrigation. Studies conducted at CAZRI show (Table 5.4) significantly higher production of crops with drip system of irrigation over conventional (furrow) system with 50% saving in irrigation water (Singh and Mann, 1979). Also saline water of EC 3000 micromhos/cm^2 was successfully used with drip system with as high yield of potatoes as 24.5 tons/ha against 19.5 tons/ha obtained with furrow irrigation.

Table 5.4: Crop yields as affected by different irrigation systems.

Crop	Yield (t/ha)	
	Drip	Furrow
Tomato	100	25
Potato	33	25
Cabbage	36	30
Cauliflower	26	20
Maize	12	4

Source: Singh and Mann (1979).

Drip and sprinkler system of irrigation though have not been found highly useful for vegetable crops, these have not been tried for orchard crops of afforestation purpose. In Indira Gandhi Canal Command areas, sprinkle irrigation is being used for afforestation of sand dunes. In Egypt (Sinai desert areas) and erstwhile USSR (Karakum desert) drip and sprinkle systems are being successfully used for plantation of orchard crops.

Shelterbelts

Shelterbelts can be defined as a single or multi rows of trees or trees and shrubs planted across the wind direction for providing protection to soil, environment and the crops. The importance and utility of shelterbelts in controlling wind erosion, reducing evaporation demand and protecting crops from hot desiccating winds particularly in arid and semi arid areas has been widely recognized throughout the world. In India, Bhimya et al. (1958), Raheja (1963), Ganguli and Kaul (1969) initiated work on shelterbelt plantation and recommended different types of shelterbelts for farmers fields and road side plantations in the arid areas.

Shelterbelt plantation and their effectiveness

Bhimaya and Chowdhari (1961) discussed the planting details of *Acacia nilotica* and *Dalbergia sissoo* shelterbelts planted at Central Mechanized Farm, Suratgarh and also along the roads and railway tracks. The planting method consisted of digging of ditches of triangular cross section (45 cm wide and 45 cm deep) along the planting line with a mechanical ditcher. Planting was done in 30 cm^3 pits staggered with each other on either side of the ditches used for irrigation purposes.

At C.R. Farm, Jodhpur three row shelterbelt was raised by planting six months old nursery raised (in polyethylene bags) seedlings in staggered 60 cm x 60 cm pits (2-3 kg manure mixed with soil) dug up with tractor driven auger during monsoon season. During first year of planting the seedlings were irrigated by giving 10 liters of water/seedling/month. Three types of shelterbelts planted this way of *Acacia tortilis – Albizziz lebbek – Acacia tortilis, Cassis siamea – Allbizia lebbek – Casia simea, Prosopis juliflora – Albizia lebbek –Prosopis juliflora.* The central row comprised of tall growing *Albizia lebbek* forming thereby pyramidal structures. These shelterbelts were planted across the regular wind direction and repeated after every 100 m distance.

The shelterbelt have been found effective in reducing the wind velocity near the ground by exerting a drag on the wind and deflecting the wind stream. The effectiveness however, depends upon many factors like wind velocity itself, direction, shape, width, tree height and density etc. A series of experiments were conducted in early seventies to evaluate the effectiveness of different shelterbelts raised at C.R. Farm, Central Arid Zone Research Institute, Jodhpur (Gupta et al. 1983, 1984). The results revealed that three row shelterbelt of *Casia siamea – Albizia lebbek – Casia siamea* was most effective (36% and 46%) in reducing wind speed at 2H distance in leeward side of the shelterbelts both during summer and monsoon season respectively (Gupta and Ramakrishna, 1988). At larger distance the effectiveness ranged from 12 to 24% only.

Shelterbelts were found to reduce evaporation from the sheltered area. Though the effectiveness has been observed upto10H distance, it was higher (8 to 12%) at 2H distance. Due to reduction in evaporation moisture status of sheltered field was generally 2-4% higher than unsheltered field (Gupta and Ramakrishna, 1988). As a result of these improvements in soil environment a 20-30% increase in yield of pearlmillet was recorded.

Shelterbelts besides reducing wind speed evaporation, were found useful in checking wind erosion and fertility loss from the agricultural fields. The results of the field experiments show (Table 5.5) that three row shelterbelt of *Cacia siamea – Albizia lebbek – Cacia siamea* was highly effective in reducing the wind speed and the loss of nutrients from the cultivable fields in western Rajasthan. Ramakrishna (1984) reported the usefulness of crop strips as micro shelterbelts in improving the growth and yield of vegetable crops grown under irrigated condition.

Table 5.5: Effect of different shelterbelts on wind speed reduction and wind erosion from soil.

Shelterbelt type	% reduction of mean wind speed in summer			Average soil loss due to wind (kg/ha) (April to June)
	2H	5H	10H	
P. juliflora-A. lebbek-P. juliflora	33	17	12	351.2
C. siamea-A. lebbek-C. siamea	36	17	13	184.3
A. tortilis-A. lebbek-A. tortilis	36	25	13	300.0
Bare without shelterbelt	-	-	-	546.8

Source: Gupta et al., (1983)
H denotes height of shelterbelt.

6. AGROFORESTRY FOR SUSTAINED PRODUCTION

Agroforestry may be defined as a practice of growing trees in association with crops for the optimum utilization of available resources for meeting the needs of grain, fodder and fuel wood. In arid areas where crop production is extremely risky the farmer depends upon animal husbandry for sustenance. Aware of the risks of crop production and his requirements, he has been following agroforestry since time immemorial.

Traditional agroforestry

In arid areas the farmer has been traditionally protecting 'Khejri', 'Bordi' and 'Babul' trees in their farmlands. He has a firm conviction that these trees besides conserving, add to the fertility and overall productivity of soil. These species are drought hardy and well adapted to the climatic conditions of the desert. Satyanarayan (1964) and 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. Gupta and Sharma (1992) reported 30-40 trees/ha in areas around Jodhpur and as high number as 104 trees/ha in Sikar region without any adverse effect on crop production. Mann and Saxena (1980) reported the effect of different densities of 'Khejri' on the major crops grown in different habitats. The data presented in Table 6.1 do not show much variations in crop yields due to tree densities. Even as high a tree density as 80 tree/ha 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 (Aggarwal and Lahiri, 1977).

Table 6.1: Average crop yield (local varieties of kharif crop) under various tree densities of khejri.

Habitat	Khejri density/ha	Bajra	Crop yields (kg/ha)			
			Moth	Gaur	Moong	Til
Flat alluvial plains	30	340	180	180	300	-
Sandy undulating plains	60	380	360	280	250	-
Flat burried pediment	45	320	-	310	-	190
Undulating burried/pediment	25	340	180	180	300	-
Interdune	52	370	60	250	-	-
Sand dune	15 •	200	60	150	-	50
Sandy plains	80	360	320	290	-	-

Source: Mann and Saxena (1980)

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).

Table 6.2: Components of traditional agroforestry practices in western Rajasthan.

District	Main tree/shrub species	Mean crops	Prominent grass species
Ganganagar	Prosopis cineraria, acacia nilotica subsp. indica, Acacia tortilis	Pearlmillet, Mungbean and clusterbean (rainfed, Wheat, Cotton, rice and mungbean (irrigated)	Lasiurus sindicus
Bikaner	Prosopis cineraria, Zizyphus nummularia, Calligonum polygonides hacquemontii	Mungbean, Mothbean, Clusterbean and pearlmillet	Lasiurus sindicus
Jaiselmer	Prosopis cineraria, Zizyphus nummularia, Calligonum polygonides Acacia Senegal, Capparis decidua	Mungbean, Clusterbean and pearlmillet	Lasiurus sindicus
Barmer	Prosopis cineraria, Zizyphus nummularia, Capparis decidua Tecomella undulata	Pearlmillet, Mungbean and clusterbean (rainfed)	Lasiurus sindicus Cenchrus ciliaris
Jodhpur	Prosopis cineraria, Zizyphus nummularia, Acacia Senegal, Capparis decidua	Pearlmillet, Mungbean and clusterbean rainfed, Wheat, Chilli, mustard and mungbean (irrigated)	Cenchrus ciliaris
Churu, Jhunjunu and Sikar	Prosopis cineraria, Zizyphus nummularia Gymnosporia montana	Pearlmillet, Mungbean and clusterbean	Lasiurus sindicus Cenchrus ciliaris
Nagaur	Prosopis cineraria Acacia Senegal	Pearlmillet and Mungbean (rainfed) and clusterbean Wheat, mustard and mungbean (irrigated)	Cenchrus ciliaris
Jalore	Prosopis cineraria, Salvadora persica, Salvadora oleoides, Acacia nilotica, Punica granatum (Fruit tree)	Pearlmillet, Mungbean Isabghol, Sorghim & cumin.	Cenchrus ciliaris
Pali	Acacia nilotica, subsp. indica, acacia nilotica, var. cupres-siformis, Acacia leucophloea, Acacia catechu Salvadora spp.	Sorghim, Pearlmillet, Mungbean and clusterbean	Cenchrus ciliaris, Cenchrus Setigerus

Besides 'Khejri' and 'Bordi' there are also other trees and shrubs used in different traditional agroforestry system prevalent in western Rajasthan (Table 6.2). In Pali *Acacia nilotica* (Babul) and *A. nilotica var. cupressiformis* (Khajoor, babul) 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. Khajoor babul is a tall, conical shaped tree with little shade and does not interfere wit crops and field operations, there is very little scope of looping for this tree. This is a phreatophyte and does not compete with crops. In *Acacia nilotica* (Babul) however, lopping is practiced.

In Nagaur, Churu, Jhunujunu and Sikar areas (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 excels* (Arru) is grown in Sikar. It is a fast growing erect tree and its leaves are fed to goat and sheep.

In Jaipur district, *Prosopis cineraria* (Khejri) and *Acacia Leucophloea* (Rhoonja) are common trees in agroforestry. The foliage of 'Rhoonja' is not of much use except goat eats it.

Some improved agroforestry systems

Although *Prosopis cineraria, Acacia nilotica and Zizyphus nummularia* are the trees commonly found in traditional agroforestry, some of the other trees recently introduced for agroforestry purposes are *Acacia aibida, Acacia tortilis, Tecomella undulata, Hardwickia binata, D. nutan* and *C. mopane.* These trees have fodder, fuel wood and other economic values and could be tried for agroforestry purposes. Some of the improved systems developed by Central Arid Zone Research Institute, Jodhpur with these trees are discussed as under.

Agri-silvicultural system

Acacia tortilis: This tree is a very fast growing 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. Sharma et al. (1992) however, reported decrease in yield of pearlmillet and clusterbean grown in association with four year old A*cacia tortilis* planted in 5 m x 5 m spacing. The reduction could possible be due to root competition however, does not seem practically feasible. *Acacia tortilis,* however, is an excellent tree for rehabilitation of wastelands due to its fast grazing nature.

Acacia albida: This tree has been recently introduce in arid regions from East Africa. It is a tall and straight growing tree and sheds its leaves in monsoon season and therefore does not seem to compete with crops. Harsh et al (1992) reported 108.2 cm mean annual height increment of this tree grown in association with mungbean and clusterbean at 5m x 5m, 10m x 5m and 10m x 10m spacings. Gupta (1992) reported maximum dry matter production of pearlmillet grown in association with this tree at 10m x 10m spacing. Spacings less than this have been found to adversely affect crop beside obstructing the movement of tractors for land preparation etc.

Acacia nilotica var. Cupressiformis: This is a tall tree with branches growing upward and it does not cast its shade on the crops growing underneath. Studies conducted at Pali have shown this tree to be highly compatible with crops. Mungbean, clusterbean and sorgum were successfully grown without reduction in yield in association with this tree planted at 5m x 5m spacing.

Holoptelia integrifolia: This is an important fodder tree. Eight years old plants planted in 5m x 5m spacings at Jodhpur markedly reduced the grain and dry matter yield of mungbean and clusterbean (Paroda and Muthana, 1979). Lopping, however improved the yields.

Agri-horticulture

Ber is an important arid zone tree which supplies fruit fodder and fuel wood. Buded ber (*Zizyphus mauritiana)* has found to grow very well with water harvesting or limited irrigation. Circular basin technique of water harvesting developed by CAZRI has been found highly useful in making more rain water available for the establishment of trees and horticultural plants. Studies conducted at Jodhpur showed that three years old ber plantation developed by this technique (400 plants/ha) performed very well in association with mung bean even under very low rainfall condition (rainfall 210mm in 1988) (Fig.6.1). Though there was reduction in yield of inter cropped mungbean, the fruit production from the trees compensated it (table 6.3). The system was rather found more profitable than raising the sole crop of moong. Although plantation at spacing of 5m x 5m was found highly useful, it is not practically feasible because it creates hindrance in the field operations. Therefore, a spacing of 5m x 10m (plant to plant 5m; row to row 20m) could be recommended (Gupta, 1992).

Bordi (*Zizyphus rotundifolia)* as a tree is protected and is allowed to grow at farmer's fields because it supplies fruit (ber). Though not of good quality, fodder (locally called pala) and thorny wood material for fuel and fence purposes. The results of a recent study of raising pearlmillet and clusterbean with four years old plantation in 5m x 5m spacing showed only marginally reduction of crop yields and tree was found highly compatible with crops (Sharma et al. 1992). This tree, therefore, could be recommended for agroforestry in rainfall zones of 200-300mm.

Pomegranate another fruit tree has been found compatible with pearlmillet, mung bean, isabgol, sorghum and cumin in the irrigated areas of Jalore district in Rajasthan.

Table 6.3. Economic feasibility of agri-horticulture system for arid lands.

Treatment	Rainfall (mm)	Ber Fruit Yield (Kg/ha)	Grain Yield (Kg/ha)	Economic returns (kg/ha)*	Net profit (Rs./ha)
Sole Crop (Moongbean)	210	-	600	4800	-
Mungbean intercropped with ber	210	800	160	7680	2800

Source: Gupta (1992)
*Ber fruit @ Rs. 8/kg: Mungbean @ Rs 8/kg.

Silvi-pasture system

Successful crop production is extremely difficult in areas less than 200mm rainfall. These areas and degraded lands could be rehabilitated by the use of silvi-pasture systems for continuous supply of fodder, fuel wood and other associated products (Fig.6.2). The main consideration for the selection of a particular system for these areas should be the total amount of available rainfall, soil type, depth and other habitat characteristics, drought hardiness of the vegetation having multiple uses. The success of the system., however depends upon the proper spacing, compatibility of different species and other management practices. Kaul and Ganguly (1963) reported that *Zizyphus nummularia* (Bordi) generally found in community grazing lands (Oran) and cultivated fallows (Beeds) and provide leaf fodder (Pala) and herbage from understorey vegetation could be grown in silvi-pasture system in 300-400 mm zone. They initiated some studies at Pali to identify the ideal ratio of shrubs to grass cover and found and inverse relationship between shrubs density and grass yield (Table 6.4). They further concluded that a density of 14% area of the community of grazing land covered by shrub was optimum for high forage production. Later studies (Sharma and Vashishtha, 1985) with two species of Jujube (*Zizyphus rotundifolia* and *Zizyphus nummularia*) planted in four different densities of 280, 210, 140, and 70 plants/ha were not found to effect the yield of buffel grass grown in Samdari (Barmer) in Rajasthan.

Table 6.4: Average yield of leaf fodder(pala) and grass in the *Zizyphus* scrubland.

Percent density of *Zizyphus nummularia*	Leaf fodder yield(kg/ha)	Grass yield (kg/ha)	Combined yield (kg/ha)
18	150	545	695
14	125	875	1000
11	105	770	875

Source: Kaul and Ganguli (1963).

Muthana et al (1980) conducted some studies on *Acacia tortilis, Colophospermum mopane and Hardwickia binata* planted in 5m x 5m and 10m x 10m spacings in association with *Cenchrus ciliaris* grass but did not observe any yield differences of grass. A spacing of 10m x 10m was generally found to produce higher yield of the grass. Ahuja (1980) observed inverse relationship between tree density and grass yield. The highest grass yield of 1.1 to 1.5 t/ha was recorded under Khejri and the lowest of 0.6 to 0.7 t/ha under Kumat plantation of 14 to 18 years of age. Muthana et al (1980) reported 7.4, 3.2 and 1.0 q/ha dry forage yield of grass with coppiced plants of *Acacia tortilis* planted at 6 x 6, 4.5 x 4.5 and 3 x 3m spacings respectively. There was negligible grass production under uncoppiced plants. Shankarnarayan and Saxena (1976) also did not recorded any yield differences of grasses grown under the species of *Prosopis cineraria,* Acacia *tortilis* and *Albizzia lebbek.* Ahuja et al., (1978) however, revealed (Table 6.5) maximum grass production under 14 to 18 years old plantation of *Prosopis cineraria* (Khejri) and minimum under *Acacia senegal* (Kumat). Higher grass production under Khejri has also been reported by various other workers (Shankar et al., 1976; Sharma et al., 1980; Shankarnarayan and Singh, 1990). Higher grass production under Khejri could be due to reduced competition for moisture and increased organic matter, available nitrogen, phosphorus and micro nutrients content in soil (Aggrawal et al., 1976).

Table 6.5: Dry forage yield (t/ha) under different grasses.

Tree species	1972	1973	1974	1975	Mean
A. Lebbek	0.53	2.59	.059	1.90	1.40
P.Cineraria	0.60	2.18	0.54	2.22	1.54
T.undulata	0.45	3.36	0.36	1.73	1.47
A.Senegala	0.16	1.80	0.15	0.63	0.69

Source: Ahuja et al (1978).

Eight years studies conducted with *Acacia tortilis* planted in different spacings at Jodhpur revealed (Table 6.6) that 10m x 5m spacing increased the grass production over control (pure pasture) particularly during normal and high rainfall years. During low rainfall years however, the yields were either comparable or marginal decreased. Muthana et al. (1985) while working economics of silvi-pastoral system reported three fold benefits with *Acacia tortilis* planted in grassland in 10m x 5m spacing over pure grassland.

Table 6.6: Dry forage production (kg/ha) with and without tree spacings.

Treatment	1977	1978	1979	1980	1981	1982	1983	1984
Annual rainfall (mm)	353	355	785	232	317	417	513	231
S_1 (10 x 5m)	1250	670	1360	670	480	460	1540	830
S_2 (10 x 10m)	990	570	900	590	350	430	1560	870
S_0 (pure pasture)	1600	590	1140	710	530	220	990	830

Source: Sharma et al., (1980)

SEM for years + 99; SEM for spacing + 86.

Recent studies (Sharma et al. 19992) with four year old *Acacia tortilis* and *Zizyphus rotundifolia* planted at 5m x 5m spacings at Jodhpur also showed reduction in yields of *Lasiurus sindicus* and *Cenchrus ciliaris* grasses under low rainfall situation. The reduction in yield was however, more in case of *Lasiurus sindicus* in association with *Acacia tortilis*.

7. SHIFTING SAND DUNES AND THEIR CONTROL

The problem of shifting sand dunes exists throughout the world along interfaces where deserts, arable lands and man come into contact. In arid areas of western Rajasthan, sand dunes are the dominant formations and their intensity varies from place to place (Table 7.1).

Table 7.1: Extent of sand dunes in arid Rajasthan.

Extent of sand dunes (%) of area affected	% of total arid area of Rajasthan
No dunes	41.50
0-20	8.90
20-40	18.60
40-60	14.70
60-80	4.80
80-100	11.50

Source: A.K. Sen (Personal communication)

They are the potential threat to all communication net work, economic establishment and productive agricultural lands (Fig. 7.1). These dunes are both old and new. The old dunes are well vegetated. Due to biotic activity however, these also become active. The following techniques have been developed by CAZRI (Bhimaya and Ganguli, 1961; Kaul, 1968) for the stabilization of these dunes. These techniques are grouped into three major steps.

(i) Protection from biotic interferences.

(ii) Erection or development of physical barriers to minimize surface sand drift.

(iii) Re-vegetation or afforestation of the treated dunes.

Protection from biotic interferences

Most parts of arid lands especially in Indian sub-continent suffer from acute biotic stress as a result of ever increasing human and livestock populations and associated demands. Therefore, it is very essential to fence the area to be stabilized by angle iron posts with three linings of barbed wires. In sandy tract ditch fencing is not feasible because of high wind velocity and with very high degree of sand movement, the ditches are often filled with eroded soil. Barbed wire fencing in Beechwal area of Bikaner for 25 years checked the biotic activity resulting in the development of a permanent cover of grasses like *Lasiurus sindicus. Cenchrus ciliaris, Panicum turgidum, Cenchrus biflorus* etc. These grasses by their extensive root system fixed the sand and checked its movement besides being a perennial source of fodder.

Sand dune fixation by establishment of artificial barriers

Sand dune fixation is essential to check the movement of sand and protect the young planted seedlings from abrasive action of the moving sand. It can be achieved by constructing checker boards or parallel hedge system depending upon the direction of the wind. Locally available materials like *Leptadenia pyrotechnica, Zizyphus nummularia, Calligonum polygonoides, Lasiurus sindicus, Panicum turgidum* and *Erianthus munja* are used for this purpose by burying them vertically downwards across the wind direction in rows 2-3 m apart particularly at the crest of the dune. It should be 5-10 m towards the base.

Afforestation of sand dunes

After fixation, sand dunes can be permanently stabilized with vegetation. It can be done by direct seedling, transplanting seedling or cuttings of indigenous or exotic but adopted species. The seedlings are planted in pits of 50 cm^3 at 3m x 3m or 5m x 5m distance in between the strips of micro wind breaks across the wind direction. The space in between the rows could be used for planting grass slips or sowing grass seed.

The success of sand dune stabilization depends upon choosing the right type of species, planting healthy seedlings, timely and deep planting, timely replacement of casualties and proper care of the plantation. Kaul (1985) reported that *Prosopis chilensis* (Syn. *P. juliflora*), *Zizyphus* tree species, *Calligonum polygonoides, Crotalaria burhia, Aerva javanica, Zyzyphus nummularia* (shrub), and *Lasiurus sindicus, Panicum turgidum. Panicum antidotale* grasses are most suitable plant species for sand dune stabilization in the arid zone of western Rajasthan. *Calligonum polygonoides* with extensive root system was found to be excellent sand binder. Though *Prosopis cineraria* is a very deep rooted and hardy tree, it grows slowly and provides complete cover after a long time. Fast growing khejri is developed by CAZRI could be used for these purposes. Tree and grass species suitable for different rainfall conditions are presented in Table 7.2.

Table 7.2: Suitable tree and grass species for sand dune afforestation.

Rainfall zone	Tree species	Grass species
150mm	*Acacia tortilis, Prosopis juliflora, Acacia nubica, Calligonum polygonoides*	*Lasiurus sindicus*
150-250mm	*A. tortilis, P. juliflora, Calligonum polygonoides, Acacia senegal, Prosopis cineraria, Acacia bivenosa*	*Cenchrus ciliaris, Cenchrus setigerus*
250m	*A. tortilis, P. juliflora, C. polygonoides, a. senegal, P. cineraria, C. mopane, A. bivenosa, C nutan.*	*Cenchrus ciliaris, Cenchrus setigerus.*

Source: J.P. Gupta (1990).

Planting techniques

About 6-8 month old plants raised in polyethylene bags in the nursery are used for planting. For successful establishment these are planted with onset of monsoon at 30-50 cm depth by removing polyethylene bag but without disturbing the block of soil and exposing the root. If water is available a shallow watering is provided for the establishment of roots. Fig. 7.2 shows successful sand dune stabilization by planting with this technique. Costin et al. (1974) reported better results by deep planting (upto 1.5 m) of long cuttings of *Tamarix aphylla* with a diameter not less than 1.5-2.6 the cutting. Shallow planting (50-70 cm) in depressions, deep planting (80-120 cm) on slopes and further deep planting (150 cm) on the top of the dunes was generally found economical by them. Planting in pits or bored holes was found better than planting by digging with a spade as in the latter case there was more loss of moisture. Gupta and Muthana (1985), however, reported higher survivability and better growth and establishment of seedlings of *Acacia tortilis* planted in the sandy plains. The previously made pits were used by placing pond sediments as subsurface moisture barrier at 60 cm depth in 5 mm thickness and refilled by mixing manure at the rate of 5 kg/pit. The higher seedling survivability and better growth and establishment is attributed to reduction in percolation loss and more availability of water to the young seedlings. In the absence of adequate rainfall, post planting irrigation's help in the establishment of seedlings. Ten liters of water per seedling per irrigation has generally been found adequate for the first two years. Spreading a thin layer of sand around the seedling after each irrigation helps in conserving moisture by reducing evaporation loss.

Economics of sand dune afforestation

Sand dune fixation by checkerboard method is labour intensive and is not economical in the countries where manpower is expensive. In such countries use of chemical has been found quite economical. In India, however, checkerboard technique was found quite effective and economical. Afforestation of sand dunes with *Prosopis chilensis* could yield fuel wood of about 38 tonnes/ha after 10 years taking average yield of 95 kg per tree with a tree spacing of $5m^2$ (Bhimaya et al. 1967). *Calligonum polygonoides* plantation at a spacing of $3m^2$ was found to yield about 21 tonnes/ha (an average of about 19 kg/plant) after six years (Kaul, 1985). The plantation of *Acacia tortilis* at $5m^2$ spacing has been reported to yield fuel wood of about 30 tonnes/ha after a period of 10 years. The cost of sand dune afforestation including fencing has been reported to be about Rs.1000/ha (Kaul, 1985). However, with the increase in inflation it could be even twice this amount. In erstwhile USSR however, the cost of fixation manually and afforestation of sand dunes (planting 3000 bushes) is much higher (1500-2000 roubles/ha). Chemical fixation and afforestation is of course cheap (250-280 roubles/ha) and is comparable with the one evolved under Indian conditions.

Aerial seeding of sand dunes

Though the success rate is much higher in case of seedling transplant technique, yet with this it is not possible to cover large areas in short period of time due to many cost inhibitive factors. Improved techniques of direct seedling seems to be the only answer for large scale sand dune stabilization. One such technique is aerial seeding of a mixture of pellitized (clay + sand + cowdung in 1:3:1 proportion) seeds of *acacia tortilis, C. mopane, D. nutans, Prosopis cineraria, Z. rotundifolia, Citrullus colocyathis* and *Lasiurus sindicus* at the rate of 14 kg/ha with onset of monsoon. The technique was found viable. However, in case of some failures repeated sowing may be necessary.

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

8. AFFORESTATION OF SHALLOW GRAVELLY AND ROCKY WASTELANDS

Shallow gravelly and stony wastelands

These lands occupy about 1.07 Mha of area mostly in Jaisalmer and Bikaner and to a lesser extent in Barmer and Jodhpur districts of western Rajasthan (Fig. 8.1). The surface of these lands is generally covered with about 15-20% gravel's but at places the presence of gravel's are as high as 70-80%. The soil has depth of 10 to 40 cm and is mixed with gravel's. The underlying strata are generally gravelly or concretionary in nature. The water retention and storage capacities of these soils are low due to the stony nature of soil and the less soil depth. A greater part of the rainfall is lost as runoff. These lands, therefore, generally support low vegetation. However, with contour furrowing, trenching and other management practices, grasses like *Cenchrus ciliaris, Cenchrus setigerus* and *Lasiurus sindicus* and trees like *Acacia senegal, Capparis sphyvlla, Acacia tortilis, Zizyphus rotundifolia* and *P. juliflora* could be grown. As regards afforestation of such areas, Bhimaya and Kaul (1960) reported highest seedling survival of *Albizzia lebbek* and *Eucalyptus camaldulensis* in pits 30 cm in diameter and 60 cm depth; of course with stunted growth under 375 mm rainfall situation. Planting in deep pits of 60 cm diameter and 90 cm depth by breaking the hard pan resulted in 100% seedling survival and mean annual height increment of 52.2 cm and 187.0 cm in *Azadirachta indica* and *Albizzia lebbek* respectively. The annual herbage production varies from 1500-2000 kg/ha and 200-300 kg/ha from protected and unprotected areas respectively.

Semi rocky areas

These soils are characterized by their shallow depth at the foothills and are formed by colluvial silt and rock fragments. Earlier studies (Bhimaya and Kaul, 1960) showed that seedling of *Acacia senegal, Prosopis juliflora, Tecomella undulata, Acacia arabica* and *Prosopis cineraria* on staggered contour ridge cum trench 3 m in length and 60 x 60 cm in cross section was highest successful with maximum survival (50%) of *Prosopis juliflora* after 9 years of planting. Planting of half sprouted stumps in 60 x 60 cm half filled pits with a crescent shaped ridge across the natural slope was also found successful with 94% survival of *Prosopis juliflora,* 96% of *Albizzia amara,* 95% of *Azadirachta indica* and 90% that of *Holoptelea integrifolia* under 225 to 350 mm rainfall condition.

Rocky and gravelly wastelands

These are mostly hill area or foothills devoid of vegetation. The rocks are exposed because of prolonged erosion and weathering. The hills are highly denuded and can not be put under any economic activity. There are, however, some spots with soil accumulation which can be used for planting purposes. The half-filled pits of 50-60 cm are dug out and planting is done. Various soil conservation measures like contour bunding, trenching, check dams and gully plugging are adopted wherever possible for successful afforestation. Various tree species recommended for such lands are *Acacia tortilis, A. senegal, Prosopis juliflora, Albizzia lebbek, Cacia siamea, Azadirachta indica* and *Cenchrus setigerus* could be grown successfully in depression wherever some soil is available.

9. MANAGING SALT AFFECTED WASTELANDS

About 0.44 Mha of area in southeastern part of arid Rajasthan suffers from primary salinity. The main problem of these areas is salinity of the substrata and the ground water. The major areas of salt affected lands have mean ECe from 18 to 65 mmhos/cm with predominance of sodium chloride and sodium sulphate salts.

Afforestation of salt affected wastelands

Salt affected wastelands can be afforested with salt tolerant plant species. Different tree and grass species are presented in Table 9.1 according to their relative tolerance. Most of the species are sensitive at germination of early stages of establishment. For successful afforestation the soil working technique would be such as to make more rain water available for leaching salts and establishment of seedling. Construction of circular catchments can be helpful in more rainwater supply. Studies conducted at Pali (Jain, 1986) showed that pits of the size of 0.6 m^3 to 1 m^3 with manure @ 25 kg/pit and gypsum 3.6 kg/pit in case of sodic soils or auger holes of 150 cm depth and 15 cm diameter filled with original soil and 2 kg gypsum + 7-8 kg manure helped in improving soil environment and establishment of tree seedlings of *Acacia nilotica*, *Prosopis juliflora* and *Casurina equisetefolia*. Studies on irrigation with saline water indicated maximum survival and early growth of *Prosopis juliflora* and *Tamarix articulata* even with 9.0 mmhos salinity waters. Seedlings of *Eucalyptus hybrid* and *C. mopane* were found sensitive to high salinity waters. Growth of *Acacia aneura*, *Tamarix articulata* and *D. glomerata* decreased with high salinity irrigation water.

Table 9.1: Tolerance of different plant species to salinity.

Vegetation	Salinity tolerance mmhos/cm			
	Very high (>16)	High (16-8)	Medium (8-4)	Low (< 4)
Trees	Prosopis juliflora, Tamarix articulata, Acacia tortilis, Chenopodium sp.	Eucalyptus camaldulensis, Eucalyptus hybrid, Leucaena leucocephala, Dichrostachys glomerata.	Azadirachta indica, Acacia aneura, Colophospermum mopane.	Casia siamea, Albizzia lebbek.
Grass/shrub species	Sporobolus marginatus, Eleusine compressa, Dactyloctenium sindicum	Eremopogon faveolatus, Sehima nervosum, Cenchrus setigerus.	Heteropogon tortus, Zizyphus nummularia.	Eragrostis ciliaris, Dichanthium annulatum.

Source: Jain (1986)

Management for raising pasture

Soil working and formation of contour furrows 60 cm wide and 20 cm deep with soil mounds helps in increased infiltration of rainwater and leaching of salts. These conditions were found to help germination and regeneration of grasses. For reseeding of pasture, the seed of tolerant species are dibbled on rain shower. Transplanting of 30-40 days old nursery raised seedlings or root slips are also recommended.

10. REHABILITATION OF MINED SPOILED WASTELANDS

Mining is one of the important economic activity in the arid areas of western Rajasthan. It however, destroys the biological potential of the land and turns it into a wasteland. The total geographic area in each districts of western Rajasthan ranges from as low as 0.03% (Jaisalmer) to as much as 0.75% (Jhunjhunu). The most vulnerable areas from mining activity point of view are Jodhpur tehsil, Barmer tehsil, Nagaur and Ladnu tehsil and Nokha and Shri Kolayat tehsils of Bikaner. The mining is carried out through both surface and underground operations. In case of surface mining the over burden material is placed to the adjacent lands and subsequently low grade minerals are piled as low to big heaps in a haphazard manner thereby converting the whole area into wastelands. In underground mining as in case of mica, tungsten and copper, the disposal of mining much low grade minerals and mill tailing are the major causes of developing wastelands. Many mines like marble, ball clay, china clay, dolomite, limestone, fire clay, brick clay, gypsum, mica bentonite, sandstone etc. are developed on agricultural lands thereby converting them to wasteland.

The mining sites are abandoned either on exhausting the mineral resources or termination of lease. These sites support low to negligible density of trees and grasses. These can be suitably treated for regeneration of vegetation. Some of the soil conservation measures like land leveling, soil compaction, stabilization of piles, slope gradation, bunding, contour furrowing and terracing could be adopted. The trees like *Acacia tortilis, Prosopis juliflora, Acacia senegal, Salvadora oleoides, Tamarix articulata;* shrubs like *D. nutans, C. mopane, Zizyphus nummularia, Grewia tenax, capparis decidua, Leptadenia pyrotechnica, Haloxylon salicornicum, Suaeda fruticosa* and grasses like *Cenchrus setigerus, Cymbopogon, D. annulatum, Cynodon dactylon, Sporobolus marginatus* etc. could be planted in the monsoon season by transplanting the seedlings raised in the nursery.

11. WASTELANDS DEVELOPMENT – A CASE STUDY

Field studies on development, refinement and demonstration of technology for biomass production and rehabilitation of degraded arid lands were conducted during 1995 and 1996 in Kalyanpur in Barmer district. The total area of project site is about 120 ha, having average annual rainfall of 200 to 250 mm. The project site in general has N-W slope of about 5%. The runoff from the entire catchment accumulates at the lowest area forming a 'Khadin'. Entire runoff occurs as overland flow causing sheet erosion in the upper reaches. Soils in the project area are mainly sand to loamy sand with depth varying from 30-50 cm. In the low lying area, soils are sandy loam to loam with depth varying from 60 to 100 cm. Soil crusting is the major problem during kharif season which hampers proper seed germination of the major crops and grasses. Common perennial nature vegetation of the area comprises of *Zizyphus nummularia, Salvadora oleoides, Prosopis cineraria, Acacia tortilis* and Capparis *decidua.* The dominant seasonal ground flora comprises of *Cyperus sp., Cenchrus biflorus, crotolaria* sp and *Tribulus terrestris.* Different integrated farming systems viz. Silvipasture, Agri-horticulture, Energy and economic plantation were developed for different soil and land use conditions and are discussed as under:

Silvi-pasture system

Silvipasture system was established during kharif season of 1995 and 1996 at farmer's fields. The technology for establishment consisted of cleaning of area from the unwanted plants and proper soil working followed by sowing of *Cenchrus ciliaris* grass (strain 358) by mixing moist sandy soil three to four times the volume of seed. After the rain the seed was drilled uniformly in lines 75 cm, apart in 8 to 10 cm deep furrows at a depth of 2-3 cm under the soil. The sowing was also done by pellets. Pellets are prepared by mixing seeds of grass, cowdung, silt or clay and sand in proportion (by volume) 1:1:3:1. The pellets were also sown in lines 75 cm apart and placed 1-2 cm deep in the furrows. The tree species in pasture land is important from the point of view of continuous supply of quality fodder. For this tree seedlings of *Prosopis cineraria, Colophospermum mopane* and *Hardwickia binata* were planted at 20 m row to row distance and 5 m tree to tree spacing in the pasture. Observation on growth parameters of *Cenchrus ciliaris* are presented in Table 11.1 showed the better performance of Cenchrus *ciliaris* grass in the year 1996 with rainfall of 140.0 mm only.

Table11.1: Performance of *Cenchrus ciliaris* grass.

	Plant population (000/ha)	Canopy (cm)	Seed yield (kg/ha)	Fodder yield (kg/ha)
1995	43.8	27.7	90 6	1228 1
1996	106 3	23.9	106.3	1509 4

Agri-horticulture system:

Horticulture has a significant role to play in wasteland development. Fruit crops in wasteland development programme have added advantages like:

(i) Fruit crops once established become a permanent source of income.

(ii) Some fruit crops in addition to fruits also provide additional income in from of fuel wood and fodder especially those, which need pruning.

(iii) Fruit crops also impart stability to agriculture especially in arid and semi arid regions.

(iv) Most efficient in resource conservation and utilisation.

Most potential fruit crop for arid region is ber (*Zizyphus mauritiana*). It is hardy fruit crop which can withstand drought, salinity and saline irrigation water. It requires few irrigations for establishments. Therefore plants of grafted ber were planted in 1995 at three sites at 10 x 5 and 10 x 10 m spacing. In 1995 at one site, soil of the planting pit was treated with Jalshakti (50 gm), FYM (5 kg), Composite material (bentonite + guar gum, 50 gm) and Mulch. Jalshakti and composite material were placed near root zone of plants.

Table 11.2 : Performance of *Zizyphus mauritiana* (ber) under different treatments.

	Height (cm)		Percent Increment
	1995	1996	
Jalshakti (JS)	49.2	71.8	45.9
FYM	34.9	70.2	101.1
Composite material	45.4	68.0	49.8
Mulch (M)	51.6	71.1	37.8
FYM + JS	40.6	85.8	111.3
M + JS	55.1	74.4	35.0
FYM + Composite Material	43.4	74.5	71.6
M + Composite Material	52.4	68.6	30.9
FYM + M	50.4	77.9	54.6
Control	43.0	66.7	55.1

Ber plant attained more height (55.1 cm) when treated with Jalshakti and Mulch during the first year of establishment (1995). However plants attained maximum height (85.8 cm) with FYM + JS during 1996. The growth increments in two years was also highest (111.3 cm) in FYM and Jalshakti treatment (Table 11.2) showing there by significant positive interaction between the two.

In the agri-horticulture system, improved varieties of Moong bean (S-8), Mothbean (Maru moth) and clusterbean (maru guar) were grown in between the ber plants in 1996. Average yield of moong, mothbean and clusterbean were 14.5, 4.8 and 10.0 q/ha respectively, which were 50% higher than the local varieties.

Energy plantation:

Every farmer should be self sufficient in timer, fuel wood, fodder etc. by raising suitable trees in his farm, especially on wasteland or marginal lands. With this aim some tree seedlings of *Acacia tortilis*, *Acacia nilotica*, *Albizzia lebbek*, *Dalbergia sissoo* and *Tecomella undulata* were planted in soil having calcareous layer (murrum) at surface (10-20 cm depth). At this site round pits (60 x 60 cm) at 5 x 5 m spacing were dug manually. With the onset of monsoon 450 seedling of above five species (30 seedlings of each species in one replication) in three replications were planted. The growth data after planting showed maximum height and canopy of *Acacia tortilis* seedlings followed by *Acacia nilotica* during both the years 1995 and 1996 (Table 11.3). The growth increment in two years period was however, higher in *Albizzia lebbek* and *Dalbergia sissoo* in comparison to others.

Table 11.3: Performance of different tree seedlings.

	1995	1996	Percent Increment
Acacia tortilis			
Height (cm)	59.7	115.6	93.6
Canopy (cm)	14.8	38.9	162.8
Acacia nilotica			
Height (cm)	48.2	103.3	114.3
Canopy (cm)	13.5	35.7	164.4
Albizzia lebbek			
Height (cm)	40.8	90.0	120.6
Canopy (cm)	7.9	20.1	154.4
Dalbergia Sissoo			
Height (cm)	34.3	69.0	103.5
Canopy (cm)	6.9	24.3	252.2
Tecomella undulata			
Height (cm)	38.0	65.8	73.2
Canopy (cm)	13.2	22.7	72.0

Arable cropping:

Different crops were grown during kharif season in 1995 in the area having relatively less problem of soil degradation. During rabi season crops were grown on conserved soil moisture in the low lying area. The performance of these crops is presented in Table 11.4.

Guar: The farmers in the area grow local variety of guar which yields very low. Three varieties of guar namely RCG, Navin and Maru guar were taken in about 2 ha area each and their yields were compared with local variety. Amongst the improved varieties, maru guar yielded highest followed Navin and RCG. Maru guar gave 32% more yield as compared to local variety.

Moth: Improved variety of moth (maru moth) was grown in about 5 ha area at two locations. A comparison of Maru moth with local variety showed bigger and bold grain and higher yields as compared to the local one.

Groundnut: This crop was introduced in Kalyanpur area for the first time. On lower side of sloppy area, rainwater accumulates and remain standing during the rainy season and farmers can raise only rabi crops. Adjacent to low lying area where runoff water either does not accumulate or recedes quickly during the monsoon season, generally stores sufficient moisture in the profile. In order to make effective use of this profile moisture possibility or raising groundnut crop was explored in kharif 1995 with encouraging results (Table 11.4).

Table 11.4: Performance of different crops.

Crop	Yield (kg/ha)	
	Grain	Yield
Gaur		
I. RCG	447	597
II. Navin	483	645
III. Maru guar	574	891
IV. Local	434	478
Moth	183	1284
Groundnut	954	2554

Gram: In the low-lying area where water accumulates during rainy season it is not possible to raise a kharif crop. The farmers therefore grow mustard and gram during the rabi season with the objective of utilising conserved moisture. A field trial was conducted in rabi season of 1995 in replicated randomised block design using two levels of nitrogen (0 and 10 kg N/ha) in combination with phosphorus (0 and 30 kgP_2O_5/ha). The fertilizers were applied before sowing. The data (Table 11.5)

...ealed that application of 10 kg N/ha in combination with 30 kg P_2O_5 increased he grain and straw yields by 25% and 23% respectively over control (N_0P_0).

Table 11.5: Grain and straw yield of gram

Treatment	Yield kg/ha	
	Grain	Straw
N_0P_0	759	1170
N_0P_{30}	818	1297
$N_{10}P_0$	856	1323
$N_{10}P_{30}$	955	1445

Unconventional economic crops

Some of the unconventional crops like Henna (*Lawsonia alba*) and Senna (*Cassia angustifolia*) were for the first time introduced in the region with the objectives of efficient utilisation of soil and water resources and economic development of the region.

The seedling of the Henna were procured from Sojat and planted at three different sites in July 1996. Senna was sown by seed in last week of August 96. The results showed (Table 11.6) higher leaves production of henna in soil having medium depth of 50 cm. In the first year of planting senna could give a yield of 143.3 kg/ha of dry leaves.

Table 11.6: Dry leaves production of 'henna' and 'senna' crops.

	Yield (kg/ha)
Mehandi	
I. Soil depth 0 cm ($CaCO_3$ layer at surface)	73.0
II. Soil depth 50 cm	111.3
III. Soil depth 100 cm	99.5
Senna	143.3

12. FUTURE NEEDS

At the current rate of increase in human and livestock population, it is expected that there will be a tremendous increase in the requirements for grain, fuel wood and fodder by the end of this century. This may lead to over exploitation and degradation of the meager resources of the arid and semi arid areas. This will have to be checked and the production increased. In the absence of the adequate irrigation water availability, the thrust will have to be on increased availability of rainwater and its conservation for more biomass production. CAZRI, over a period of four decades has developed technologies for rehabilitating arid areas and the sand dunes. These technologies are in respect of crop improvement, soil and moisture conservation, afforestation and management of pasture lands. Though lot of information has been generated and new geno type of crops, grasses and trees suited to the arid areas evolved soil and moisture conservation practices developed, afforestation techniques for different types of wastelands evolved and grasslands scientifically managed, still very little has gone to the farmers field. Sand dune stabilization and rangeland management technology has been adopted by State Government Forest Department and various other agencies for greening desert areas. It could be taken to many of the remaining areas particularly private farmers dunes. Rocky, semi rocky and gravelly areas could be afforested with the available technology. Mined spoiled and saline wastelands could be rehabilitated with the recommended species of trees and grasses. Improved crop production technology like drip and sprinkle irrigation has gone to the field in a limited way. Efforts could be made to popularize water harvesting and other conservation techniques for crop production and tree establishment. Though lot of information on shelterblts is available, the technology has not been accepted by the farmers. Efforts could be made to popularize the technology particularly the more acceptable trees like *Acacia nilotica, Tecomella undulata, Zizyphus nummularia* and *Acacia tortilis* on the bunds. Farmers have generally been observed reluctant to plant trees in their field primarily because of the obstruction they cause to mechanization. With suitable spacing (10 to 20, from row to row), trees like *Prosopis cineraria, Acacia nilotica, Tecomella undulata, Zizyphus mauritiana* could be recommended for agroforestry system in 300-400 mm rainfall zone. In areas less than 200 mm rainfall, *Prosopis cineraria, Acacia tortilis* and *Zizyphus nummularia* could be recommended with *Cenchrus ciliaris* and *Lasiurus sindicus* grasses.

There is need to further develop management practices and site and rainfall specific models of agroforestry/silvipasture and also to study their long term effects on soil and environment. This is particularly important for imparting economic stability to the region beside environmental improvement.

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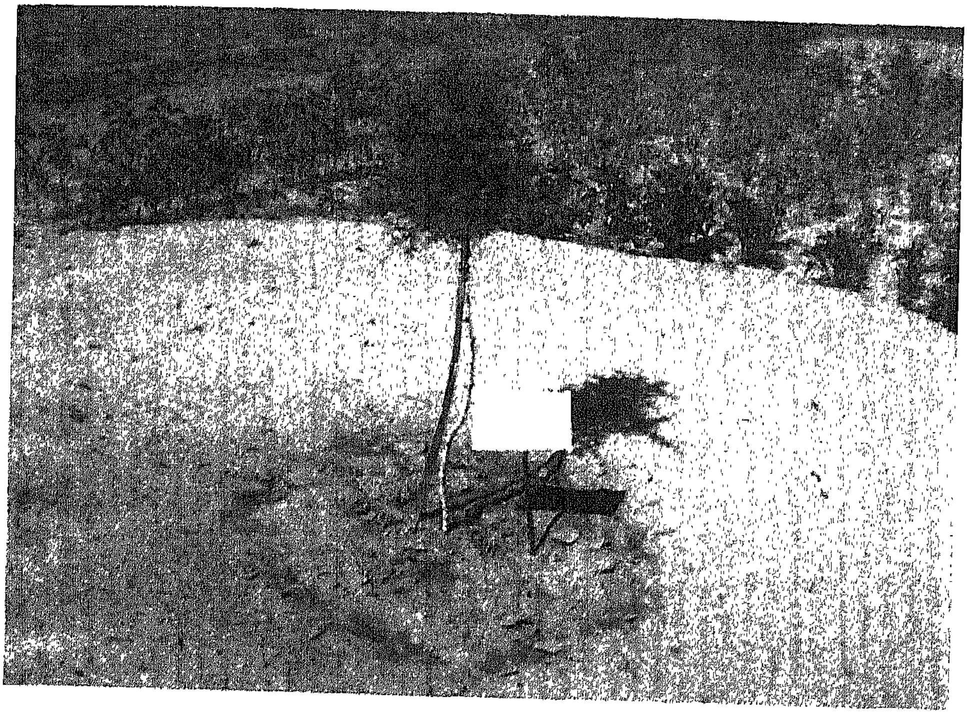

Fig. 5.1: A circular catchment technique for the establishment of tree seedlings.

Fig. 5.2: A 'Tanka' for harvesting rainwater for multi purposes.

Fig 5 3 Mulching for increasing crop production

Fig 6 1 Agri-horticulture system - Ber intercropped with clusterbean

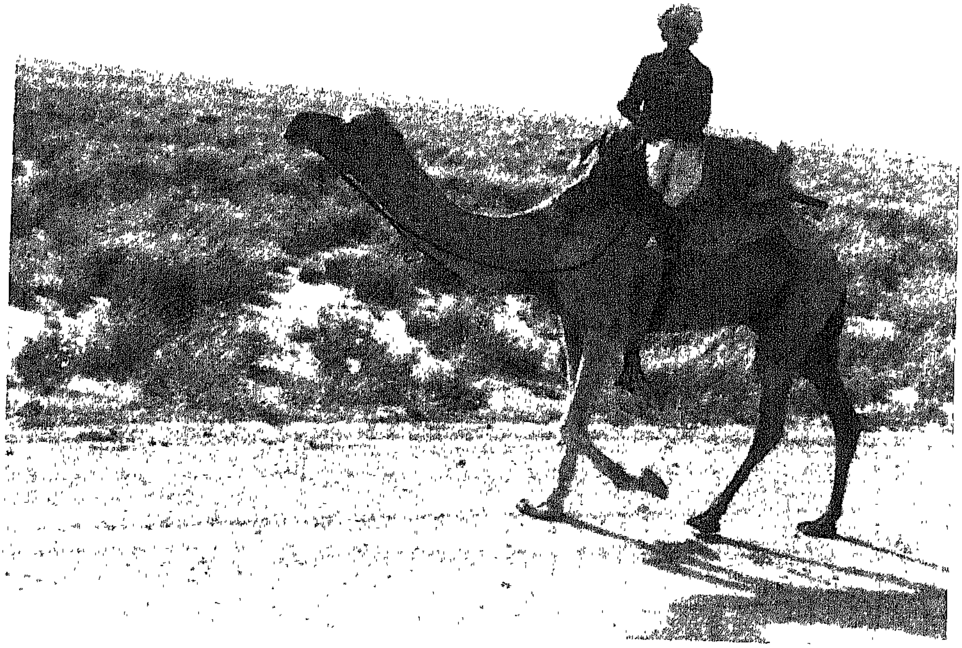

Fig. 6.2: A natural pasture of *Lasiurus sindicus* in Jaisalmer area.

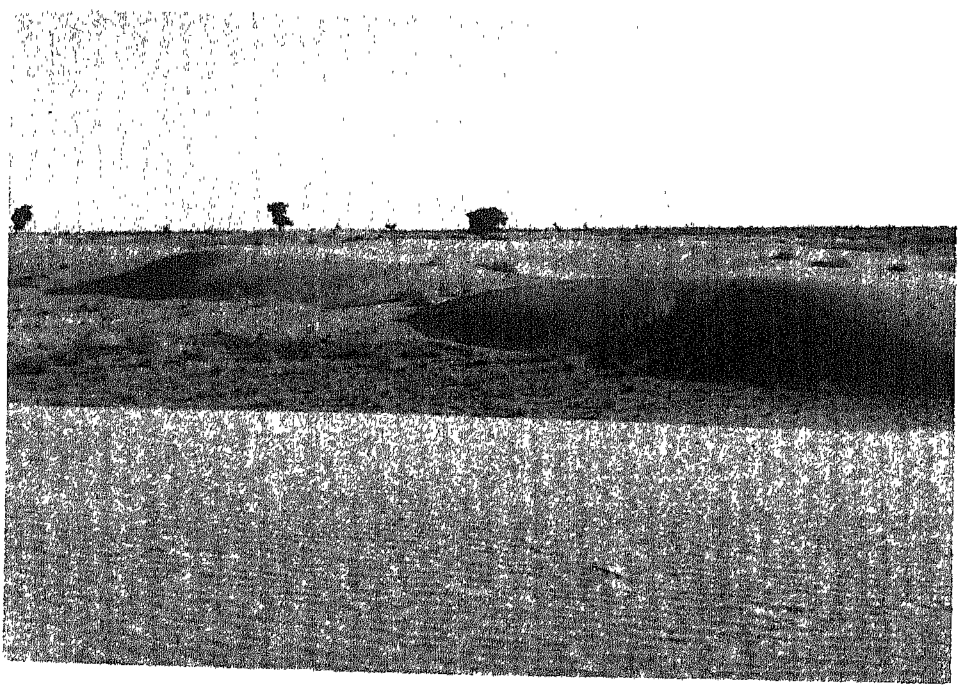

Fig. 7.1: Moving sand dunes.

Fig. 7.2: Sand dune stabilized with *Acacia tortilis*.

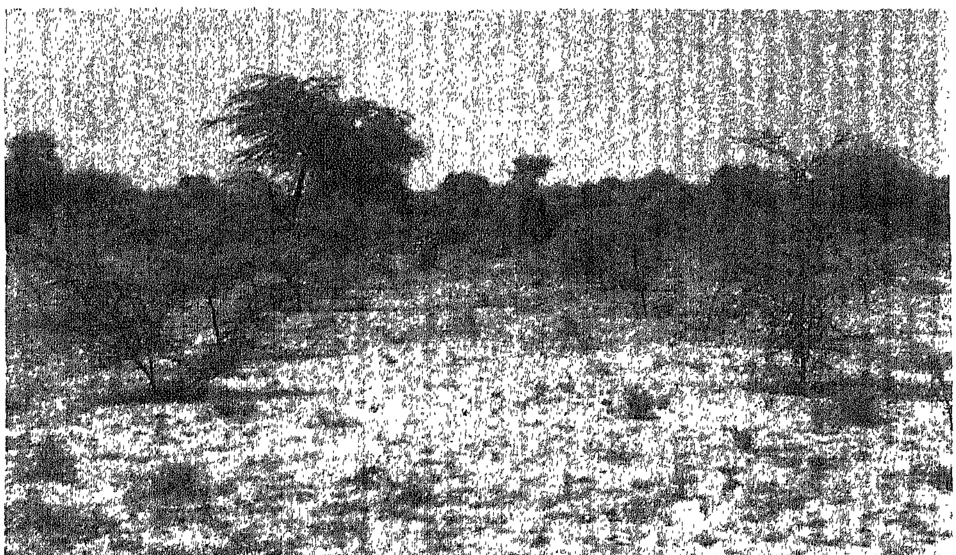

Fig. 8.1: A stoney/gravelly wasteland.