AGRICULTURAL RESOURCES OF WESTERN RAJASTHAN AND THEIR MANAGEMENT FOR SUSTAINABLE PRODUCTION

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FOREWORD

The Indian arid region is going through a rapid change under the present liberalized economic policies of the country. The region's industrial sector has shown a fast growth due to which the population of the region has gone up by about 40% in the past decade (mostly resettlements from outside the State). The agricultural sector, however, still has low and uncertain productivity. Adoption of the latest agricultural technologies are not realized in the major parts of the region. Because of the climatic constraints and increased biotic pressure, the environment of the region is under a serious threat. Efforts are, therefore, required both by the developmental agencies and the people to stabilize the ecological balance of the region. On the basis of several years of research by the scientists at the Central Arid Zone Research Institute, Jodhpur, the authors have brought out this manual which presents the appropriate technologies for the arid region agriculture. In order to streamline the development efforts, the authors have attempted to form a simple and easy to identify ecological land classes and suitable agricultural practices are presented for each ecological class. The report is prepared for three main arid districts Jodhpur, Bikaner and Jaisalmer. It is hoped that this manual will be useful to research/extension workers, the state developmental agencies and the NGO's in carrying out the sustainable agricultural development.

(R. S. Paroda)
Secretary, DARE
Government of India
and
Director General
Indian Council of Agricultural Research
New Delhi

April 10, 1995

PREFACE

The planning of village area development on an integrated basis requires some preliminary information about the available agricultural resorces and technologies to address the specific problem. It has long been felt that such information should be compiled for district as a unit in the arid region. Thus, an effort is made to compile the information on available agricultureal resorces and the appropriate technologies developed for improving the district-wise productivity on sustainable basis. Our emphasis is mainly on the resources management which can be done through various development programmes either on individual or community basis. It is hoped that this report shall be helpful to the personnels engaged in various rural development programmes in planning and deciding the priorities for their work.

We are grateful to Dr. A.S. Faroda, Director, Central Arid Zone Research Institute for his support and encouragement in bringing out this report. We are also grateful to Dr. J. Venkateshwarlu, former Director, CAZRI for his interest in this report. We acknowledge with thanks the work of different scientists of CAZRI which is included appropriately in this report. In particular, thanks are due to Drs. Y.S. Ramakrishna, A.S. Kolarkar, P.C. Chaterjii, B.B. Vashishtha, D. Kumar and A.S. Rao for giving the material support. Thanks are also due to Sh. Raj Kumar Mathur for preparing the line diagrams.

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INTRODUCTION

General

Agricultural environment in the arid district of western Rajasthan is delicately balanced. However, the ecosystem is under various degradation processes due to ever increasing pressures of both human and livestock populations. Although the majority of arid lands are not suitable for crop production, more and more marginal lands are being brought under the plough. One reason for this practice may be the fact that it is difficult to draw a sharp line between use and abuse of the resources in the arid areas. A majority of desert dwellers (about 70%) are engaged in subsistence type arable farming. In order to bring the economy of the arid areas on a sound footing it becomes imperative to develop the appropriate production technologies matching with the variations in the agro-ecological conditions.

Limitations of the Agricultural Ecosystem

Natural limitations

The arid regions are characterized by considerable variability in the amount of rainfall and its distribution. The climatic factors that lead to aridity are low rainfall, its high coefficient of variation, uni-modal distribution which results in frequent terminal stresses, high thermal and wind regimes resulting in high evaporation losses. Soil is the other major resource. Unfortunately, it is also problematic due to its poor texture and low water holding capacity. Besides this, the region has poor water resources due to the absence of any well defined river system. The ground water is scarce and poor in quality and more often it is available at depths. Due to these natural constraints, the crop production in the region is mainly rainfed which suffers from low productivity and high level of uncertainty. Further, the region is devoid of permanent vegetation cover because of over-exploitation and over-grazing. Even though the existing land use data show that in some districts about 80% of the total area is under cultivation. Since crop cultivation is not assured, it is clear that the available resources are not being properly utilized. The natural resources remaining the same, the increasing population pressures can cause further degradation of the already disturbed ecosystem. Although, the true potentials of the ecosystem have not been estimated (in terms of how much biotic pressure it can sustain) but the existing land use pattern, the level of consumption and the level of production project a bleak picture and sign of warning for the time to come.

Ecological limitations

The natural limitations described above give an impression that there are limits to economic growth of the region. However, neither such absolute limits exist nor

the limits are likely to be imposed by a finite supply of the resources. Instead, the limiting factor is the ability of the ecosystem to absorb the biotic pressure. Hence, the ecological limitations are determined by the state of technology and social organization, by political will and capital investment.

Within this frame work the sustainable development comes into the picture. In practice, however, it is difficult to distinguish growth that is sustainable from growth that is not. Doing so requires a detailed knowledge of various biological relationships. In fact, with the present level of knowledge it is difficult to fix the type of sustainabilities and monitor them. However, it is possible to pursue development projects for a particular type of sustainability. One approach may be to have ecosystem type sustainability which emphasizes sustaining a general land use or ecosystem type (in this case the desert ecosystem). Project success, then, is defined as the capability of land to support some product over a long period. For example, some areas where crop cultivation is in practice may be more suitable for forest or grass land. In some areas with additional capital investment the productivity of land can be increased and so on. Hence, in this approach management tries to preserve the resources for their optimum utilization while preventing such processes like the desertification or the degradation of natural resources.

An Overview of the Solutions

Keeping in mind the limitations of the ecosystem and acknowledging the fact that these limits are elastic, several technologies may be practised to develop the ecosystem. Suggested technologies for area development are given in the last section. From the resource management point of view, the district area can be divided in to suitable ecological classes. Each class represent a distinct, though not mutually exclusive area which is suitable for some particular type of cultivation practices. If development projects are planned considering the capabilities of these ecological classes then it is expected that a sustained ecosystem development can be achieved. However, planners should select a land use for an area based on the ownership, human (farmer's) needs and community's needs.

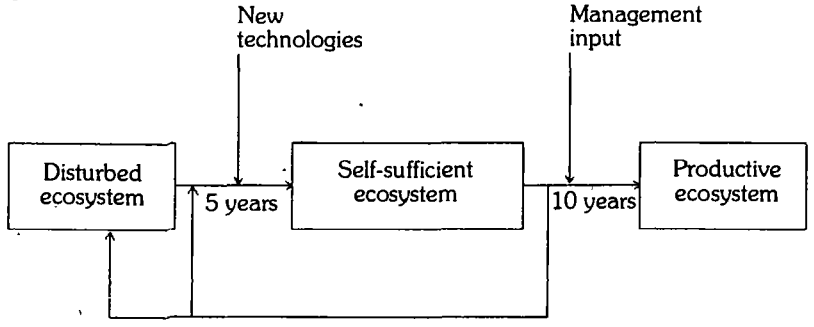


Figure 1 Hypothetical ecological cycle from disturbed to productive state.

Another important point is the time frame required for the changes that are brought by the adoption of a technology to be effective permanently. Figure 1 shows a hypothetical ecological cycle for a disturbed ecosystem.

It is proposed here that a minimum 5 years period is required for a disturbed desert ecosystem to change to a self-sufficient ecosystem with the adoption of appropriate technologies. Similarly, when an ecosystem has changed to self-sufficient, balanced state, then with proper management it can be made productive. The return arrows show that if at the self-sufficient state proper management is not provided then the ecosystem may gradually return to disturbed state. Once the productive state has reached, then it is expected that society will maintain it for its own benefit.

Most of the development projects that the government agencies take up are for 5 years duration. After 5 years the project area is left unattended, that is before the self-sufficient state has reached and hence the ecosystem returns to its original state as is shown in Figure 1. This is the main reason why the results of development work are not as striking as they should be. However, it may not be possible for government agencies to continue the work for such a long duration due to several other commitments. Therefore, it is obvious that people's participation both at individual and at community level is a must for the success of all macro and micro level development projects.

In this report various ways and means are suggested to improve the ecosystem through conservation and development. The plan is presented for three main districts viz., Jodhpur, Bikaner and Jaisalmer. For each district the report presents the existing natural resources inventory, the description of various ecological land classes (ELC) and their extent, and for each ELC the most suitable production activity that will lead to conservation and efficient utilization of available resources. The appropriate agricultural technologies for the implementation of proposed production activities are also given.

JODHPUR

General Features

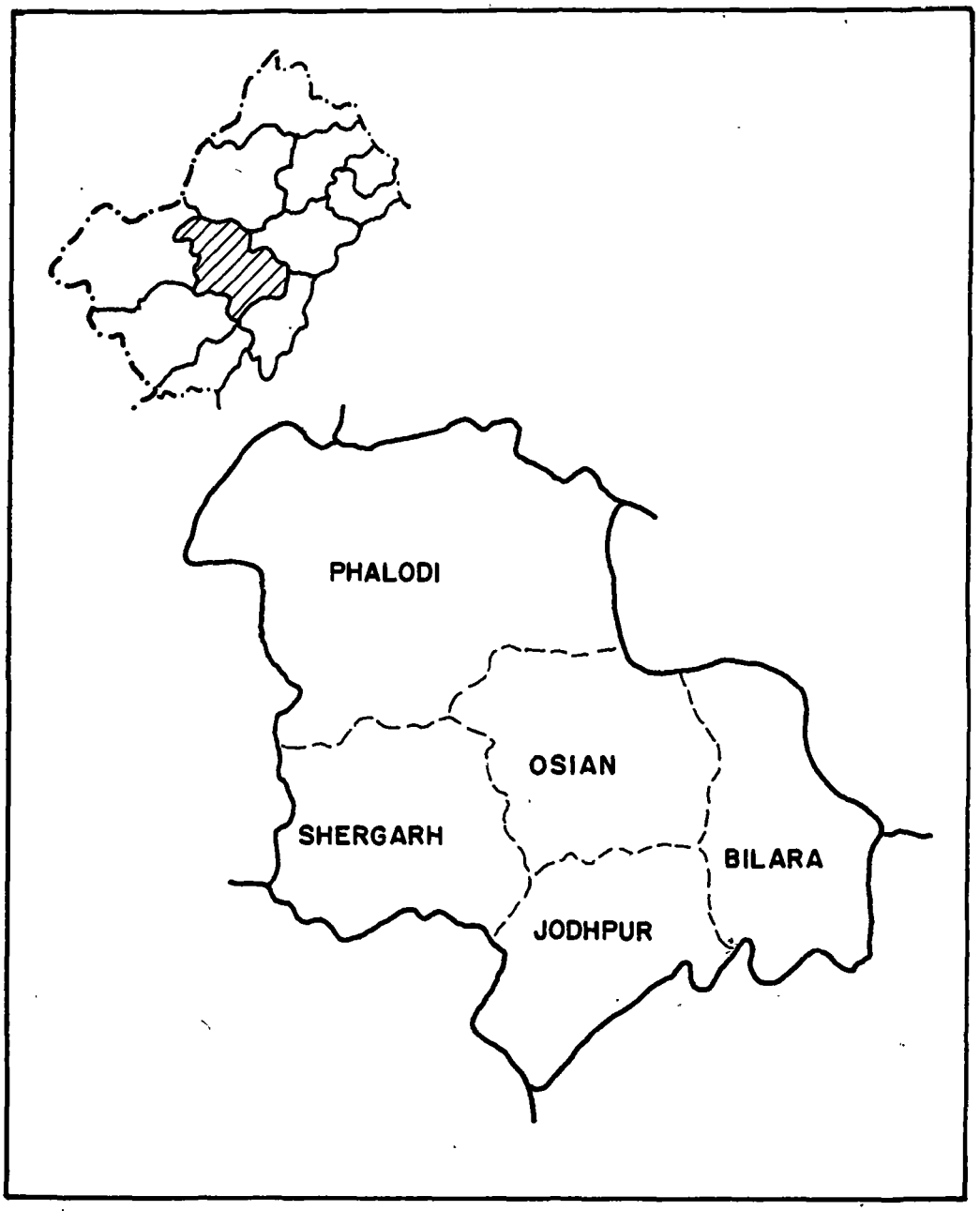
The Jodhpur district extends from 71°47'E to 73°52'E longitude and from 28°02'N to 26°01'N latitude. It has an area of 22850 Km^2 which accounts for 11.6% of the arid zone of Rajasthan and 6.7% of the total area of the State. The district comprises of six tehsils namely, Jodhpur (3330.3 km^2), Bilara (1619.4 km^2), Shergarh (3829.1 km^2), Osian (3499.6 km^2), Phalodi (7679.2 km^2), and Bhopalgarh (2428.2 km^2). The administration is exercised through 9 blocks. It has four towns and 705 villages. The area of villages mostly ranges from 1000 to 3500 ha. The total urban area in the district is only 464 km^2. The population of the district as per the Census, 1991 was 2153 thousand which is 4.89% of the State. The population growth registered an increase of 29.12% over the decade. The livestock population was 2039 thousand which is 4.11% of the State.

Climatic Features

The average annual rainfall across the district varies from 424.1 mm at Bilara in the east to 243.7 mm at Phalodi in the west of the district (Table 1). The mean annual rainfall of the district is 307.8 mm. The coefficient of variation of annual rainfall across the district varies between 35% and 55%. The monsoon rainfall normally sets over the region between 30th June and 10th July and the withdrawal can at times extends up to 10th September. The normal crop growing season in the region is for a period of 12 weeks between 27th and 36th week. Rainfall records from 1901 shows that the district received early (4th June to 1st July) sowing rains (>20 mm/week) in 31% of the years whereas late (after 29th July) rains occured in 16% of the years. Rainfall distribution model of Jodhpur recorded average to above average (350 to more than 400 mm) rainfall which shows that once in two years the area received good rainfall which can be capitalized. The region also experienced agricultural droughts for 13, 20 and 25% of the years under early, normal and late monsoon rainfall conditions.

Table 1. Mean annual and extreme rainfall in Jodhpur district and its variability

Station	Normal annual rainfall (mm)	Coefficient of variation (%)	Extremes of annual rainfall (mm)			
			Max	Year	Min.	Year
Jodhpur	365.5	53	1176.5	1917	37.0	1918
Bilara	424.4	53	1214.8	1908	98.2	1918
Shergarh	253.8	49	825.7	1908	59.8	1968
Phalodi	243.7	55	631.8	1917	31.3	1918
Osian	251.8	35	383.1	1959	98.6	1963



DISTRICT JODHPUR

The air temperature is highest during May and June in the district with mean maximum temperature remaining around 40°C and at times touching 45 to 47°C. The period December to February is the coldest period with mean minimum temperature of 10°C or less. The lowest extreme temperature so far recorded is -3.3°C in Phalodi and -2.2°C in Jodhpur. During 7 out of 35 years (1945-80), the region experienced cold waves with air temperatures of 4°C or less extending over period of 2-4 days. The chances of cold wave occurrence are slightly higher during second fortnight of December to first fortnight of January. Intensive heat during the summer favours frequent occurrences of dust raising winds during April to June in this region.

Characteristic Soils

Soils of this district are predominantly coarse textured, of which 60% are associated with dunes and hummocks and 15% are with compact strata underneath. Medium to fine texture soils cover 14% of the area and 10% area is under hills and shallow gravel exposure. A description of the dominant soil groups is given in Table2.

Table 2. Major Soil Groups, their Extent, Characteristics and Limitation

Soil group	Location	Limitations	Utilization
Deep hummocky sandy soils	Phalodi Shergarh, Osian	Severe wind erosion, low WHC, low fertility	Energy plantation on high hummocks, silvipastoral system on flat lands
Light textured sandy plain soils	Jodhpur, Osian	Wind erosion, low fertility	Suitable for cropping with appropriate soil and water conservation measures
Medium texture deep sandy soils	Jodhpur, Bilara	No major limitations	Improved agronomic practices
Fine texture soils	Bilara	No major limitations	Improved agronomic practices
Shallow gravelly soils		Water erosion, shallow depth	Pasture development, runoff harvesting
Salt affected soils	Bilara, Osian, Shergarh	Salinity and water logging	Afforestation in high salinity zones
Duny complex	Shergarh, Phalodi, Jodhpur	Severe wind erosion	Suitable for energy plantation

Surface Water Potentials

The only well defined drainage system in the district is of the Luni river that passes through the south eastern part of the district. The length of Luni river in Jodhpur is about 122 km. In rest of the area the runoff occurs in short distance, ephemeral streams. This runoff, if not stored, gets absorbed in the plain fields. Presently, there are 10 reservoirs with a total capacity of 121.91 Mm^3 and 292 medium and large nadis with a total capacity of 20.66 Mm^3 (Table 3).

Table 3. Surface Water Storage in Various Tehsils

Tehsil	Reservoirs		Nadis	
	Number	Capacity, Mm^3	Number	Capacity, Mm^3
Jodhpur	5	48.99	93	7.91
Bilara	3	54.20	66	4.40
Phalodi	1	8.76	42	2.54
Shergarh	–	–	42	2.27
Osian	1	9.96	49	3.54

Source : Anonymous (1982)

Groundwater Potentials

There are five major hydrogeological formations viz. alluvium, sandstone, limestone, granite and rhyolite which contain the ground water. Alluvium is composed of coarse and gravel schist and clay. The depth to water in this formation ranges from 30 to 50 m. Sand stone forms extensive aquifer and covers major portion of the area. The ground water occurs under unconfined as well as semi-confined conditions. The depth to water ranges from 4-103 m. The yield of wells and tube wells in general ranges from 20000 litres/day to 190000 litres/day and 135000 litres/day to 256000 litres/day, respectively.

Limestone mainly covers the eastern and northern part of the district. Ground water occurs under unconfined to semi-confined conditions. The depth to water in this formation varies from 5- 102 m below ground level.

Granites are essentially grey to pink in color, massive and well joined. The depth to water ranges from 5-47 m. The quality of water is fresh to saline. Rhyolite is hard and compact formation with limited weathered and fractured zones. The depth to water ranges from 6-39 m. Rhyolite, schist and slates form poor aquifer conditions. The extension of weathered and fractured zone is limited below water table, hence, the water yield from such formations is low.

Existing Cropping Pattern

Bajra is the predominant crop occupying 710360 ha area followed by kharif pulses (133054 ha) and til (38038 ha). In rabi season wheat and raya are grown

with irrigation occupying 18328 and 27053 ha, respectively. Tehsil-wise analysis of area under different crops during kharif (Table 4) reveals that maximum area of bajra exists in Phalodi, followed by Jodhpur, almost similar area in Shergarh and Osian, and least area in Bilara Tehsil. Whereas in kharif pulses, maximum area exists in Shergarh followed by Jodhpur, Osian, Phalodi and almost negligible area in Bilara tehsil. In the case of til maximum area exist in Bilara and Jodhpur.

Table 4. Tehsil-wise area (ha) under principal kharif crops

Tehsil	Bajra	Til	Kharif pulses
Jodhpur	123888	3839	44065
Bilara	29362	12649	1290
Shergarh	123027	68	48971
Phalodi	174893	408	23518
Osian	118068	410	34330
Bhopalgarh	74262	16805	17290

In Jodhpur district, the productivity of bajra is almost 33% of the State and 25% of the Country (Table 5). Almost similar is the trend in the case of til. However, the productivity of kharif pulses is better in the district than State. This is mainly due to the fact that agro-climatic conditions of the district are more conducive for the cultivation of grain legumes.

Table 5. Average Productivity (kg/ha) of Principal Crops (1980-1992)

Crops	District	State	India
Bajra	132	402	500
Kharif pulses	241	181	502
Til	53	127	175

Present Land Use

The land use pattern of Jodhpur district is given in (Table 6). It shows that the forest cover is only in 6590 ha which is very low from the ecological point of view. Irrigated area is just 4.8% of the net sown area (1164487 ha).

Description of the Ecosystem

Jodhpur district is divided into 14 different units based on their land resources (Anonymous, 1982). The division of these units is based on the similarity in their natural land forms, soils and vegetation. Fragmentation of area into a large number of different units may not be appropriate for the existing technology base. Therefore, some regrouping of the conjunct units are required for undertaking area development programme. From the agricultural development point of view, following regrouped units are considered. These units may be called the ecological land classes (ELC).

Table 6. Present Land Use Pattern of Jodhpur District

Particulars	Area (ha)
Forest	6590
Area not available for cultivation	227197
land put to non-agric. use	81442
barren uncultivable land	145755
Cultivable land	203375
permanent pasture/grazing land	119540
land under misc. tree crops	64
cultivable wasteland	84271
Fallow land	654256
fallow other than current fallow	376631
current fallow	277625
Total cropped area	1193347
net sown area	1164487
area sown more than once	28860
Area under wasteland	606657
Total area	2256405

1. Sand dunes (ELC 1)
2. Area with light textured soils (ELC 2)
3. Flat plains with deep soils (ELC 3)
4. Flat plains with shallow soils (ELC 4)
5. Saline-alkaline areas (ELC 5)
6. Hills and rocky plateau (ELC 6)

Each ecological class represents an unique area from the perspective of supporting the ecologically most suitable land use. Most suitable land use is defined here as that utilization of land which requires minimum capital investment and minimum human attention in the long run. This definition itself infests that with sufficient capital investment and technical input these ecological classes can be put to other type of land uses also. A detailed description of each ecological class is given as follows.

1. Sand dunes (ELC 1, 3536 km^2)

The major area of dunes is in Phalodi and Shergarh tehsils. The height of these dunes varies from 5 to 40 m. Isolated bodies of 3 to 7 m height also occur in other areas. The major soils of the area contain 2.5 to 5% clay, 1.5 to 3% silt, 70 to 80% fine sand and rest is coarse sand. The soils can retain 40-50 mm of water per meter depth. The soils contain 0.04 to 0.15 % organic carbon, 8 to 15 kg P_2O_5/ha and 70

to 150 kg K_2O/ha. About 70-95% of the area is under cultivation in a system of fallow farming. Due to severe biotic interference the vegetation in the area is sparse. The common perennial vegetation consists of *Prosopis cineraria, Calligonum polygonoides, Calotropis procera, Zizyphus nummularia,* and *Acacia senegal*. This class lies mostly within the 250-300 mm isohyet.

2. Area with light textured soils (ELC 2, 9719 km^2)

This area comprises of either the hummocky plains or the flat plains. This class mainly occurs in Jodhpur, Shergarh, Osian and Bilara tehsils. The representative soils have a very loose, structure-less sandy surface. Soils are less deep mostly 50-80 cm thick, underlain by a concretionary/gravelly layer. This layer is no limitation for penetration of roots and moisture, therefore, the soils behave as deep. The soils can hold 50-110 mm of water per meter depth. The soils have 0.04-0.35% organic carbon, 12-24 kg P_2O_5/ha and 75-220 kg K_2O/ha. About 60-70% area is under rainfed cultivation, except in Osian and Phalodi tehsils where cropped area is 30-50% due to less annual rainfall. The main perennial vegetation of this class are *Prosopis cineraria, Zizyphus nummularia, Acacia senegal* and *Calligonum polygonoides*. This class is spread within the 220-370 mm isohyet.

3. Flat plains with deep soils (ELC 3, 4070 km^2)

This class occurs in the Bilara and Osian tehsils. Dominant soils have medium to fine texture with 10-22% clay and 6-17% silt. The soils contain 0.25-0.50% organic carbon, 12-25 kg P_2O_5/ha and 140-350 kg K_2O/ha. The water holding capacity varies from 130-230 mm of water per meter of depth. In Bilara tehsil small pockets of clay loam or clay are also found with 33-40% clay and 18-20% silt. The flood plains of Luni river are covered in this class. Due to depositions of fresh alluvium, the water holding capacity of these flood plains is relatively low (60-80 mm of water/meter). However, the fertility status of the entire area is sufficient to support good crop growth. Hence, this area is regularly cropped. Parts of the flood plains of Luni river have excellent ground water potential and hence they are double cropped. In good rainfall years, the area with fine textured soils are also double cropped. The conspicuous perennial vegetation of this class are *Prosopis cineraria, Zizyphus nummularia, Acacia nilotica, Salvadora oleoides,* and *Capparis decidua*. This class falls within 280-430 mm isohyet.

4. Flat plains with shallow soils (ELC 4, 3332 km^2)

The major area of this class occurs in Phalodi tehsil. A small area also lies in Shergarh and Jodhpur tehsils. The dominant soils are light texture with a hard, compact strata at 40-60 cm depth. At some places the hard, bouldery strata is exposed to the surface in irregular patches. The soils above the hard strata contain

7.8-11% clay and 4.4-10% silt. It can retain 25-60 mm of water per meter depth. The soils contain 0.13-0.22% organic carbon, 8-18 kg P_2O_5/ha and 130-300 kg K_2O/ha. The soils have severe depth limitation and hence support poor natural vegetation. Crop cultivation is limited to about 20% area. Rest of the area is either left as fallow or contains permanent pastures. The common perennial vegetation is *Prosopis cineraria* but it has stunted growth. This class lies within the 220-250 mm isohyet.

5. Saline-alkali areas (ELC 5, 317 km^2)

This class occurs in Bilara and Phalodi tehsils. The soils are saline-alkali throughout or in the sub-soil with an alkaline surface. The pH values varies from 8.3 to 9.6 with EC values in surface layer of 0.4-3.5 mmhos and in sub-soil of 1.5 to 6.3 mmhos. At places, isolated pockets of highly saline depressions are found. Some of these depressions are used to extract common salt. In general, the soils contain 0.20-0.25% organic carbon, 12-24 kg P_2O_5/ha and 140-250 kg K_2O/ha. Due to the saline-alkaline regime in the soils, only a small percentage of flat land is cropped. *Salvadora oleoides, Capparis decidua, Prosopis juliflora* are the main perennials found in the area. Saline depressions with high salinity zones are devoid of any vegetation. Major part of this class falls within the 400-430 mm isohyet.

6. Hills and rocky plateau (ELC 6, 1887 km^2)

The area of this class is scattered throughout the district. The hills are mostly 50-150 m in height. Most hills have steep slopes. Dominant slopes in the rocky plateau area are 1-3%. Soil cover is practically non-existent over the hills whereas rocky area is made up of shallow (15-20 cm) miscellaneous soils with rock exposures. The soil cover in the plateau area occurs in some places only. The area is dominantly an open grazing land. The presence of such areas provide an excellent source of surface water runoff. A number of natural drainage lines originate from such areas. However, most of the surface runoff thus produced remains unutilized. This class is dominated by various kinds of shrubs. Common occurrences are *Euphorbia caducifolia, Maytenus emarginatus, Capparis decidua, Acacia senegal* and *Zizyphus nummularia.*

Sustainable Land Uses For The Ecosystem

Various land uses for sustainable development of each ecological land class are presented as follows.

1. Sand dunes (ELC 1)

Mostly suitable for fuelwood plantation. The idea is to have maximum perennial vegetal cover in such areas so that not only the movement of sand is checked but

also the micro-climate improves. Presently, some of the interdunal area is under crop cultivation. This should be continued only in association with proper wind erosion control measures.

2. Area with light textured soils (ELC 2)

Crop cultivation can be practised in the area that is hummocky or flat but with sufficient soil conservation measures. The area which are highly hummocky and eroded are most suitable for silvipasture system. In general, crop cultivation should be restricted to the area that receives more than 250 mm annual rainfall. Otherwise, permanent silvipastoral cover should be provided. Considerable scope of water harvesting exists in this class. This may be done through catchment preparation or from nearby existing hills or rocky plateau. Techniques of in-situ moisture conservation may prove to be extremely fruitful for the crop cultivation.

3. Flat plains with deep soils (ELC 3)

The fertility status and water holding capacity of the soils of this class are quite good. Hence, assured crop cultivation can be capitalized in this area. Capital investment for more underground water exploitation should be made. Dry farming techniques should be used to a maximum extent for better crop yields. Areas with medium or fine textured soils may better be managed for agri-horticulture or pure horticulture practices.

4. Flat plains with shallow soils (ELC 4)

Soil depth being shallow, this class is most suitable for permanent pastures. Excellent scope exists for creating large water bodies and runoff collection in the field for better forage yields.

5. Saline-alkali areas (ELC 5)

Rabi crop of wheat or raya can be taken up in low salinity zones and with irrigation where canal water is available. Some of the highly saline depressions are already being exploited for extraction of common salt. In rest of the area, where possible, forest cover should be provided with appropriate tree species.

6. Hills and rocky plateau (ELC 6)

One of the advantageous features of the desert ecosystem is the presence of hills and rocky areas. They are the potential source of surface runoff and subsequently ground water recharge. Surface runoff from such areas should be harnessed to a maximum extent. The harvested water can be used for various purposes like drinking, supporting assured establishment of forest plantation, horticultural or silvipastoral systems in the vicinity.

BIKANER

General Features

Bikaner district extends from 71°54'E to 74°12'E longitude and from 27°11'N to 29°03'N latitude. It has an area of 27244 km^2 which accounts for 13.8% of the arid zone of Rajasthan and 7.96% of the total area of the State. The district comprises of four tehsils namely, Bikaner (8947.7 km^2 area), Lunkaransar (6214.0 km^2), Nokha (3767.7 km^2) and Kolayat (7318.6 km^2). The district administration is exercised through four blocks. The district has 4 towns and 571 villages. The total urban area in the district is only 184.8 km^2. The human population of the district as per the Census, 1991 was 1211 thousand which is 2.75% of the State population. The population growth registered an increase of 42.70% over the decade. The livestock population was 2059 thousand which is 4.15% of the State.

Climatic Features

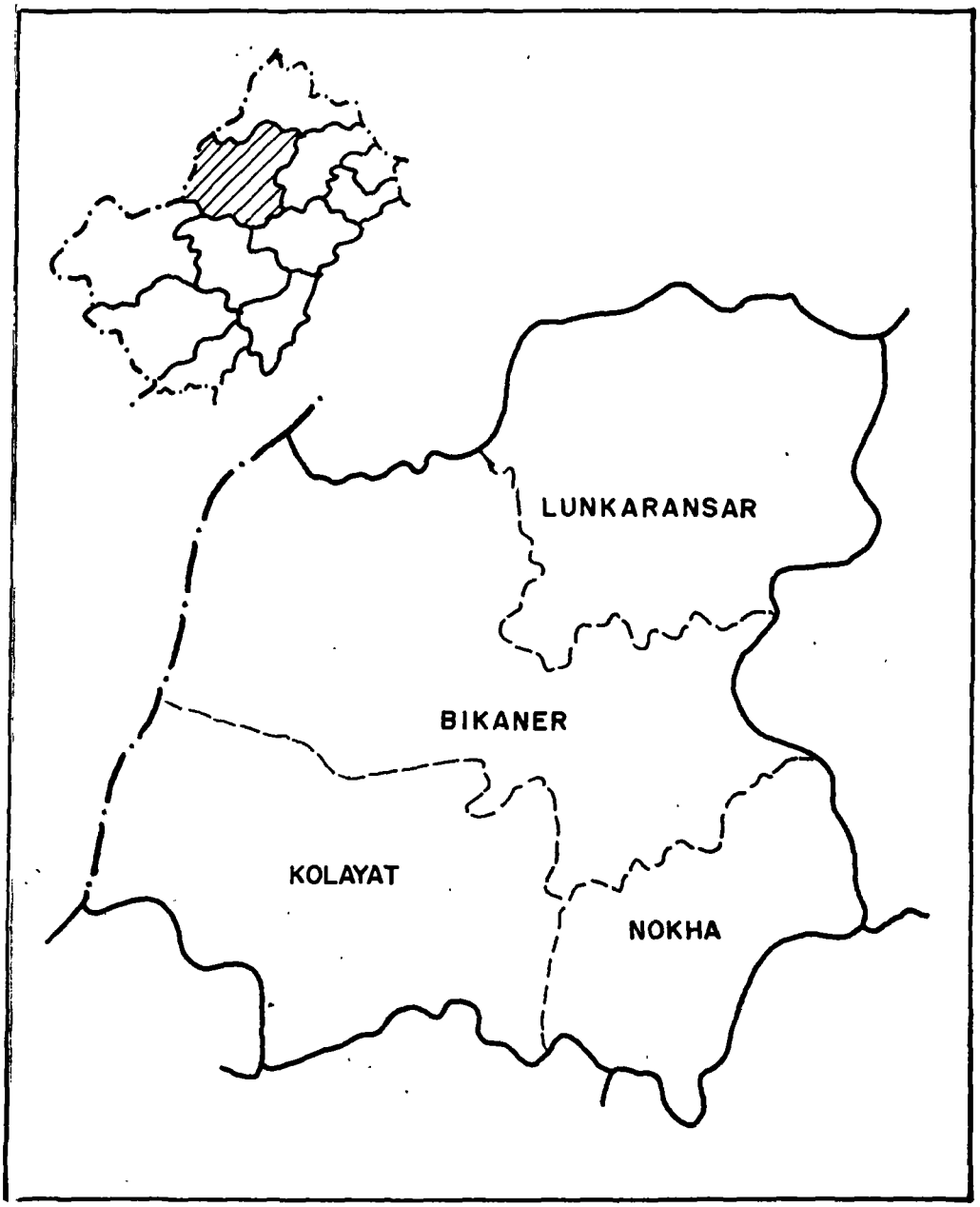
The average annual rainfall across the Bikaner district varies form 237.1 mm at Lunkaransar to 289.0 mm at Bikaner. The mean annual rainfall of the district is 258 mm. The coefficient of variation of mean rainfall over the region varies from 49-65%. The mean annual rainfall, the coefficient of variation and the normal crop growing period at different stations in the district are presented in Table 7.

Table 7. Mean annual rainfall and normal crop growing period in Bikaner district

Station	Normal annual rainfall (mm)	Coefficient of variation (%)	Normal crop growing period (weeks)
Bikaner	289.0	55	10
Lunkaransar	237.1	49	9
Palana	249.9	65	9
Nokha	270.3	53	10
Gajner	244.8	52	8

The monsoon rainfall normally sets over the region between 1st week and 2nd week of July and the withdrawal extends up to 2nd week of September under the normal rainfall conditions. Rainfall records of Bikaner show that the district received early sowing rains (>20 mm/week) in 31% of the years and normal onset of rains occurred in 43% of the years. Further, the rainfall distribution pattern of Bikaner indicated that out of 85 years, 52 years recorded average to above average rainfall which shows that ones in two years the area receives good rainfall. The region also experienced droughts of varying intensities in 24 out of 87 years.

The region experiences high temperatures during May and June with average maximum temperature of 41.6°C and at times touching 45°C. Intensive heat during



Central Arid Zone Research Institute, JODHPUR

DISTRICT BIKANER

the summer favours frequent occurrence of dust raising winds during April to June. The period December to February is the coldest period with mean minimum temperature of less than 7°C with occasional coldwaves of less than 4°C.

Characteristics Soils

The area of the district is highly variable in soil resources. Description of the dominant soil groups is given in Table 8.

Table 8. A Brief Description of Major Soil Groups in Bikaner District

Soil group	Extent	Location	Limitations
Duny complex, sand to fine sand texture	12918	North, n-e, n-w and west of Bikaner	Excessively drained, low fertility, severe wind erosion
Sandy plains, loam to sandy loam texture	5560	Scattered occurrence	Sand depositions, poor water holding capacity, low fertility
Flat interdunal plains, loamy sand to sandy loam texture	1698	Between isolated high dunes	Lime concretionary layer, salinity in patches
Undulating interdunal plains, sand to fine sand texture	–	Between the dunes, scattered occurrence	Wind erosion, poor fertility
Medium textured soils	3178	South and s-w of Bikaner, also in Nokha and Kolayat	Sand depositions
Flood plains, clay loam to silty clay loam texture	876	Extreme north of the district	Salinity, low fertility, impeded drainage
Saline soils, loamy sand to sandy loam texture	–	Mainly in Lunkaransar and Bikaner tehsils	Soil salinity
Hard pan soils, sand to loamy sand/gravelly texture	364	Localized in south and s-w of Kolayat up to Nokha	Compact sub-horizon, shallow soil cover

Surface Water Potentials

In the absence of any drainage network and sandy terrain conditions, surface water potentials of the district are very meagre. However, from gravelly aggraded

plains of Nal and Sarunds- Chitana-Basni section considerable runoff could be diverted in the adjoining areas. Similarly, eroded rocky areas of Kolayat have large runoff generation potentials.

Ground Water Potentials

Except a few isolated occurrences, major part of the geological formations are concealed beneath the thick cover of dune sands. The subsurface geology of the district has been elucidated on the basis of lethologs of open wells and tube wells. Major hydrogeological units in the district comprises of Nagaur sandstone, Eocene sandstone, and quaternary formations.

Nagaur sandstone series is generally encountered in the southern part of the district and towards south-west of Lunkaransar. These formations yield low to moderate discharge. The quality of ground water occurring in these formations is fresh to brackish. The depth to water in these formations ranges from 18.0 to 34.0 m.

The Eocene sandstone is coarse to medium grained poorly consolidated with gravel silt and clay. These are exposed near Bikaner, Kolayat and Mud village. These formations supply moderate to fair quantity of water. The quality of ground water is fresh to saline. The depth to water in these formations ranges from 31.0 to 120.0 m.

The quaternary formations comprises of sand silt, silty and occasionally gypseous clay, Kanker and dune sand. The yield of these formations is low to moderate and quality of ground water varies from fresh to brackish. The depth to water ranges from 6 to 67 m below ground level.

Existing Cropping Pattern

Among crops, the kharif pulses occupy the highest area (273836 ha) in the district, followed by bajra (251967 ha), and til (9575 ha). In rabi season, gram, wheat and raya are grown in 20018, 20913, and 16884 ha, respectively. In the case of pulses, Nokha tehsil has the highest area (123092 ha) followed by Bikaner tehsil (86821 ha). Til has similar areas in Bikaner and Kolayat tehsils and very small areas in other two tehsils. With the advent of irrigation, groundnut in kharif, and gram, wheat and raya in rabi are mainly cultivated in Bikaner and Lunkaransar tehsils.

Present Land Use

The present land use pattern of the district is given in Table 9.

Table 9. The Land Use Pattern of Bikaner District

Particulars	Area (ha)
Forest	77248
Area not available for cultivation	273775
land put to non-agric. use	234048
barren uncultivated land	39727
Cultivable land	1147065
permanent pasture/grazing land	44060
land under misc. tree crops	5584
cultivable wasteland	1097421
Fallow land	309454
fallow other than current fallow	227232
current fallow	82222
Total cropped area	936336
net sown area	935025
area sown more than once	51311
Area under wasteland	1364380
Total area	2742567

Description of the Ecosystem

Bikaner district is divided into 10 distinct land units (Anonymous, 1974). However, from the perspective of development of agriculture following ecological land classes (ELC) are considered.

1. Sand dunes (ELC 1)
2. Interdunal plains (ELC 2)
3. Alluvial plains (ELC 3)
4. Flood plains (ELC 4)
5. Rocky/garvelly areas (ELC 5)
6. Saline areas (ELC 6)

The description and distribution of various ecological land classes of the Bikaner district are as follows.

1. Sand dunes (ELC1) (14018 Km^2)

The duny areas occur in west, north-west, north-east and south-west parts of the district. The dunes are 10-60 m high and are mainly stabilized. The active dunes are found scattered in the district and cover about an area of 240 Km^2. The soils are mainly fine sandy with clay 3-5%, and silt less than 1%. The lower flanks of the stabilized dunes are cultivated in a system of fallow farming, otherwise the area is not put to any economic use. The main vegetation found in the area is *Calligonum*

polygonoides, Haloxylon salicornicum, Panicum trugidum, Cenchrus biflorus and *Zizyphus nummularia*. This class falls within the 180-300 mm isohyet.

2. Interdunal plains (ELC2) (3713 Km^2)

This class occurs in association with sand dunes. The soils are moderately deep to deep sandy to loamy fine sand in texture. The subsoil is loamy fine sand to sandy loam, underlain by indurated concretionary deposits. Soils are generally calcareous. About 50% of the area is with undulations of 0.3-0.9 m high which are formed due to severe wind activity. The area is cropped during kharif season in a system of fallow farming. The main vegetation consists of *Prosopis cineraria, Capparis decidua, Calligonum polygonoides, Zizyphus nummularia, Eleusine compressa*. This class lies within 180-300 mm isohyet.

3. Alluvial plains (ELC3) (8054 Km^2)

This class is distributed centrally in the district covering Nokha, Bikaner, Kolayat and western and eastern parts of Lunkaransar tehsils. Soils are moderately deep to deep fine sand to loamy sand at the surface and loamy fine sand to fine sandy loam in the subsoil underlain by lime concretionary zone. Soils are mostly calcareous. About 981 Km^2 area occurs in Lunkaransar and Kolayat tehsils with irregular slopes and 0.4-1.0 m high surface undulations. The fertility status of these soils is generally poor. The area is mainly single cropped during kharif season with intensity of cropping varying from 20-80% depending on the rainfall. The main vegetation comprises of *Prosopis cineraria, Zizyphus nummularia, Capparis decidua, Lasiurus sindicus* and *Cymbopogon jawarancusa*. This class lies within 200-300 mm isohyet.

4. Flood plains (ELC4) (399 Km^2)

This area occurs in the north-west corner of the district. This class is the part of former flood plain of ancient rivers which used to drain in the Rann of Kutch, but now occurs as the silted up water channels and at many places is buried under aeolian sand. The dominant soils are medium to fine in texture. The soils are underlain by fine textured impervious substrata or gypsiferous material due to which sub-horizons are usually saline. Some parts under this class are used for rainfed cropping, otherwise it is left as the natural grazing lands. The main vegetation consists of *Haloxylon salicornicum, Suaeda fruticosa, Eleusine compressa, Lasiurus sindicus* and *Cymbopogon jawarancusa*. This class lies within the 180-200 mm isohyet.

5. Rocky/gravelly areas (ELC5) (985 Km2)

This area occurs mainly in south of Nal and north-west of Kolayat tehsil. The soils are very shallow, gravelly sandy to loamy sand in texture, underlain by gravelly calcareous or hard weathered rock strata. The land is mainly used as an open grazing area. The vegetation is sparse and mainly consists of *Acacia senegal, Capparis decidua,*

Grewia tenax, Eleusine compressa, Aristida and *Cymbopogon jawarancusa*. This class falls within the 200-250 mm isohyet.

6. Saline areas (ELC6) (157 Km^2)

This area occurs in Bikaner and Lunkaransar tehsils as the saline depressions either in alluvial plains or in flood plains. The soils are medium to heavy textured, underlain by gypsiferous and calcareous material. The area is largely a waste land and used as grazing land. In Jansar and Nal, the area is quarried for gypsum. The characteristic vegetation is *Peganeum hermala*, which grows on gypsiferous soils. Where salinity is less, the vegetation consists of *Zizyphus nummularia, Prosopis juliflora, Capparis decidua, Sporobolus marginatus* and *Eleusine compressa*. This class occurs within the 180-250 mm isohyte.

Sustainable Land Uses For The Ecosystem

Following are the suggested land uses for various ecological land classes for the long-term development of agriculture in the region.

Sand dunes (ELC 1)

The duny areas, as usual, are most suitable for tree plantation and development of grassland. Fortunately, a major part of this class comprises of stable dunes, where protection for the first few years alone would suffice for the establishment of trees and grass cover. The area in the western and north-western parts are covered in the Indira Gandhi Canal command area where forestry with timber species and irrigated pastures can be developed with a proper irrigation system design.

Interdunal plains (ELC 2)

About 35% area of this class is covered in the canal command area. However, proper management of irrigation water will be required because of the presence of indurated concretionary sub- strata. The area with undulations will need proper irrigation system design. The irrigated area is suitable for cropping, whereas the rest of the rainfed area should be utilized for rangeland development and tree plantation.

Alluvial plains (ELC 3)

A part of this class comes under the command area of Lunkaransar high distributary and therefore, will form good irrigated areas where production of both cereal and cash crops can be taken. In the relatively flat plains the existing crop production can be strengthened with the adoption of dry farming techniques. The plains with undulations are best suited for pasture land development.

Flood plains (ELC 4)

This class comes under the command area of Anupgarh Shakha. The flat areas with medium to fine textured soils can be utilized for irrigated cropping. However,

proper design of irrigation system is required to avoid the salinity hazards as the texture of substrata may induce such problems. The land with moderate undulations can be put under irrigated agriculture after land levelling. The rest of the area with somewhat duny formations may be best utilized for pasture development and tree plantation.

Rocky/gravelly areas (ELC 5)

This class has the potential for runoff generation and utilization in the vicinity. Forest woodlots and pastures can be developed together with the runoff generation in the vast gravelly areas.

Saline areas (ELC 6)

The commercial gypsum mining will continue on the sites suitable for such purpose. However, efforts should be made to put some green cover on such sites with salt tolerant tree and grass species. The patches where soils are not very saline, grazing lands can be developed.

JAISALMER

General Features

The district Jaisalmer extends from 69°30'E to 70°00'E longitude and from 26°95'N to 28°00'N latidude. Its geographical area is 38401 Km^2 which accounts for 19.6% of the arid zone of Rajasthan and 11.22% of the State. The district comprises of two tehsils namely, Jaisalmer(28669 km^2) and Pokaran (9606.9 km^2). The administration is exercised through 3 blocks. It has two towns and 462 villages. The total urban area in the district is only 131.3 km^2. The population of the district as per the Census, 1991 was 344 thousand which is 0.78% of the State. The population growth registered an increase of 41.73% over the decade. The livestock population was 1630 thousand which is 3.28% of the State.

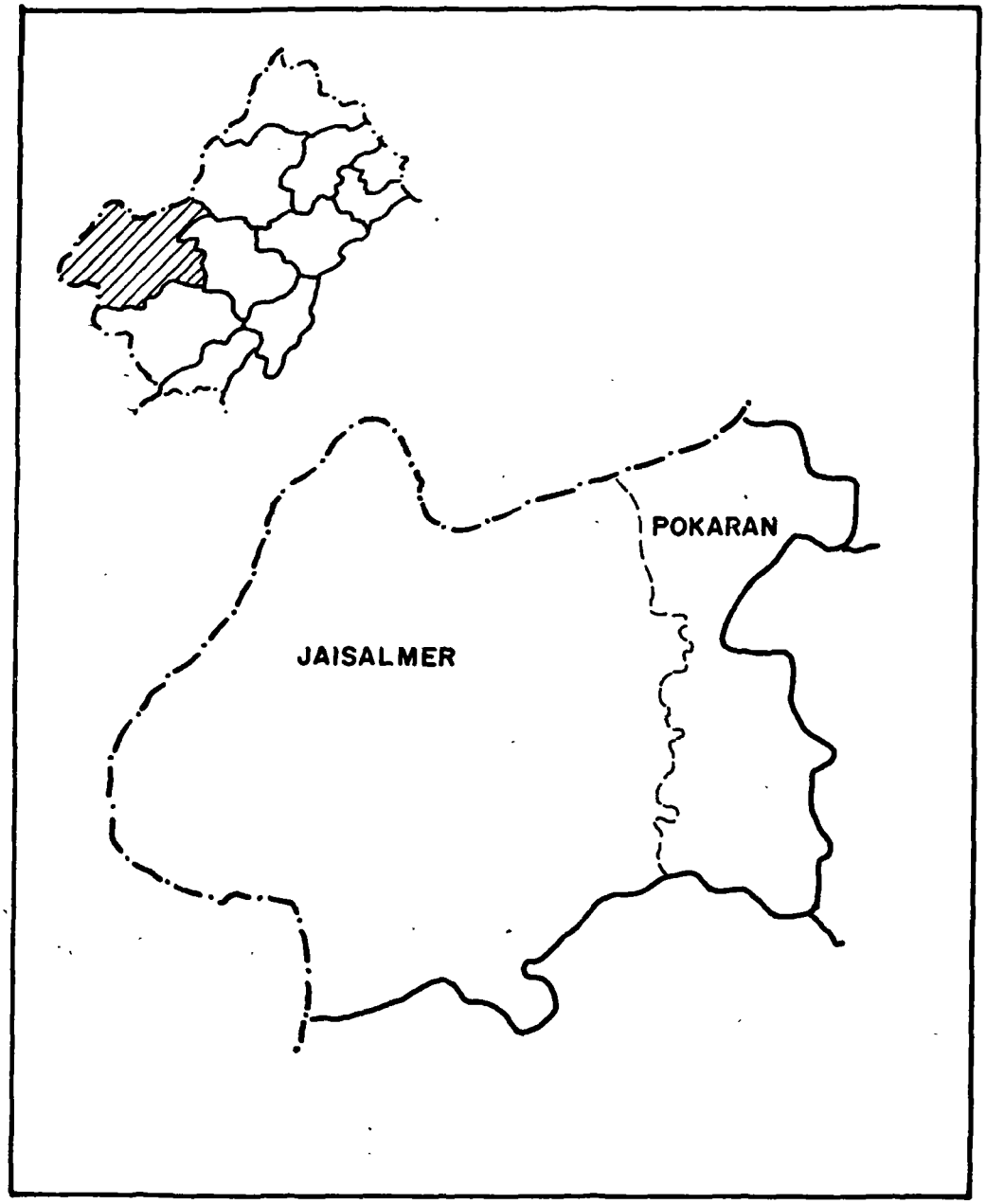
Climatic Features

The annual average rainfall of Jaisalmer district is 156 mm but the rainfall in the region varies from 200 mm in the eastern part to less than 100 mm in the north-western parts. The district receives not only the lowest quantity of rainfall in the entire arid regions of Rajasthan but also the most variable rainfall from year to year. The coefficient of variation of annual rainfall of the district is between 49% to 91% (Table 10).

Table 10. Mean annual rainfall and normal crop growing period in Jaisalmer district

Station	Normal annual rainfall (mm)	Coefficient of variation (%)	Normal crop growing period (weeks)
Jaisalmer	188.1	85.4	7
Ramgarh	133.8	73.2	4
Fatehgarh	157.4	67.2	4
Sam	210.7	90.9	7
Pokaran	171.9	40.7	6

The monsoon normally sets over the region between 5th and 15th July and withdrawal from the region during the first week of September. The normal crop growing season in the area is for a period of 4-8 weeks between 28th (9-15 July) and 35th (27-2 Sep) week. The rainfall records from 1901 onwards showed that the district received early (4th June to 1st July) sowing rains (>20 mm/week) in 18% of the years whereas 63% of the years account for normal onset of sowing rains. The rainfall distribution pattern of Jaisalmer indicated that the district recorded average to above average rainfall in 43 out of 85 years. The highest one day observed rainfall was between 71 mm at Pokaran and 178 mm at Ramgarh. Similarly, the highest observed weekly rainfall was between 190 mm at Pokaran to 396 mm at Sam which



Central Arid Zone Research Institute, JODHPUR

DISTRICT JAISALMER

indicates that the annual rainfall occurs in shorter spells of heavy rainfall creating an imbalance in the distribution of rainfall. The probability studies for the region shows that the area gets surplus rainfall of about 200-300 mm once in 10 years whereas rainfall can be as low as 50 mm or less once in 10 years. The region experienced agricultural droughts in 3, 13, and 77% of the years under early, normal, and late monsoon rainfall conditions.

Besides low rainfall condition, the district also experience high temperatures up to 45°C during May to July with mean day time temperature of about 41°C. Similarly, during winter the average minimum temperatures are less than 10°C. The recorded highest temperature in the region is 47.8°C whereas the lowest is -4.4°C. During winter period, occasionally cold waves prevail resulting in frost damage to vegetation. A strong wind regime prevails from March onwards resulting in dust storms and dust raising winds.

Characteristic Soils

Jaisalmer district has various types of soils, developed on varied type of parent material. A brief description of each soil group is presented in Table 11.

Surface Water Potentials

The district is covered with medium to high dunes, having poor drainage system. Drainage channels are totally absent. However, few drainage channels which are visible on the surface flow for a short distance and disappear in the sandy areas. The water harvesting is limited to collection of runoff in Tanka and Khadins. The Khadins are used for crop cultivation. Because of low and highly variable rainfall, relatively large catchments are required for water harvesting.

Ground Water Potentials

Ground water occurs in almost all the formations ranging from precambrian to quaternary. These formations are rhyolite and granites, Jodhpur sandstone, Lathi sandstone, Jaisalmer formations, Baisakhi formations, Badasar formations, Parewar formations, Deena formations and wind blown sand.

Lathi sandstone and Parewar sandstone form very promising ground water aquifers where it occurs under semi-confined and unconfined conditions. In Jaisalmer limestone and crystalline igneous formation, ground water occurs in limited quantities. A number of perched aquifer containing good quality water also occur. In major parts of the district, 50% area has inferior quality water where EC value ranges from 5000-7800 microsiemens/cm. Aquifers belonging to Lathi and Parewar sandstones have comparatively higher yields. A part of Khuiala formations and very limited zones in wind blown sand, rhyolite and Jodhpur sandstone also form

promising aquifers and yield water of good quality with EC values ranging from 800-2350 microsiemens/cm. Depth to water in the district varies from 6.2 m at Pokaran to 129 m at Bhakrani in Lathi formations.

Table 11. Major Soil Groups, their Extent, Characteristics and Limitation

Soil group	Extent (km^2)	Location	Limitation
Duny complex, deep and fine sand throughout the profile	18377	Major occurrence in n-e, n-w of the district	Severe wind erosion, poor texture and fertility, low water holding capacity
Moderately deep to deep and very deep sandy plains, sand to loamy fine sand	5244	Occur in s-w, n-w and n-e, s-e and south of the district	Susceptible to wind erosion, excessively drained, low fertility
Medium textured soils with sandy loam to loam texture	1432	Occur mainly in east and s-e of the district	Sheet erosion, low fertility
Moderately fine textured soils	3134	north, n-w, south, s-e and s-w of Jaislamer	Sand accumulation, water erosion
Khadin soils, medium to fine textured		Distributed throughout the central parts	Limitation of only good rainfall
Saline Ranns, loam to clay loam and silty clay loam texture	195	Scattered occurrence	Salinity
Shallow Misc. soils	1403	Scattered all over the district	Soil depth and undulating topography
Rocky hills	2494	Scattered, but concentrated more near Jaisalmer town	Negligible soil cover, steep slopes

Existing Cropping Pattern

Bajra is the only predominant crop occupying 90469 ha in Pokaran and 44049 ha in Jaisalmer tehsils. Among other crops, Jowar is grown on 1046 ha in Jaisalmer and in 746 ha in Pokaran tehsils. Cultivation of other kharif crops like sesamum and pulses is almost negligible with a total area of 239 ha only. In rabi season, wheat

occupies about 1282 ha and gram 196 ha area which are grown in khadin areas on conserved moisture.

Present Land Use

Jaisalmer is the largest district of Rajasthan but very little area is put to the economic landuses. The most of the area including the cultivable land is characterized as wasteland. Forest cover is negligible in comparison to the total geographical area of the district. The present land use pattern of the district is presented in Table 12.

Table 12. The Land Use Pattern of Jaisalmer District

Particulars	Area (ha)
Forest	16319
Area not available for cultivation	442421
land put to non-agric. use	78088
barren uncultivated land	364333
Cultivable land	3032722
permanent pasture/grazing land	107509
land under misc. tree crops	1423
cultivable wasteland	2923790
Fallow land	114556
fallow other than current fallow	96499
current fallow	18057
Total cropped area	235070
net sown area	234647
area sown more than once	423
Area under wasteland	3384622
Total area	3840665

Description of the Ecosystem

Jaisalmer district is divided into 11 units based on their land forms (Chatterji and Kar, 1992). However, following ecological land classes (ELC) are considered for undertaking the development activities.

1. Duny complex (ELC 1)
2. Flat colluvial/alluvial plains (ELC 2)
3. Sandy undulating plains (ELC 3)
4. Saline areas (ELC 4)
5. Hilly, rocky, gravelly areas (ELC 5)

The description and distribution of various ecological land classes of the district are as follows.

1. Duny complex (ELC1) (20253.4 km^2)

It occurs in the west and south-western parts of Jaisalmer tehsil and in the northern portions of Pokaran tehsil. The soils are mainly coarse textured with 2-6% clay, 1.7-3.3% silt, 72-85% fine sand and 9-15% coarse sand. Soils contain 0.01-0.07% organic carbon, 6017 kg P_2O_5/ha and 140-477 kg K_2O/ha. The water holding capacity is 50-70 mm/m depth of soil. Sand dunes in the major area are mobile; others are relatively stable and vegetated. The associated interdunal plains are occasionally mono-cropped during Kharif season, otherwise the area is mostly used as an open grazing land. The main vegetation found in this area consists of *Prosopis cineraria, Calligonum polygonoides, Calotropis procera, Zyziphus nummularia, Acacia pseudotomentosa, Lasiurus sindicus, Penicum turgidum, E. compressa*. This class falls between 100-150 mm isohyet.

2. Flat colluvial/alluvial plains (ELC2) (11524.2 Km^2)

Mainly occurs in Pokaran tehsil, but scattered occurrences are also found in Jaisalmer tehsil. The dominant soils are medium to moderately fine textured with 10-16% clay, 9-12% silt, 47-68% fine sand and 11-28% coarse sand. The subsoil is finer in structure with 17-36% clay, 8-26% silt, 14-56% fine sand and 6- 15% coarse sand. The soils contain 0.04-0.36% organic carbon, 10- 20 kg P_2O_5/ha and 190-514 kg K_2O/ha. The water holding capacity varies from 90-110 mm/m in the medium textured and 110-190 mm/m in the fine textured soils. The area is mostly monocropped during the kharif season. Most of the khadins are found in this area, where soil can hold 130-220 mm water per metre depth. Fertility status is also better in khadin areas. Some of the area is covered under the permanent pastures. The main vegetation consists of *Prosopis cineraria, Capparis decidua, Zyziphus nummularia, Salvadora oleoides, Lesiurus sindicus, E. compressa*. This class mainly occurs between 125-200 mm isohyet.

3. Sandy undulating plains (ELC3) (3051.6 Km^2)

This class mainly occurs in the northern parts of Jaisalmer tehsil, scattered occurrences in the central and south-eastern parts of the district are also found. The dominant soils vary from sand to loamy sand underlain by lime concretion, gypsum layer or rock. The slopes are irregular and vary from 1-3%. The fertility status is generally the same as that of the soils of ELC1. The water holding capacity varies from 50-70 mm/m depth. Ground water depth varies from 40 m to more than 60 m. The area is mainly used as an open grazing land. The main vegetation consists of *Capparis decidua, Haloxylon salicornicum, Lesiurus sindicus, E. compressa*. This class falls between 125-200 mm isohyet.

4. Saline areas (ELC4) (191.2 Km^2)

Scattered saline patches within the rocky areas or steep slopes are mainly found in Jaisalmer tehsil. The soils vary from sand to loamy sand, sandy loam and clay loam. The electrical conductivity ranges from 100 mmhos to 2200 mmhos. The area is mainly barren. The saline depressions are devoid of any vegetation, however, only in the area of low salinity the vegetation consists of *Tamarix dioica, Salvadora oleoides, Sporobolus marginatus, Zyziphus nummularia*. This class falls between 150-200 mm isohyet.

5. Hilly, rocky, gravelly areas (ELC5) (3380.6 Km^2)

Such areas are scattered from northern to central and south- eastern parts of the district. Hills are formed of sandstone, limestone, granite and ryholite. Soil cover is negligible and is found only in gravelly areas where it has sand to loamy sand texture. The main vegetation of the area is *Salvadora oleoides, Capparis decidua, Zizyphus nummularia, Aristida, Orepetium thomaeum*. This class lies between 125-200 mm isohyet.

Sustainable Land Uses For The Ecosystem

The guidelines discussed for the ecosystem development of Jodhpur district also apply to this region. However, due to rainfall constraints the characteristics of ecosystem are different. Following are the suggested land uses for various ecological land classes for the long-term development of agriculture in the region.

Duny complex (ELC 1)

The major area containing the mobile dunes should be left undisturbed in order to encourage the establishment of natural grass and shrub cover. The grass and shrub species native to this region can adequately check the erosion hazards and sustain themselves under the extreme drought conditions provided that they are protected from the biotic interference.

In the Indira Gandhi Canal command area, the interdunal plains and even sand dunes can be made highly productive. The emphasis should be placed on irrigated pastures or forestry with timber species. Cropping should be done only in the form of farm- forestry so as to ensure some degree of vegetative cover on soil throughout the year.

Flat colluvial/alluvial plains (ELC 2)

The area covered in this class has some potential for the annual crops. However, since monsoon rainfall is highly erratic, the cropping should be practised in the form of agroforestry. Otherwise, because of its nearness to the rural settlements the best use would be to develop permanent protected rangelands. Drip irrigated orchards may also be developed where tube wells are available.

Sandy undulating plains (ELC 3)

Undulating topography with irregular slopes formed by continuous wind activity are the major features of the area falling in this class. Such area is, therefore, best suited for the development of natural rangelands with proper management. Drip irrigated orchards may also be developed.

Saline areas (ELC 4)

In low salinity tracts, plantation of salt tolerant species of trees and grasses is the only possible development for this class.

Hilly, rocky, gravelly areas (ELC 5)

Such areas can be the potential source of rainwater harvesting even in low rainfall years. The harvested water should mainly be used for the water requirements of human and animal population. The rocky-gravelly area, where some soil cover exists, can be utilized both for the water harvesting as well as for the pasture development.

TECHNOLOGIES

Suitable technologies for taking various developmental work are described as follows. The technologies discussed are the outcome of various experiments and demonstration work. We have laid emphasis on the implementation part of the techniques. The experimental data have not been given because it is understood that these are the viable solutions to the problems discussed in the previous chapters.

WATER HARVESTING

There are mainly two types of schemes for the development of surface water resources.

a) Development of water resources by storage of runoff.

b) Use of natural flow of water without storage.

a) Schemes for Storage of Runoff

Excavated ponds

Excavated ponds are often the only source of water for man and animals in the arid zone. These can be constructed either on community basis or on individual basis. On individual fields ponds up to a maximum capacity of 400 m^3 can be constructed. However, the capacity of pond depends upon the rainfall, soil type and the available catchment area.

Under the arid conditions rainfall of 20 mm and above may be considered as capable of generating runoff. Weekly normal rainfall data should be considered for estimating the runoff generating rainfall. The runoff volume is calculated from the following equation

$$V = R \times C \times A/1000$$

where, R=rainfall, mm

C=runoff coefficient which varies from 0.20 to 0.45 depending upon the catchment condition

A=catchment area m^2.

After estimating the runoff volume, the dimensions of the pond are calculated from the following equation.

$$V = \pi (a_1^2 + a_1a_2 + a_2^2) / 3$$

where,

h = depth of the pond,m

a1 = top radius

a2 = (a1-zh), bottom radius

z =side slope.

For all practical purposes the depth should not be greater than 4.5 m. Only incase of small tanks, which are for drinking purpose and where water lifting is by means of a bucket the depth may exceed this limit. Catchment of the pond is generally prepared. A slope of 2-3% should be provided in the catchment. To increase the runoff efficiency of the desert soils several methods are there. Sometimes simple compaction may serve the purpose or otherwise chemicals like silicon water repellents and sodium salts particularly NaCl has been successfully tried. The design and construction details of a pond of 271 m3 capacity are given in Figure 2. Such a pond was constructed in the farmer's field in Jhanwar watershed and is shown in Figure 3.

Underground barrage

This system of water storage partly belong to the category of ground water. The water is stored in the sandy beds by creating and artificial aquifer. The most suitable site for storage is in the deep and wide sandy beds underlain by impervious material. Flat stream gradient are naturally more suitable as they provide more storage. The volume of water stored is about 23% in sandy beds. It may go up to 34% in the case of coarse depositions.

The barrage must extend sufficiently into impervious foundation to achieve best results. Although a partial closure by a floating diaphragm may also be accepted. The crest of the barrage should be kept below the bed level. The barrage can be built of masonry or clay core. The water is drawn from the infiltration gallery by means of a bucket, hand pump or any other convenient water lifting device. A schematic underground barrage is shown in Figure 4.

Water harvesting-cum-check dam

This structure is constructed to serve the twin purpose of water harvesting and preventing soil erosion from gullied areas. The site suitable for such structures are the upper reaches of ephemeral nalas. The check dam has also found to recharge the ground water aquifers substantially. It is recommended that the catchment of the dam should be planted with suitable tree species. The details of a masonry check dam with straight drop spillway are given as follows.

Hydrologic design :

The runoff discharge from the catchment is calculated as

$$Q = C\,I\,A/36$$

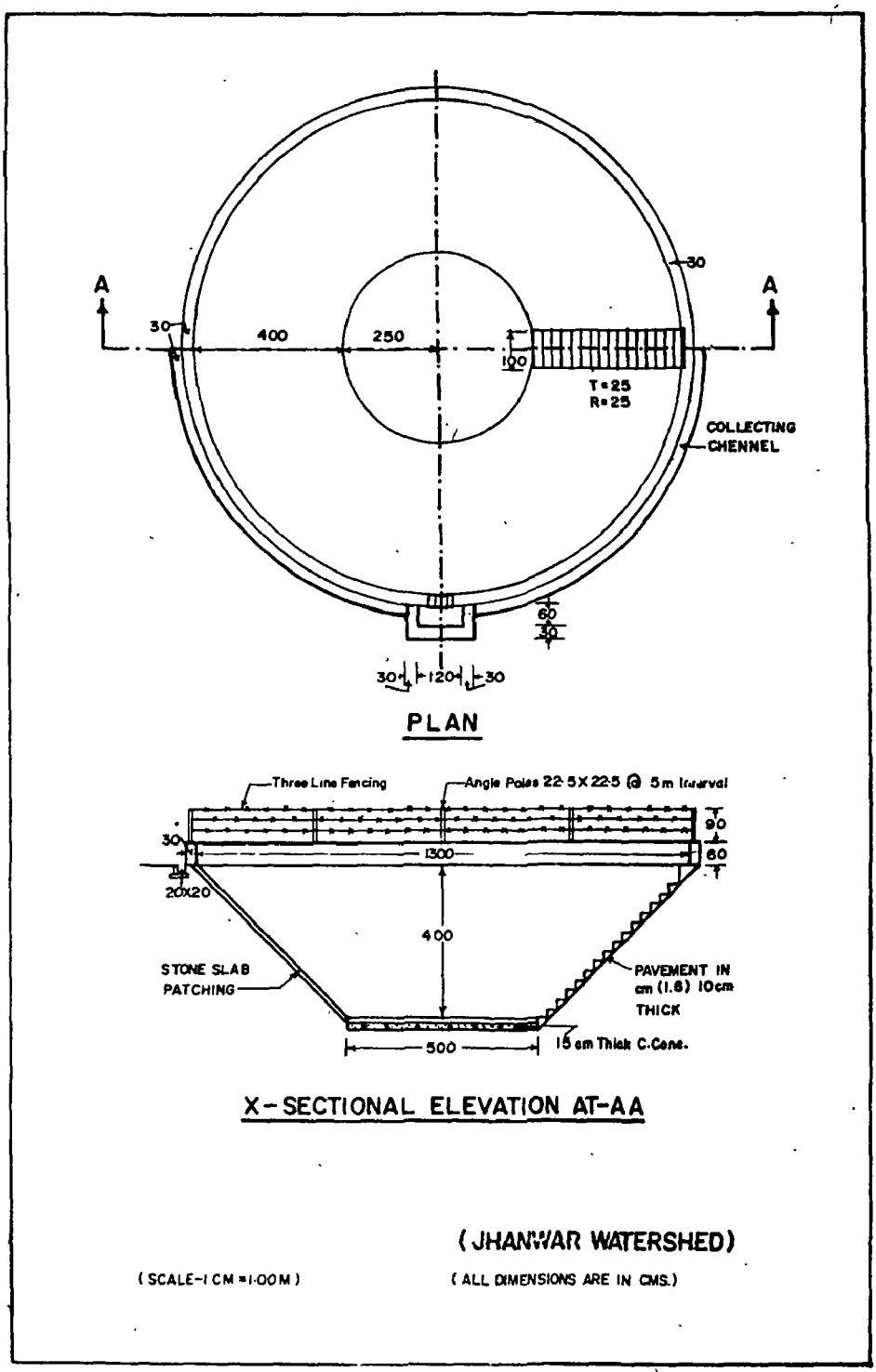


Figure 2 Details of a farm pond of 271 m^3 capacity.

Figure 3 A farm pond of 271 m^3 capacity.

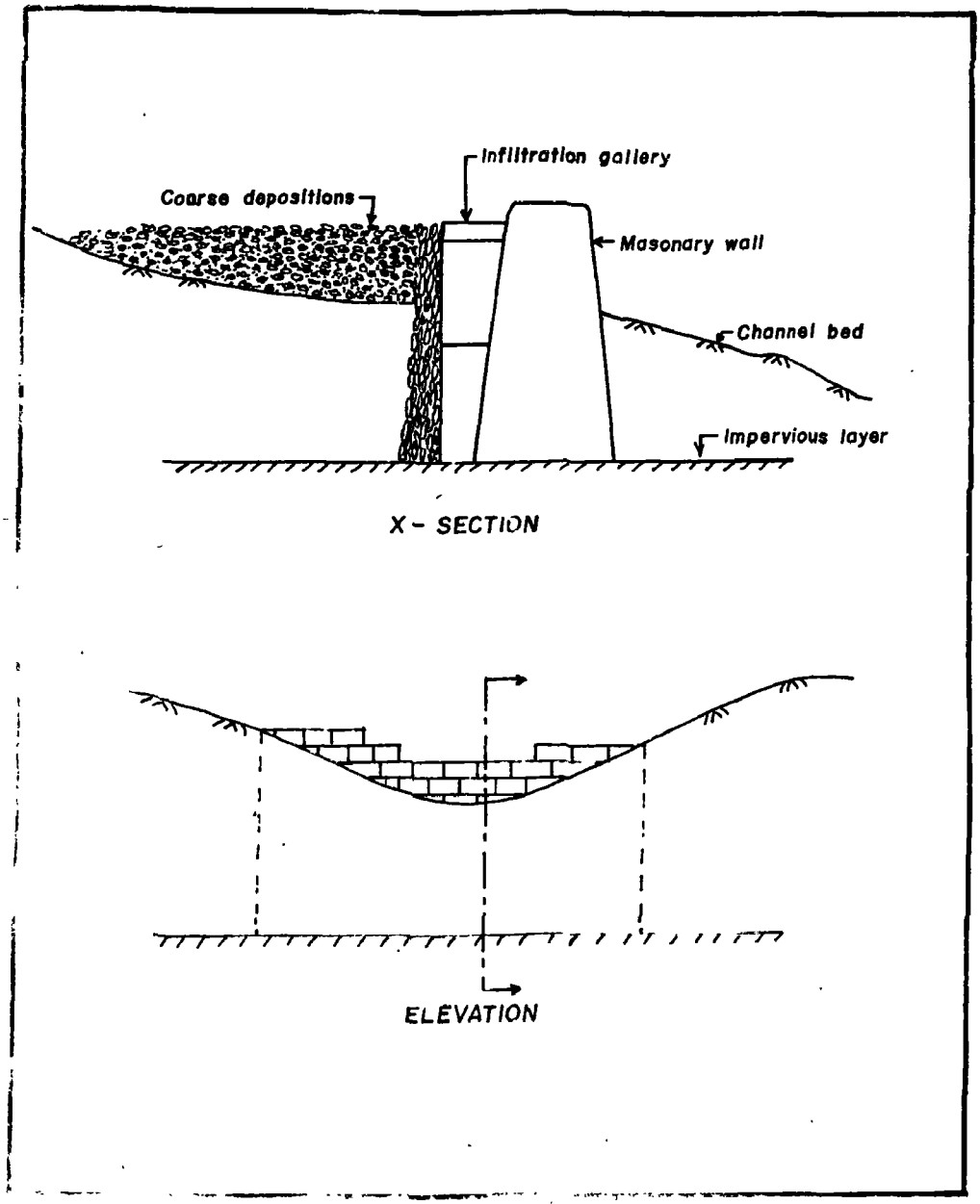


Figure 4 An underground barrage for water harvesting.

where, Q is the peak discharge in m^3/s, I is the rainfall intensity for the period of time of concentration, A is the catchment area in ha, and C is the runoff coefficient which can be taken as 0.4 to 0.6 for the rocky-gravelly conditions.

Hydraulic design :

For designing the dimensions of the dam, the crest height and crest length are decided a priori. These parameters depend upon the site, width of gully or nala, u/s catchment conditions, submergence area etc. The depth of flow (H) is calculated as

$$Q = 1.75\ L\ H^{3/2}$$

where, L is the crest length in m, and H is depth of flow in m. Height of wing wall (d) is given by d=H+f, where f is the free board and generally is taken as 0.30m.

Length of apron is calculated as

$$Lp = 0.75(D+d)+D$$

where D is the spillway fall or the height of crest in m.

In the case of wide nalas flanked by stabilized dunes or rocky-gravelly hills it may not be feasible to construct masonry dam across the entire width. Therefore, it is recommended that the structure should be constructed in the middle of an earthen embankment. This reduces the cost of construction and also provides the stability to the structure. Stone pitching should be provided on the upstream side of the embankment. The height of embankment should be equal to the total height of the structure. In some cases, it is advantageous to construct the spillway at the end of the embankment instead of in the middle. The structural design of the dam should be undertaken by a qualified engineer because it depends upon the site conditions. The design details of a masonry check dam are shown in Figure 5. A water harvesting check dam constructed in Jhanwar watershed is shown in Figure 6.

b) Utilization of the Natural Flow without Storage

Water diversion and spreading

There is a great scope for such schemes in the arid areas. In this method, the seasonal runoff is diverted from an ephemeral stream or rocky catchment to an adjacent land surface. It is adaptable to gently sloping fields with upstream watersheds that experience at least 3 to 4 runoff events annually. Traditional 'khadin' system is one such practice where runoff is stored in the kharif season and crops are cultivated in the rabi season.

The system consists of a cross dyke or masonry weir over the stream which would divert the water to the required area. If the flow is more a series of dykes may be constructed. The design of water spreading system requires data on the watershed

characteristics, rainfall and stream flow. Sites nearer to the rocky outcrop are more suitable. The depth of water spread varies depending upon the infiltration rate of the receiving area. However, in general water application depth of 75 to 100 mm produces good agricultural crops as well as the forage species. This technique is relatively suitable for turning fallows into grasslands.

IN-SITU WATER CONSERVATION

The in-situ methods of water conservation during kharif season have been found to be successful for the field crops as well as the orchards. These methods are discussed as follows.

Ridge-furrow system

Under this technique furrows (15-18 cm deep and 30-35 cm wide) with adjoining ridges (45-50 cm wide) are constructed against the field slope. Two lines of crop are then sown in the furrows. In case of the level fields, it may be appropriate to align the system against the prevailing wind direction. This system is suitable for any kharif crop and has proved to give better yield levels.

Micro-catchments water harvesting

This method consists of construction of micro-catchment to harvest water for an individual plant or the entire row. In the case of individual plants, a circular catchment with a slope of 3-5% is constructed around the plant. Its surface should be slightly compacted by a small roller or any other suitable equipment (for example, a spade). The size of the catchment depends upon the dependable rainfall of the area and plant to plant spacing. For example, in the case of ber a catchment of 3 m diameter is capable of generating 30 litres of water from a rainfall event of 20 mm. No area is lost in the catchment if the plant to plant spacing is kept 5.0 m. In the same case, if a plastic mulch is provided the runoff generation is of the order of 70 litres. If the soil type is light sandy in nature then providing plastic mulch or soil treatment as mentioned before may be necessary. A circular catchment with plastic mulch for the establishment of ber plants is shown in Figure 7.

For the large scale orchards, construction of micro- catchment for the entire row is recommended. As shown in the Figure 8, the catchment is provided on both sides of the tree row. A slope of 7-10% may be provided in the catchment. The fruit trees are planted in 1 m wide furrows. Construction of such catchments require some land shaping which can be efficiently done with the help of a mould board plough. The catchment area thus provided is about 4 sq.m/meter running length of row. Immediately after construction the catchment may need compaction or soil treatment. Figure 9 shows the system of row catchment for kharif crop in sandy soil.

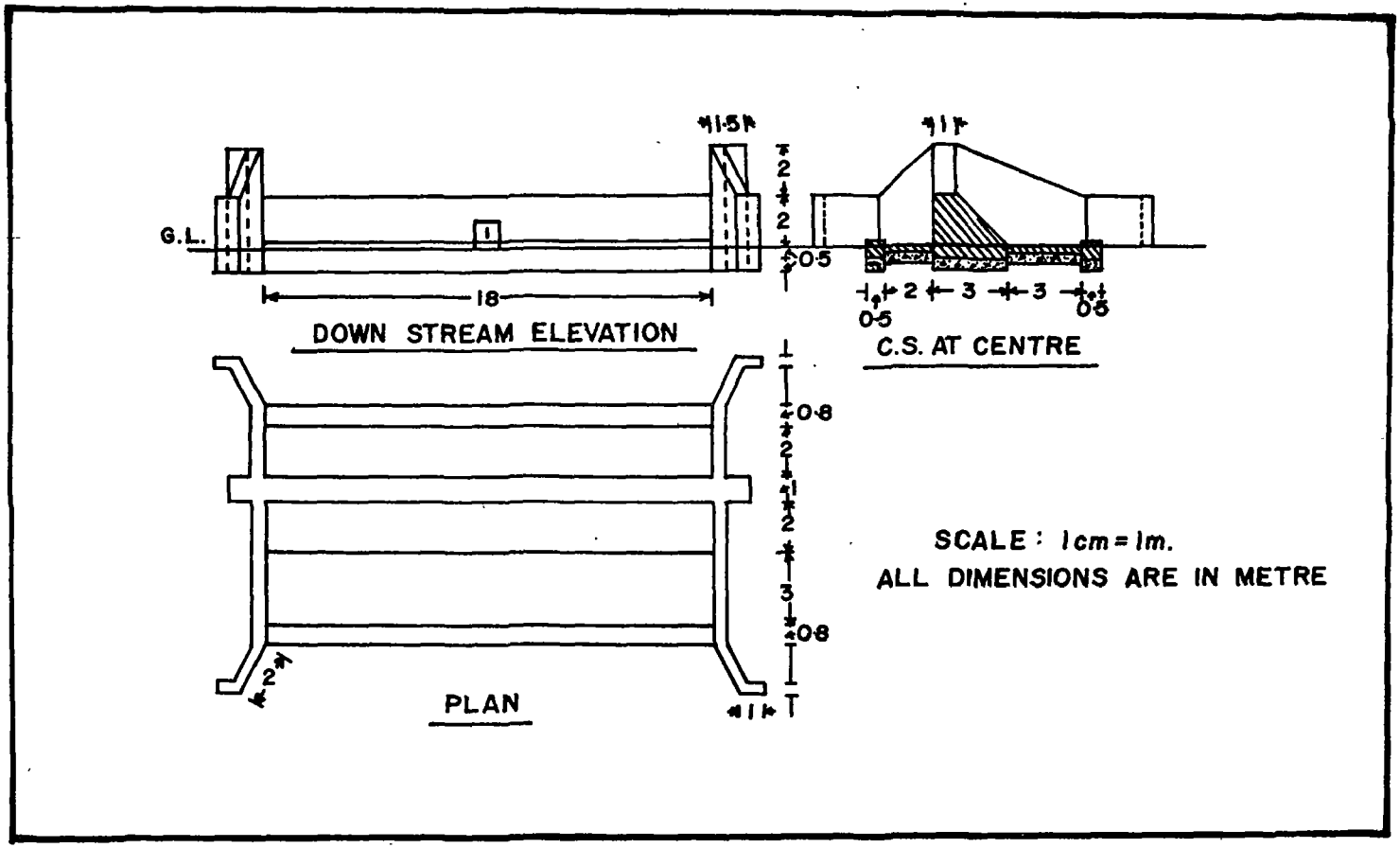


Figure 5 Details of water harvesting-cum check dam.

Figure 6 A masonry check dam for water harvesting.

Figure 7 Circular Catchment with plastic mulch for the establishment of ber plants.

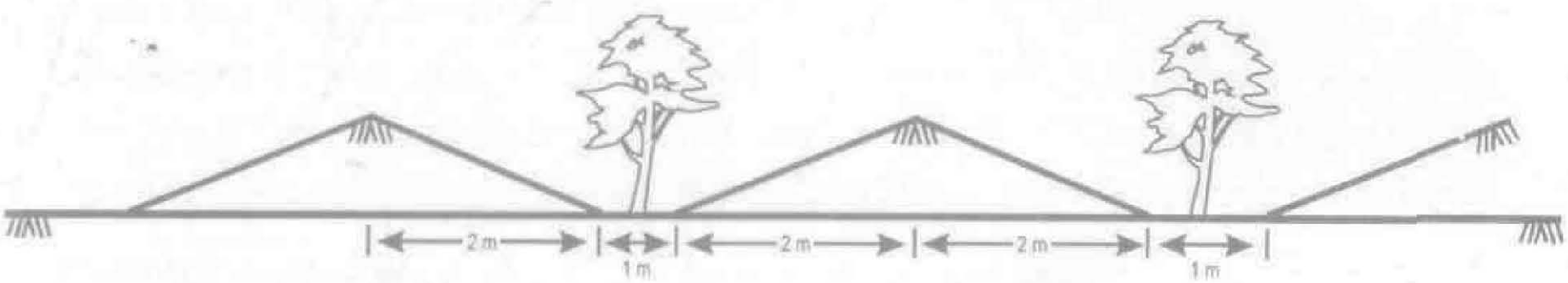


Figure 8 Details of row catchment for the ber orchards.

Figure 9 Row catchments for micro water harvesting in kharif crop.

AFFORESTATION TECHNIQUES

The afforestation is recommended on sand dunes, sandy plains and saline-alkaline areas. Besides these, trees can be planted in a silvipastoral system as indicated in the pasture development section.

1. Sand dunes

The following steps are involved in tree plantation on the sand dunes.

a) Protection from biotic interference

For the protection of sand dunes angle iron post with barbed wire fencing is recommended. Other type of fencing will not be effective. The fencing should be provided till the tree seedlings have established and have accumulated some growth.

b) Treatment of dunes

High wind velocity erodes the top soil of the dunes which results in the exposure of roots of the planted saplings or sometimes due to erosion the seedlings get buried by moving sand. Therefore, to check this, microwind breaks should be erected at right angles to the wind direction. The microwind breaks are erected in parallel rows at a spacing of 5 m or sometimes in the form of chequer board fashion. By doing this the wind erosion from the dune surface can be reduced. Locally available shrubs can be used for preparing the microwind breaks. These are *Zizyphus nummularia, Crotolaria burhea, Aerya persica,* and *Calotropis procera*. The protection of dune with microwind breaks is shown in Figure 10.

c) Afforestation

The treated dunes can be put under afforestation. The suitable tree seedlings, which are raised in nursery can be planted in between the parallel strips of microwind breaks at a spacing of 5x5 m. The seedlings of 45 to 60 cm height are preferred. The planting should be deep enough (40-50 cm) to utilize the deep moisture available in sand dunes. Besides tree plantation, the sowing of grass species should be done to check the surface erosion with immediate effect. The sowing should be done after the first effective rainfall. A stabilized sand dune is shown in Figure 11. Following tree species are suitable for afforestation of sand dunes.

Acacia tortilis, Cordia rothii, Zizyphus rotundifolia,
Zizyphus nummularia, Prosopis cineraria.

2. Sandy plains and other areas

Following tree species are recommended for afforestation of sandy plains and other similar areas.

Ailanthus excelsa, Prosopis cineraria, Albizzia lebbek, Moringa olefera, Zizyphus nummularia, Mytenus emarginatus, Salvadora oleoides, Leucaena leucocephala, Acacia nilotica.

3. Saline-alkali areas

Casurina equisetifolia can be grown in poor, alkaline and water logged soils. It has the ability to exhaust soil moisture and lower the water table. It requires 200-700 mm rainfall and can tolerate dry season of 6-8 months. *Prosopis juliflora* has shown good establishment potentials in the saline areas.

4. Development of plantation woodlots

The forest woodlots can be developed in the undulating, deep sandy land of the IGNP command area. The recommended perennial species for the **Jaisalmer** district are given as follows.

Suitable tree and shrub species

Under irrigation (timber species) : Tecomella undulata, Delbergia sissu

Under rainfed condition : *Acacia senegal, Acacia tortilis, Prosopis juliflora, Salvadora oleoides, Calligonum polygonoides, Capparis decidua, Zizyphus nummularia*

The recommended perennjal species for the **Bikaner** district are given as follows.

Suitable tree and shrub species

Under irrigation (timber species) : *Tecomella undulata, Dalbergia sissu*

Under rainfed condition: *Acacia nilotica, Azadirachta indica, Prosopis cineraria, Calligonum polygonoides, Salvadora oleoides, Capparis decidua, Acacia tortilis, Prosopis juliflora.*

DEVELOPMENT AND MANAGEMENT OF RANGE LANDS

Suitable grass species for Jodhpur

Cenchrus ciliaris :	plain areas.
Cenchrus setigerus :	low salinity soils, plains.
Dichanthium annulatum :	in mixture with above spp.

Suitable grass species for Bikaner

Lasiurus sindicus :	sand dunes, sand drifts.
Cenchrus setigerus :	low salinity soils, plains.
Dichanthium annulatum :	plain areas.
Eleusine spp. :	shallow gravelly soils.

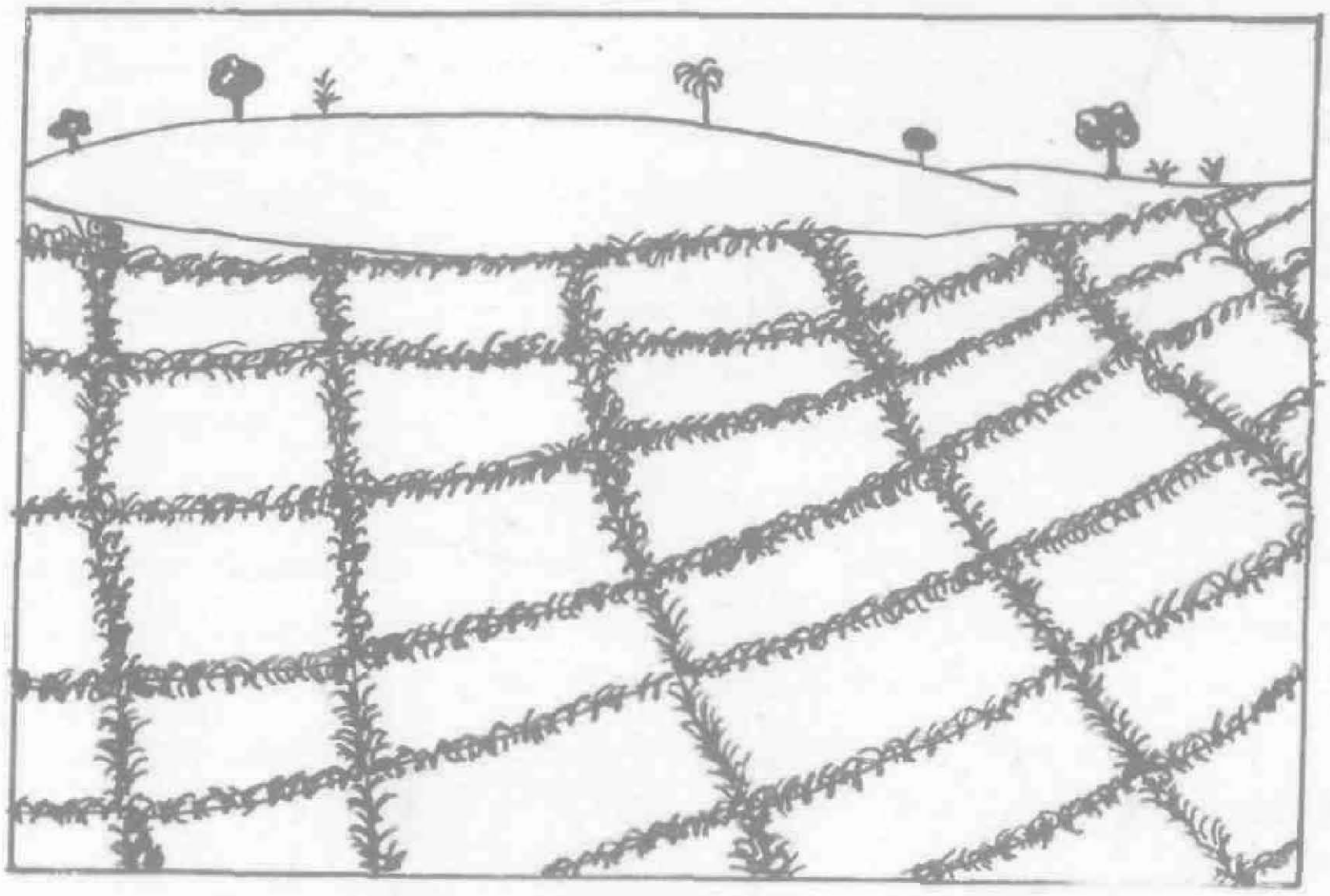


Figure 10 Micro wind breaks for the protection of dune.

Figure 11 A stabilized sand dune with *Acacia tortilis* plantation.

Suitable overstory species

Prosopis cineraria, Zizyphus nummularia, Acacia tortilis

Suitable grass species for Jaisalmer

Lesiurus sindicus :	sandy soils, plains, sandy drifts, sand dunes.
Eleusine compressa :	shallow, gravelly soils.
Panicum turgidum :	dunes and shifting sand deposits.
Aeluropus lagopoides :	saline areas.
Chloris virgate :	saline, waterlogged areas.

The last two species are not for commercial production.

Suitable overstory species

Acacia tortilis, Azadirachta indica, Dicrostychis nutans, Colophospermum mopane, Prosopis juliflora (saline areas), Salvadora oleoides (saline areas).

Following steps are to be followed for the development of range lands.

1. As a first step the rangeland must be protected by the barbed wire fencing. Although costly but it is absolutely necessary.
2. Shrubs like *Lycium barbarum, Mimosa hamata, Leptadaenia pyrotechnica and Mytenus emarginata* which are troublesome for cattle and sheep should be removed. The application of 2-4-5 T provide an effective control.
3. In rocky, gravelly and sloppy areas construction of staggered contour furrows with mounds on the downstream side effectively conserve the soil and water and increases the forage yield.
4. Reseeding of suitable grass species should be done in lines 60-75 cm apart. Seeding with pelleted seeds is beneficial even in low rainfall years. Pellets are prepared by mixing grass seeds with cowdung, clay and sand in proportion of 1:1:3:1 using sufficient amount of water. In the case of Sewan grass, rooted tillers or rooted slips raised in the nursery lead to good establishment and survival.
5. Application of 10-20 kg N/ha is beneficial for the Sewan pasture.
6. Tree density of 25-30 suitable trees per hectare should be maintained in the range lands.
7. Grazing should be avoided in the first year of establishment.
8. After the successful establishment of pasture, the rotational grazing should be allowed.

9. In order to have regular supply of good quality forage, it is essential that the grass should be harvested at pre-flowering stage and stored as hay. It can then be utilized for stall feeding during the period December to June.

10. An adequate water source for drinking is a must for proper utilization of rangelands by livestocks. About 200 m3 of water storage is sufficient for 100 hectare of good condition range land.

    In addition to above following points should also be considered.

11. Pre-monsoon sowing of *Cenchrus ciliaris* is advantageous over monsoon sowing with a seed rate of 6 kg/ha.

12. Seeds of *Cenchrus ciliaris* should be mixed with moist soil three to four times the volume of seeds and drill seed uniformly in lines 50 cm apart in 8-10 cm deep furrows with a soil cover less than 3 cm.

Figure 12 shows a rehabilitated Cenchrus ciliaris pasture along with a water harvesting pond which was constructed inside the pasture area.

Figure 12 Rehabilitated Cenchrus ciliaris pasture with a water harvesting pond.

TECHNOLOGY FOR ARID HORTICULTURE

The selection of fruit crops largely depend upon the rainfall of the area. Based on the annual rainfall following fruit crops can be grown in the district under rainfed condition.

Less than 300 mm	:	Ber, Gonda, Kair, Pilu
300-400 mm	:	Ber, Gonda, Kair, Khirni, Jamun, Bael

Under irrigation following fruit crops can be raised in the district.

Ber, Pomegranate, Guava, Datepalm, Lime and Kinnow.

Selection of cultivars

Following cultivars of some fruit crops are recommended.

Ber	:	Seb, Gola, Mundia
Bael	:	Faizabad selection
Pomegranate	:	Jalore seedless
Guava	:	Allhabad safeda, Lucknow-49
Gonda, Kair, Pilu Khirni	:	Seedling plantation

Regulation of flowering for fruit production

Fruit crops such as lime, lemon, guava, pomegranate etc. flower two to three times a year. For coinciding the flowering and fruiting with abundance of soil moisture, the flowers appearing during January-February should not be allowed to set fruits. For dropping these flowers withhold irrigation for about 20 days at the time of flowering. therefore, the flowers appearing in June-July should be allowed to form fruits. In pomegranate fruits ripening in summers do not develop good color in arils and also fetch low price in the market.

Propagation and planting

The usual method of propagation in nursery and their planting in the field will not be suitable under rainfed conditions. The tap root of such plants is often lost as a result of repeated transplanting, a common practice with nursery man. Plants for dryland conditions must have a root architecture with a strong tendency to penetrate deep in the soil. therefore, soft wood grafting on in-situ raised seedlings in guava, aonla etc. is advocated. In-situ budding in ber should be done to avoid mortality.

Adopted from Vashishtha (1989)

However, rooted cuttings of pomegranate, gonda, jamun etc. should be planted during rainy season to get better establishment. The planting should be done in such a way that runoff water is available to the roots for establishment and for better fruit production. Nonetheless, the planting geometry will depend on the location, topography and other physical soil properties.

Management of fruit crops

Water remaining the foremost constraint in dryland horticulture, its conservation and judicious use is an important aspect. This can be achieved by adopting water harvesting, use of mulches and sub-soil barrier.

Water harvesting

This is done by making artificial catchments of appropriate area and slope along the planted trees. The catchment area should be sufficient enough to generate runoff, required by the plant, under existing rainfall conditions. Wherever, site facilitates the runoff can be stored in the excavated ponds from where irrigation is given to the plants. It has been found that, in case of ber in sandy soil, 54 m^2 catchment area with 5% slope has been found to be suitable for optimum fruit production.

Use of sub-soil barrier

Sub-soil barriers are used to reduce the percolation of water beyond root zone. Clay can form a good barrier and can increase water holding capacity of the soil. Since the fruit plants are planted in pits, the initial application of clay in the pits will be better and would help in establishing the plants. But in sandy areas it is difficult to get clay. Hence, bentonite/or pond sediments can be used for this purpose which is very easily available and is not costly. The bentonite layer of 2-3 cm thickness should be placed at the bottom of the pit. Sides of the pit can be filled with bentonite soil mixture by lowering a cylinder having 2-3 cm less diameter than the diameter of the pit. The interspace of pit and frame should be filled with bentonite+soil mixture. The pit should be irrigated and cylindrical frame is taken out.

Use of mulches

The mulch cover of grass, straw or dry plants should be provided around the plant canopy to minimize evaporation losses from the soil surface. Although costly, some progressive farmers have started using polythene sheets as a mulch for high valued crops.

Pruning and training

It is best to train fruit trees to be low budded except if a horti-pastoral management system is envisaged. This helps to keep the cost of orchard management at a low level. Only one branch should be allowed from a node and these

should be balanced around the trunk. Shoots emerging below the bud union must always be removed. Ber trees are pruned every year in the second week of May to induce new shoots on which the flowering and fruiting takes place. Phalsa should be heavily pruned in the month of February. Pruning is seldom done in aonla, lime, lemon etc. except to regenerate old, less productive trees.

Nutrition to the trees

In the orchards, developed in watershed, which are normally rainfed, application of manure and fertilizers would improve tree growth and productivity. Each application must however coincide with rainfall incidence. Initially 15 kg farm yard manure, 100 gram each of single super phosphate and muriate of potash are applied to each pit. In ber orchards besides 30 kg FYM, application of 100 g N, 50 g P_2O_5 and 50 g K_2O every year to each tree depending upon availability is recommended.

Control of insect/pest and diseases

In ber, the insect-pests causing damage are fruit fly (*Carpomyia vesuviana*), bark eating caterpillar (*Inderbila quadrinotiata*), leaf chafer (*Adoretus pallins*) and white grub. Fruit fly can be controlled with the spray of systemic insecticide (0.03% a.i.) when fruits are in pea stage, second spray should be given three weeks after the first spray. To control bark eating caterpillar, insert cotton swab absorbed with fumigant insecticide in the hole and plug it with clay. Powdery mildew (*Oidium* spp.) can be controlled by three sprays of 0.1% Karathane at 10 days interval starting from initiation of symptoms.

In aonla, rust can cause serious losses. It can be controlled by the sprays of 0.1% Bayleton or 0.2% Diathane M45. Fortunately, no diseases or insects/pests cause serious damage in phalsa, jamun, karonda etc.

AGROFORESTRY

The agroforestry systems have been found to be successful under varying rainfall conditions. In particular, the system of ber+moong or ber+guar have resulted promising results. An spacing of 10 x 5 m (200 plants/ha) for ber plants is ideal for such practice. An spacing of 5 x 5 m (400 plants/ ha) has also been successfuly tried in higher rainfall (>350 mm/yr) areas. A ber+moong agroforestry system is shown in Figure 13. Another agroforestry system comprising of ber+grass (*C. ciliaris*) is shown in Figure 14. The system comprising of planting *Acacia senegal* or *Acacia tortilis* on the field boundary serves the twin purpose of fuelwood supply, protection and crop yield.

Shelterbelts

The shelterbelts or vegetative barriers placed across the wind direction results decreased wind erosion. The effectiveness of shelterbelts in reducing wind velocity depends on wind velocity, direction, tree height, width and density. Studies have shown maximum soil loss from a bare field without shelterbelt followed by sheltered field with *Prosopis juliflora, Asacia tortilis,* and *Cassia siamea*. Total nutreint loss was also observed to follow the same order. The *Cassia siamea* type shelterbelt is most effective in reducing the wind velocity up to 2H (2 x height) distance. The Cassia siamea shelterbelt also results in higher moisture status in the field. The recommended shelterbelt consists of three rows of tree plantation of the type *Cassia siamea-Albizzia lebbek-Cassia siamea* across the prevailing wind direction. The shelterbelt tree geometry is shown in Figure 15.

Figure 13 Agroforestry with ber and moong in kharif season.

Figure 14 Agroforestry with ber and *C. ciliaris* grass.

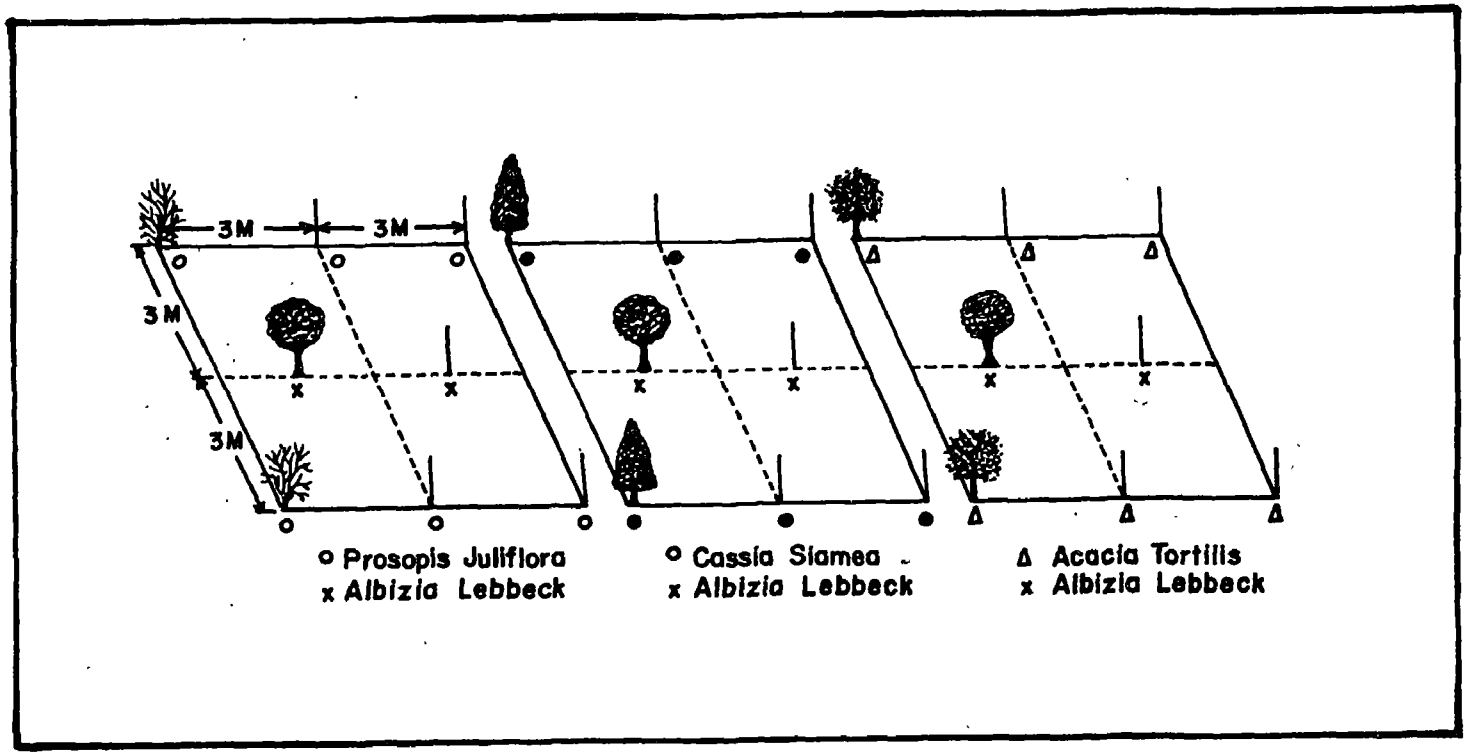


Figure 15 Tree geometry for *Cassia siamea* type shelterbelt.

IMPROVED PACKAGE OF PRACTICES FOR PRINCIPAL DRYLAND CROPS

The arid districts contribute about 1.7% and 4.8% to India's total cereals and pulses production respectively. The average yields of the crops in western Rajasthan are very low as compared to either Rajasthan State of India as a whole. Because of large area under these crops, even a small increment in the productivity of these crops can contribute substantiallv to the cereal and pulse production in the country. A sound dry farming technology is now available for improving the crop production in these areas.

Bajra (*Pennisetum typhoides*)

Bajra is an important staple food grain and fodder crop in western Rajasthan. It is a well adapted and drought resistant crop of this region.

Variety:	WCC-75, RCB-2, CM 46, MH-179
Land preparation	A clean and mellow seed bed should be prepared by sweep cultivator or cross disc harrowing. Keep the field well-bunded and levelled for better spread of rain water. If possible, prepare deep furrows alternated by raised micro-catchments for effective inter- row water harvesting.
Seed rate:	4 to 5 kg/ha.
Sowing time:	4th week of June to 2nd week of July. Grain yield decline if sown after 2nd week of July.
Sowing:	Sow seeds in paired rows (30/60 cm) with plant to plant distance maintained at 15-20 cm apart. Use improved seed drill having fluted roller metering device. Do not sow the seed deeper than 5 cm.
Fertility management :	Apply 40 kg of nitrogen/ha. Alternatively, if FYM is available, apply 10 tonnes of FYM and top dress 10 kg of N per hectare. Use phosphorus if needed as per soil test values. Use full dose of phosphorus and one half of nitrogen (20 kg of N/ha) 10 cm deep before sowing. Top dress the remaining 20 kg of N 3 to 4 weeks after sowing, only of rains are received. If the rainfall received at the time of sowing is inadequate, sow the crop without applying any N fertilizer. If the season progresses nor-

	mally, then top dress full dose of N in 2 to 3 equal splits with subsequent rains. A saving of 20 kg N/ha is also possible by following mung- bajra rotation.
Diseases and pest management	Soil borne pests like termites and white grub can be effectively controlled by incorporating 10% BHC dust at 20 kg/ha while field crickets, leaf cutter and blister beetle can be controlled by dusting the crop with 5% BHC at 5 to 10 kg/ha.
Interculture	Make the crop weed free by 1 to 2 weedings by means of a wheel hoe.
Mid season	i) In the event of early seeding mortality due to drought, fill in gaps through transplanting 20-25 days old seedlings. ii) Under unusual delayed onset of monsoon, a successful bajra crop can be raised through transplanting techniques. iii) Under conditions of prolonged drought at active growth stage, thin out the crop within rows or even remove alternate rows when moisture stress becomes too severe.
Transplanting	Raise a nursery on a plot of size 100 sq m which caters seedlings to an area of one hectare. Preferably raise the nursery near a water source. The seedlings should be kept well watered for a period of 20-25 days when they will be ready for transplanting. Transplant on a drizzling day in the evening hours or on a cloudy/clear day. Transplant two seedlings per hill, 25-30 cm, apart in furrows spaced at 45 cm apart.
Harvesting	The crop is harvested in about 80 to 85 days.
Yield	In normal rainfall years, 15-20 quintals grain can be expected per ha. If there is late onset of rains, about 8 q/ha of grain can be expected. Under these situations, 4 and 2 tonnes of dry fodder per ha can also be expected. The long run average yield is 2 q/ha grains and 0.6-1.0 tonnes/ha fodder.

Storage	Damage in store can be avoided by treatment of empty storage structures and containers using Malathion. Grains should be fumigated when placed in storage.

Guar (*Cyamopsis tetragonoloba*)

Guar is extensively grown in western Rajasthan contributing about 70% of production in the State. Endospermic gum from guar is of industrial significance. Guar meal that is left as byproduct after gum extraction is a high protein (42%) source as cattle feed. Of late, it has become an industrial crop and more than 90% of the gum is exported, earning about more than Rs. 80 crores in foreign exchange.

Varieties	Maru-guar, Durgapura saffed, HG-75, Naveen, GAUG-34, FS-277.
Land preparation	Prepare the seed bed by one or two ploughing with cultivator.
Seed rate	12 to 15 kg/ha.
Sowing time	From the onset of monsoon to 1st week of August.
Sowing	Drill seeds at a depth of 5-7 cm in rows spaced at 45 cm. Thinning should be done 10- 15 days after sowing and maintain plant to plant distance of 10-15 cm.
Interculture	Intercultural operations like weeding should be done within 20-25 days of sowing.
Fertility management	Apply 15 kg N/ha to give the crop a good start. On soils low in phosphorus, application of 30 kg P_2O_5/ha is beneficial. Inoculation of seeds with appropriate rhizobium culture at 10 gm for each kg seed, should be done for ensuring good nodulation and efficient nitrogen fixation.
Disease and pest management	Guar crop does not suffer from any major insect pests. However, because of other legume crops in the vicinity, pests of these crops also attack guar. Termites, white grub, red hairy caterpillars, aphids, white fly and Jassids cause damage to the crop in some areas. For effective control of termites and grubs, application of 25 kg/ha of 5% Aldrin dust and its thorough incorporation into the soil at the time of last ploughing is necessary. Bacterial blight and alternaria blight are the major diseases, which

	can be controlled effectively by the seed treatment with steptomycin (1000 ppm) for the former and with two sprays of dithane Z-78 (0.2%) at 15 days interval for the latter.
Harvesting	The crop is harvested in 90-110 days after sowing depending on the variety and rainfall distribution.
Yield	In normal rainfall years, 12 q/ha of grain can be expected. If there is occurrence of drought in the late season, only about 4-6 q/ha yield can be expected.

Moth (*Vigna aconitifolia*)

Western Rajasthan is the major producer of this crop in India, producing about 0.16 M tonnes of grain in an area about 1.3 M ha. It is mainly used as pulse and fodder. It is also used for the preparation of Bikaner bhujia.

Varieties	IPCMO-926 (Jwala), JMM-256, Maru-moth and Jadia.
Land preparation	Seed bed preparation by one ploughing by cultivator.
Seed rate	10 to 12 kg/ha.
Sowing time	First fortnight of July to first week of August.
Sowing	Drill seeds at a depth of 5 cm in rows spaced at 45 cm. Thinning should be done 10- 15 days after sowing and maintain plant to plant distance of 5-10 cm.
Interculture	The weeding of the crop should be done within 30 days of sowing.
Fertility management	Apply 30-40 kg P_2O_5/ha below seeds at the time of sowing. However, in new area where the crop has not been sown previously, seeds should be inoculated before planting with a suitable culture of rhizobium.
Disease and pest management	Yellow mosiac virus is the most important disease. This can be controlled by applying Rogar (0.03%) @ 1 liter per hectare. Termites and white grub can be controlled by applying Aldrin dust (5%) at the rate of 35 kg/ha.
Harvesting	The crop is harvested in 90 to 105 days after sowing depending upon the variety and rainfall distribution.
Yield	Under normal rainfall conditions, 6 q/ha grain and 1 tonne/ha dry fodder can be expected which reduces to

	2 q/ha and 0.4 tonne if there is drought late in the season. The long run average grain yield is about 1.5 q/ha.
Storage	All empty storage structures and containers should be treated with Malathion.,Moth grains should be fumigated before placement in the containers.

Moong (*Vigna radiata*)

In Rajasthan moong is cultivated on an area of 203000 ha producing about 31000 tonnes of grain.

Varieties	S-8, PS-16, K-851, RMG-261.
Land preparation	Primary tillage with a sweep cultivator is recommended. The field should be well bunded and levelled for better inter-row water harvesting.
Seed rate	12 to 15 kg/ha.
Sowing time	Third or fourth week of July.
Sowing	Drill seeds at a depth of 5 cm in rows spaced 30-45 cm apart. Thinning should be done 8-10 days after sowing and maintain plant to plant distance of 5-10 cm.
Interculture	Intercultural operations should be done within 20-25 days after sowing.
Fertility management	Apply 30 kg P_2O_5/ha. In new areas, the seeds should be treated with appropriate rhizobium culture.
Diseases and pest management	For control of the soil borne insects like white ants, white grubs, incorporate 20 kg BHC 10% dust/ha at sowing time. The other pests are shoot fly, plant hoppers, pod worms, aphids, leaf rollers, blister beetles, stink bug and seed weevil for which field rotation and systemic insecticide is beneficial.
Harvesting	The crop is harvested in 60 to 70 days after sowing depending upon the variety and rainfall distribution.
Yield	Under normal rainfall conditions, 12 q/ha grain can be expected. If drought occurs in the late season, yield may go down to 4 q/ha. The long run average grain yield is about 2 q/ha.

Storage	All storage facilities should be treated with Malathion before filling. Moong grains should be fumigated before the filling operation.

Raya (*Brassica junecea*)

In western Rajasthan, raya occupies an area of 0.2 M ha and mainly grown under limited irrigation. Its area is increasing every year as it is replacing crops like wheat during the Rabi season.

Varieties	T-59, Pusa Bold.
Land preparation	After the withdrawal of monsoon, keep the field free of weeds. It requires a clean, weed free but firm seed bed with adequate moisture in the seeding zone.
Seed rate	3 to 4 kg/ha.
Sowing time	First fortnight of November.
Sowing	Drill seeds at a depth of 3-5 cm in rows spaced 30-60 cm apart. Thinning should be done 10-15 days after sowing and maintain plant to plant distance of 10-15 cm.
Interculture	Intercultural operations should be done within 25-30 days after sowing.
Irrigation	If possible, give 1 to 3 supplemental irrigations for higher yields.
Fertility management	Apply 30 kg N/ha. Apply phosphorus as per soil test values. In case the crop is raised under rainfed conditions, nitrogen may be placed below the seed at the time of seeding.
Disease and pest management	In dry climate, disease do not become a serious problem. However, some of the diseases which can infest raya are white rust, downy mildew and white blight. *Bagrada picta* attacks the crop immediately after germination and can be controlled by dusting BHC 5% @ 15 kg/ha. Infestation of leaf minors generally occurs in the early growth, flowering and pod formation stages. Both these insects can be effectively controlled by spraying with any systemic insecticide like Dimecron or Rogor or Nuvacron (1 lit/ha).
Harvesting	The crop is harvested in about 115 to 120 days after sowing.

Yield	Under 1 to 2 supplemental irrigation condition, about 10 q/ha yield can be expected. Under conserved moisture condition, only 4 q/ha yield can be obtained.
Storage	Pre-treatment of storage containers with Malathion and fumigation of seeds is essential to control the insect/pest in storage.

Til (*Sesamum indicum*)

Til is one of the important edible oilseed crops grown in Rajasthan. It cover an area of 0.32 M ha.

Varieties	T-13, TC-25.
Land preparation	Prepare a clean firm seed bed by a cultivator.
Seed rate	3 to 4 kg/ha.
Sowing time	With the onset of monsoon in the end of June or first fortnight of July.
Sowing	Sow seeds at a depth of 2 cm in moist soil in rows at 30-40 cm apart. Thinning should be done 10-15 days after sowing and maintain plant to plant distance of 10-15 cm.
Interculture	Intercultural operations should be done 25-30 days after sowing.
Fertility management	Apply 20 kg N/ha at sowing and 20 kg N/ha at 30-35 days after sowing on the occurrence of rainfall. In mineral deficient soils, apply calcium and sulphur rich phosphate as per the soil test values.
Disease and pest management	Frequent rains and high humidity may cause diseases like phyllody, leaf spot, blights etc. Disease prevention is possible through rotation of crops and disposal of all residues of harvested crop. Sphinx caterpillar and leaf web are the important pests. These can controlled by the application of 0.03% Quinophos (0.75 ml/ha) or 0.05% Methyl parathion. Prompt planting at the very beginning of the rains after a dry period can reduce most of the insect problems.
Harvesting	The crop is harvested in about 85-90 days after sowing depending upon the variety and rainfall distribution.

	Yield Under normal rainfall conditions, about 4 q/ha yield can be expected which may reduce to 2-3 q/ha under late onset of monsoon. If drought occurs late in the season, only 1.5- 2 q/ha yield can be obtained.
Storage	Treat all empty containers before filling with Malathion.

MANAGEMENT OF SUBSURFACE HARD PAN/GYPSUM LAYER IN THE INDIRA GANDHI CANAL COMMAND AREA

Gypsum contained in the soil, under the extreme cases, can form a hard horizontal crust. Accumulation of gypsum in the subsurface horizons tend to inter-block and indurate the horizon leading to the formation of cemented gypsic layer. The application of excess irrigation water could lead to the formation of a perched water table and to gypsum accumulation in the surface layer of the soil profile. This gradually develops the salinity in the soil. This is one of the major problem now being faced in the Indira Gandhi Canal command area.

Much work has not been done to overcome this problem. However, from the information available, following can be considered to decide the irrigability of such soil conditions.

I. Suitable for irrigation, good for all types of crops and trees :

   a) the depth to gypsic horizon is greater than 200 cm

   b) the gypsum content in top 80 cm is less than 5%

   c) the gypsum content is less than 25% in 80-120 cm layer and less than 30% in the 120-150 cm layer.

II. Suitable for irrigation but crop yield may be lower than the normal :

   a) the depth to gypsic horizon greater than 200 cm

   b) the gypsum content is less than 15% in the top 60 cm

   c) the gypsum content is less than 30% in the 60-100 cm layer and greater than 40% in the deeper layer.

III. Suitable for managed irrigation, crop yield may be lower :

   a) the depth to gypsic layer greater than 150 cm

   b) the gypsum content is less than 30% in the first 60 cm

   c) the gypsum content is less than 20% in the top 30 cm, less than 40% in the 60-100 cm layer, and exceeds 40% in layers beyond 100 cm.

IV. Limited irrigability with shallow-rooted crops :

   a) the depth to gypsic layer is 75 cm or more

   b) gypsum content is less than 30% in the top 30 cm

   c) gypsum content is less than 40% in the 30-60 cm layer and up to 40% in the following layers.

V. Not suitable for irrigation :

a) Presence of gypsic layer at a depth less than 75 cm from the surface

b) gypsum content of more than 30% in the top 30 cm

c) total gypsum and CaCo3 content exceeds 60% in the lower horizon.

Above classes of irrigability give the broad guidelines to manage the fields with semi-pervious/impervious substrata when flood irrigation method is to be used. However, efficient irrigation methods can also be used in order to check water logging under such conditions.

EFFICIENT IRRIGATION METHODS

Subsurface irrigation

This system of irrigation comprises of laying the pipes below the soil surface and riser openings at the ground level to discharge the water. Under the pressure operated condition it can be installed in a field with undulating topography. The outlet discharge levels can be adjusted so that a required depth of soil column is irrigated. Because of high pipe flows velocities and discharge levels the problem of clogging is negligible. In this system about 3-4% land area is saved and the system does not interfere with movement of farm machinery in the field. Asbestos cement pipes can be used for constructing the underground pipe network. They can be used for wide range of pressures and have long life. Plastic pipes are suitable when a high pressure system is to be installed. Besides pipe network, other components of the system include pump stand for maintaining the required operating static head for the network, sand trap (if necessary), gate stands, outlets or riser pipes and end plugs. The design of the system depends upon the field conditions and therefore the details are not presented here. An illustration of the subsurface irrigation system is shown in Figure 16.

Drip irrigation

This is a system of highly controlled water application and therefore is most suitable for arid conditions. Because of low pipe flow velocities, the pipes may get clogged if irrigation water contains high suspended sediments. Therefore, with canal irrigation water its applicability is limited. However, with an efficient filter and proper management of pipe networks, this method can be successfully used for orchards and horticultural crops. This irrigation system, however, requires high initial investment and high level of skills for its operation and maintenance. The design of drip system also depends upon a particular field condition and therefore details are not presented here. Various components of a drip irrigation system are shown in Figure 17.

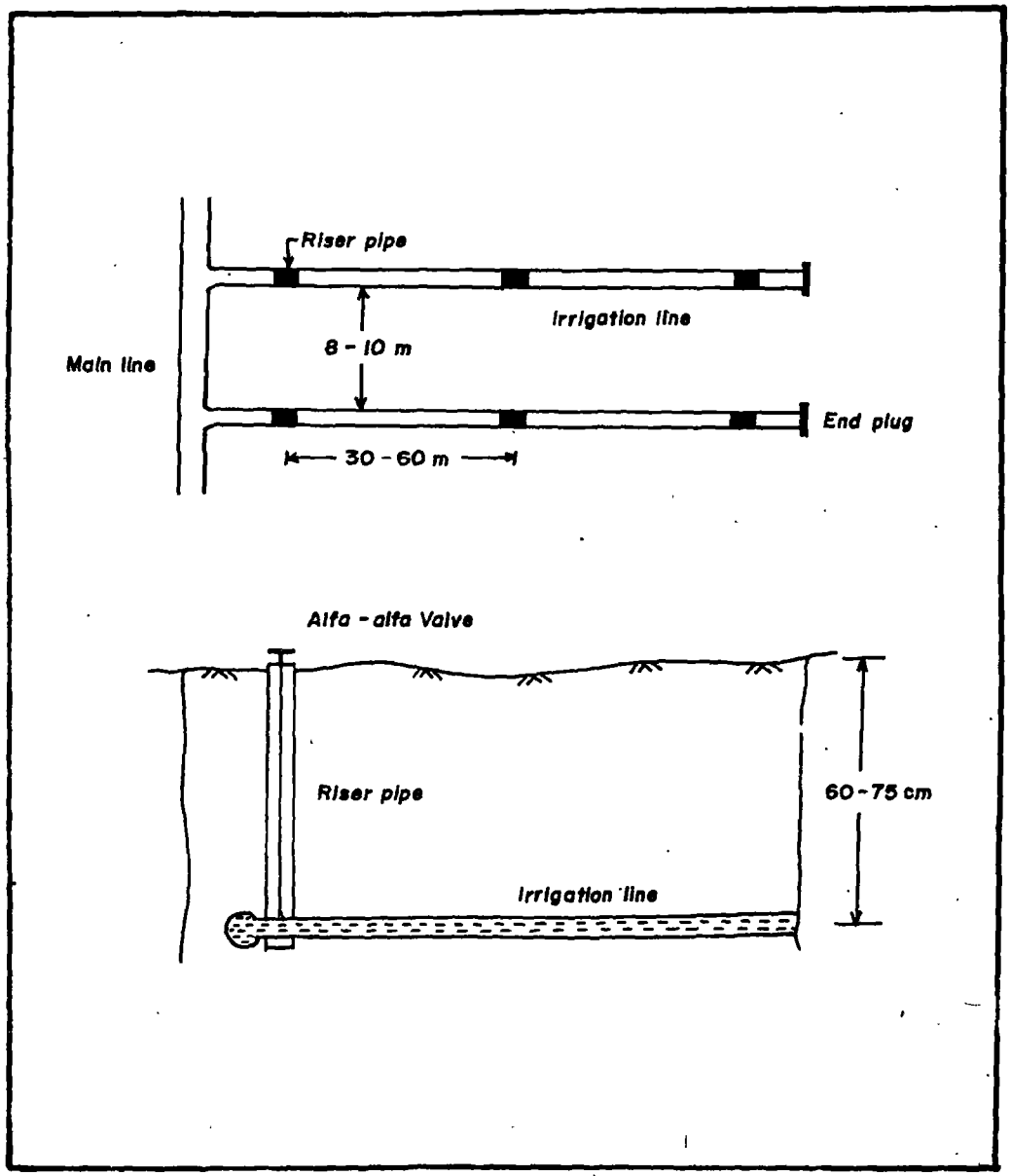


Figure 16 Sub surface irrigation system.

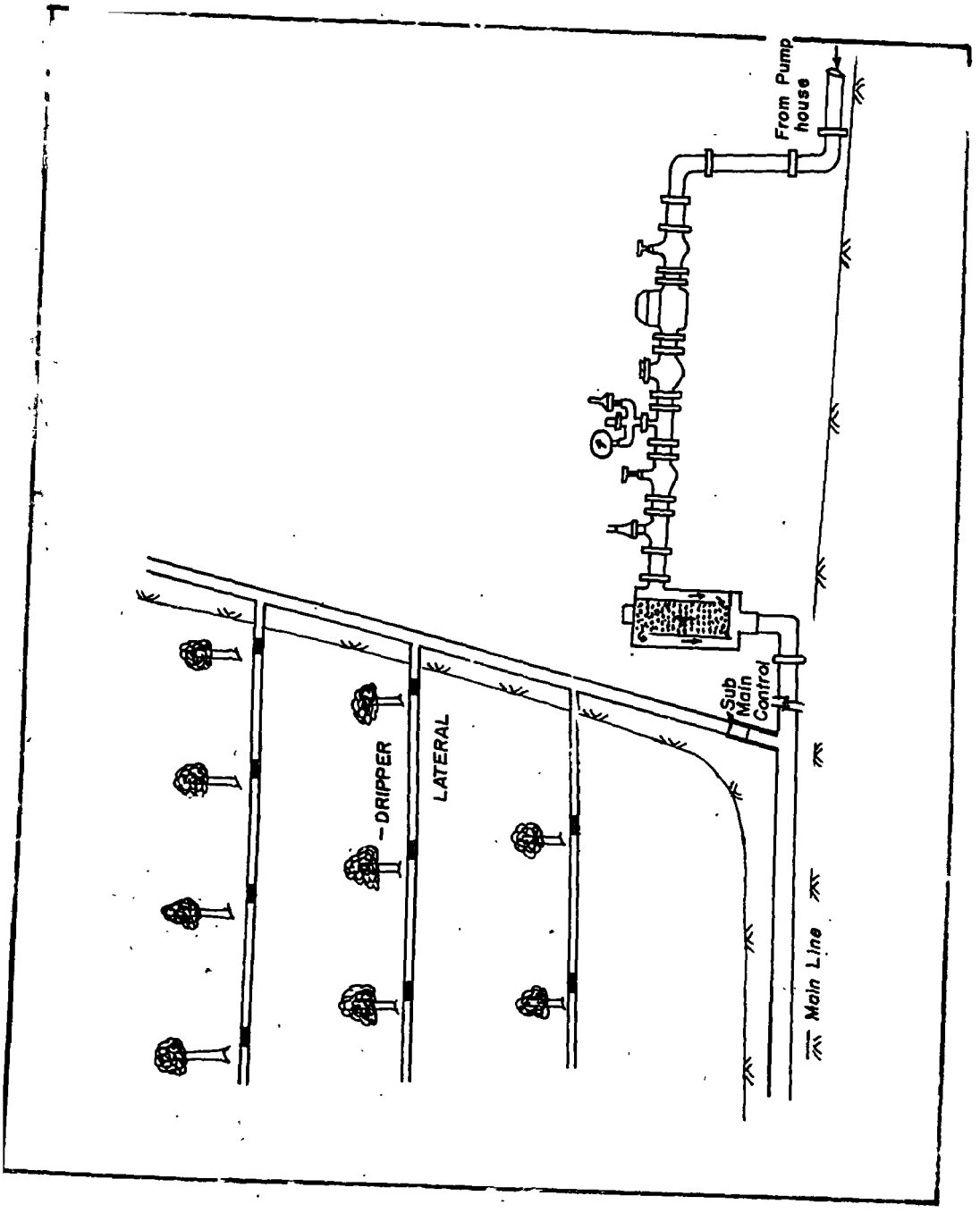


Figure 17 Components of drip irrigation system.

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