Soil and Moisture Conservation for Increasing Crop Production in Arid Lands

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Contents

Foreword

Low and erratic rainfall, high evaporative demand of the atmosphere and the wind erosion are some of the physical constraints for crop production in arid lands. Efforts have been made at the CAZRI to evolve and develop technologies like water harvesting, subsurface moisture barriers, mulches, amendments etc., for moisture conservation and wind strip cropping, use of stubbles, proper cultivation and the shelterbelts. Dr. J.P. Gupta, Scientist-3 of the Division of Soil-Water-Plant Relationship, CAZRI, has studied the effect of these technologies on soil and moisture conservation in relation to crop production. These technologies have been found useful in improving soil physico-chemical environment for crop production. These techniques resulted in increased and sustained production during adverse rainfall years. Dr. Gupta has compiled the results of his ten years (1972 81) studies on these aspects and the same are presented in the monograph. It is hoped that this monograph will be useful to research and extension workers engaged in soil and moisture conservation work for increasing crop production in arid lands.

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CHAPTER 1

Introduction

Two major problems of plant production in arid areas of western Rajasthan, are scarcity of water and high evaporative demand of the atmosphere. These factors coupled with sandy soils having poor moisture retention and storage characteristics and higher vulnerability to wind erosion make plant production difficult if not impossible. This, therefore, warrants evolution and use of soil and moisture conservation techniques and proper soil management for increasing the productivity of arid lands.

It may be emphasised here that there is very little area in the country which is free from the hazards of soil erosion and destruction of land as a natural resource. It has been estimated that in India out of 306 million hectares of reporting area, 145 million hectares are immediately in need of proper management and conservation measures (Anonymous, 1968). This assumes greater importance because of the increase in human and animal pressure on the land and a squeeze in agricultural land because of increasing urbanization. Therefore, there is an urgent need to conserve and properly manage the soils.

Different techniques of moisture conservation like water harvesting, subsurface moisture barriers, soil amendments, soil cultivation and the mulches were evolved and used for increasing and stabilizing the agricultural production. Efforts were also made to quantify the movement of sand and the nutrients associated with it. Different techniques were evolved and used for checking the movement of sand. An attempt has, therefore, been made in this monograph to describe the effect of above mentioned soil management and conservation technologies in increasing plant production in arid lands of western Rajasthan.

CHAPTER 2

Soil and Climate

Soils : Soils of western Rajasthan are, in general, of aeolian origin. These are generally loamy sand to sand with 2.0-6.0% clay, 1.5-4.0% silt, 10.0-30.0% coarse sand and 65.0-80.5% fine sand underlain with a material called 'murrum' which generally appears at one to several metres depth. The nitrogen and organic matter status of these soils is generally low with 0.03% nitrogen and 0.21 % organic carbon. The pH ranges from 7.5-8.0 and Ec is 0.1 mmhos/cm. The moisture retention capacity values at 0.1 bar and 15 bars tension range from 8.0-10.0% and 2.0-3.0%, respectively. These soils predominantly have macro-porosity and, therefore, there is fast movement of water into and through the soil. The initial infiltration rate ranges from 15-30 cm/hour. Saturated hydraulic conductivity is generally 5-10 cm/hour. The bulk density of the surface soils is 1.5 g/cc and that of subsurface soil ranges from 1.5 to 1.6 g/cc.

Climate : The climate is arid with low, erratic and generally high intensity rainfall, about 90% of which is received during monsoon season. (July-September) Mean annual rainfall of the region varies from 100 mm in the north-western sector of Jaisalmer to 450 mm in the eastern boundary of arid zone of Rajasthan. The mean annual rainfall of Jodhpur, Bikaner and Jaisalmer is 380 mm, 290 mm and 100 mm, respectively. Temperatures are high in summer (April-June), May is the hottest month with mean maximum temperature of 42°C. Winters are normally rainless with mild temperatures. January is the coldest month with mean minimum temperature of 4°C in Bikaner and Jaisalmer to 10°C in Jodhpur. The pan evaporation values range from 8 to 10 mm/day during monsoon and 5-6 mm/day during winter. In summer, however, pan evaporation values of 10-15 mm/day are not uncommon. Relative humidity of 60-80% is found during monsoon but values ranging from 15 to 20% are observed during winter. Mean wind velocities of 8.0, 10.0 and 20.0 km/hour were found to prevail at Jodhpur, Bikaner and Jaisalmer, respectively during summer months (April-June).

CHAPTER 3

Water Conservation for Crop Production

In arid areas of western Rajasthan as the rainfall is generally low and erratic, soil and water conservation techniques and proper soil management can play an important role in increasing and stabilizing plant production from such lands. These techniques are therefore, discussed as under :

3.1 Water Harvesting and Recycling

Runoff water utilization for agricultural purposes is a common practice in Israel which has inherited large desertic areas (Bunyard, 1973). In arid zone of western Rajasthan also, '*khadin*' cultivation, '*nala*' bunding, etc., for supplemental irrigation and ground water recharge are the age old practices. In order to overcome the harmful effects of droughts and increase the crop production, two types of techniques for *in situ* water harvesting can be used depending upon the availability of land, type of crop and the soil depth for storing the runoff water. Studies conducted at C.A Z.R.I. showed (Anonymous, 1974) that with water harvesting in catchment to cultivated area ratio of 0.5, there was one to two times more production potential than over flat lands. With this technique, higher production of such crops as pearlmillet, greengram, cowpeas, sorghum and sesamum was obtained than the flat lands.

Another most important system of water harvesting is runoff collection in tanks and its recycling for supplemental irrigation. In India, tanks have been used for centuries as a source of domestic water and water for limited irrigation. The amount of runoff depends upon the amount and intensity of rainfall, the infiltration of soil, the slope and the vegetation. The runoff water thus collected can be used as life saving irrigation or supplemental irrigation. Mann *et al.* (1980) reported that parts of western Rajasthan under rocky, semi rocky or slopy areas with suitable treatment can generate a high amount of runoff. Nine years data on computed runoff have shown that there was maximum runoff during surplus rainfall years with an average rainfall of 700 mm. Further, higher amount of runoff was available during the years with more frequency of high intensity showers although the total rainfall was lower than the normal. Drought years with an average rainfall of less than 90 mm were not found to generate any runoff. It has also been found that soils with poor infiltration rate and as high as 9% slope generate more runoff than the soils with 5% slope. Moderately fine soils were found to give more runoff than the sandy soils having the comparable slopes. Runoff water collected from the catchments could be stored in cement-concrete tanks of appropriate sizes with more depth so that evaporative surface is reduced. Runoff water thus collected can be utilized for growing short duration and low water requiring crops like gram, mustard, etc. It can also be used as a life saving irrigation during drought periods of the crops grown in the *Kharif* season.

3.2 Subsurface Moisture Barriers

A large area of western Rajasthan is occupied with sandy soils. These soils inspite of having some of the good characteristics like high infiltrability, more aeration, self mulching, etc., their productivity is severely affected by poor water retention and storage characteristics. High percolation rates of these soils further aggravate the problem by allowing heavy leaching losses of nutrients resulting in low fertility of soil. Such soils can be made productive by the use of subsurface moisture barriers. It has been found (Gupta and Aggarwal, 1978, 1980) that the placement of asphalt as moisture barrier at 60 cm soil depth in 2 mm thickness improves moisture and nitrogen retention capacity of the soil and increases crop production. Other materials like bentonite clay and pond sediments were also tried as subsurface moisture barriers. It was found that the placement of barriers like bentonite clay and pond sediments at 60 cm depth in 5 mm thickness was 60-70% and 50-60% effective in retaining the total rainfall in the root zone, respectively. Water characteristics of soil as affected by asphalt moisture barrier are discussed as follows.

(i) *Water retention capacity* : After a heavy rain or irrigation, water percolates down to the barrier and then across to its edge. When the drainage of free water ceases a low tension water is retained over the surface of the barrier. Fig. 1 shows 24 mm of percolation loss from the soil profile with barrier while it was 120 mm from the profile without barrier. This shows that there was about five times more percolation loss from soil profile without barrier. In this way the moisture retention capacity of the sand soil could be doubled without affecting its good qualities. However, this was a potential value which could be achieved by the placement of 2 mm thick barrier and with the application of heavy irrigation.

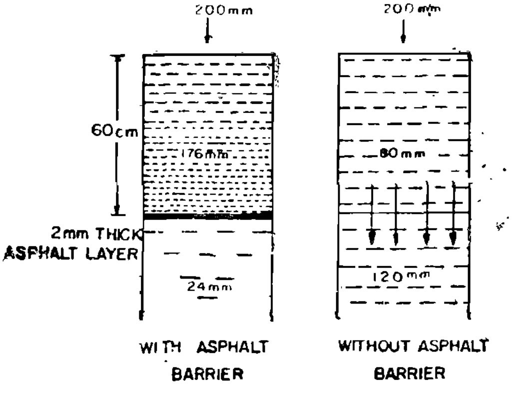

Fig. 1. Moisture distribution in normal and modified soil with asphalt barrier.

(ii) *Water depletion* : Water depletion from a soil depends upon the climatic factors, the hydraulic and thermal characteristics of soil and the type of vegetation it supports. In a bare soil without vegetation, it is mainly governed by the hydraulic and thermal gradients operating in the soil. Higher rate of water depletion was observed from a soil without barrier up to eight days after irrigation beyond which the rate of depletion was higher

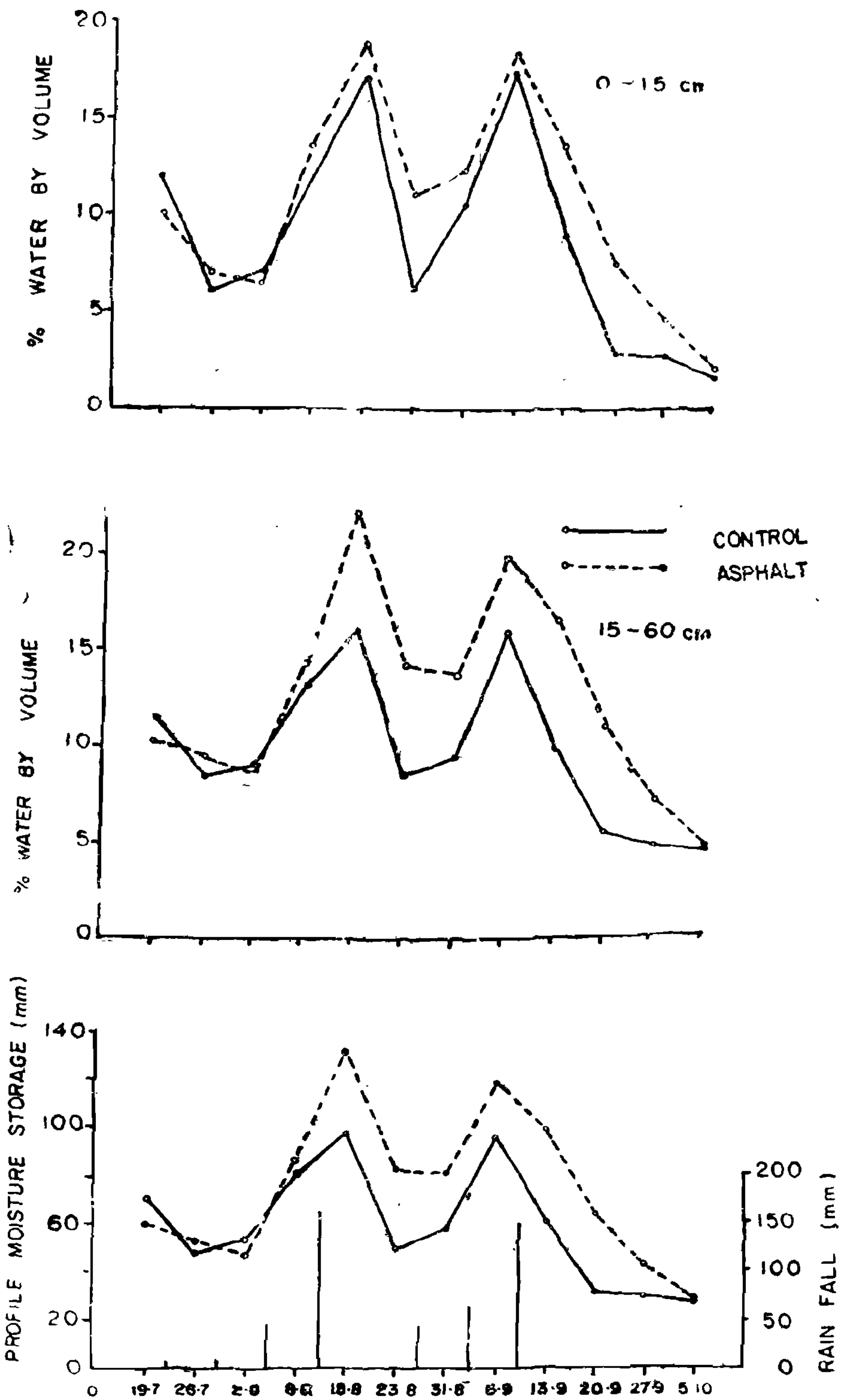

Fig. 2. Soil water variations in normal and asphalt barrier profiles during growing season of Pearlmillet.

in barriered -soil. Higher depletion rate from a normal soil during early period after irrigation was probably due to the processes of evaporation and drainage operating in the soil. Cumulative evaporation during 30 days period after irrigation from barriered soil was 3-5 mm higher than the normal soil, showing thereby, that in a barriered soil additional stored water remained mostly conserved due to self mulching properties of the sand. Nevertheless evaporation loss from a barriered soil can be checked by the use of mulches or manipulation of plant population.

(a) *Use of mulches* : In sand soils mulches do not find much use in conserving soil moisture because of the self mulching properties of sand. However, during early period after rainfall or irrigation, coupling of mulches with AMOBAR (AMOCO, 1971) may be useful in checking evaporation.

(b) *Manipulation in plant population* : Unproductive evaporation loss of conserved water from the barriered soils can be checked by manipulating plant population. Marginal increase in plant population can convert unproductive loss due to evaporation to productive loss as ET.

3.2.1 Moisture Storage and its Variations as Influenced by AMOBAR

The moisture status of barriered soil was found to be higher than the normal soil (Fig. 2). However, the variations were more in 15-60 cm than in 0-15 cm depth. In 0-15 cm depth, barriered soils were found to contain 2-4% more moisture than normal soils while in 15-60 cm depth it was 2-10% more. Profile moisture storage of barriered soil was generally higher and on an average, it contained 20-30 mm more moisture than the normal soil. The differences in moisture retention in 1977 were less than in 1976 because of less rainfall received during 1977. Though it was well distributed during the season there was hardly an event of rainfall which appreciably increased the moisture storage of the barriered profile.

3.2.2 Effect on Nitrogen Conservation and Use by Pearlmillet

The placement of asphalt barrier resulted in an increase in the retention of mineral nitrogen in soil (Table 1). There was an increase in NO_3-N in all the three depths of soil with asphalt barrier, showing thereby, reduction in leaching losses of nitrogen. On an average, there was 66% increase in nitrogen retention in soil with an asphalt barrier than in soil without such a barrier at low nitrogen levels. At medium and high nitrogen levels, however, the retention of nitrogen in soil with a barrier was 89 and 50%, respectively. The higher availability of nitrogen and moisture in plots with barrier led to higher concentration of nitrogen in the grain. The total uptake of nitrogen by the plants increased with increase in nitrogen levels. The mean crop response to N-fertilizer with barrier was found to be 75, 34 and 19% more than the control at low, medium and high levels of nitrogen, respectively. This could be due to reduced leaching and better utilization of the nitrogen when the moisture content of the soil was higher. Therefore, it appears that even with a low dose of fertilizer an asphalt barrier can be quite effective in increasing the crop production in sandy soils.

Table 1. Mineral nitrogen in soil and nitrogen composition of pearlmillet as influenced by asphalt barrier

Nitrogen levels (kg/ha)	Mineral nitrogen in 0-15 cm depth (NO_3+NH_4) N (ppm)	NO_3-N	Nitrogen% Grain	Straw	Total nitrogen uptake (kg/ha)
		1976			
No barrier					
40	16.8	6,7	0.89	0.42	10.5
80	26.8	12.3	1.42	0.46	22.1
120	33.6	14.5	1.51	0.43	48.2
Asphalt barrier					
40	25.8	11.2	1.20	0.55	22.0
80	49.5	26.0	1.63	0.54	35.2
120	56.0	19.0	1.99	0.54	51.8
		1977			
No barrier					
40	20.2	7.8	1.21	0.36	30.4
80	30.6	13.4	1.34	0.33	38.5
120	45.7	16.8	1.44	0.57	72.4
Asphalt barrier					
40	35.6	19.0	1.21	0.35	42.6
80	58.4	30.6	1.34	0.33	52.0
120	61.5	25.4	1.55	0.41	94.8

3.2.3 Effect on Water Use and Crop Production

Higher grain and straw yields of pearlmillet were achieved with asphalt subsurface moisture barrier (Tables 2 and 3). Interaction between subsurface moisture barriers and nitrogen levels produced 50-60% increase in grain yield under both low and medium levels of nitrogen. With high levels of nitrogen

Table 2. Effect of significant interaction between barrier and levels of nitrogen (N) on the grain yield (q/ha) of pearlmillet for the year 1976

Nitrogen levels (kg N/ha)	No barrier	Asphalt barrier	N mean ± 0.4
40	5.5 a*	9.0 b	7.2 a
80	8.5 b	12.3 c	10.4 b
120	20.8 c	17.0 d	18.9 c
Barrier mean ± 0.3	11.6 a	12.7 b	

* Marginal means and means in the body of Table followed by the same letter do not differ significantly at the 5% level of probability by the L.S.D. test.

Table 3. Effect of an asphalt barrier and levels of nitrogen (N) on yields of pearlmillet. Interaction term was not significant

Treatment	Grain yield (q/ha) 1977	Straw yield (q/ha) 1976	Straw yield (q/ha) 1977
	± 1.5	± 2.3	± 0.9
No barrier	22.0 a	24.7 a	39.6 a
Asphalt barrier	30.7 b*	27.3 a	54.2 b
kg N/ha	± 1.9	± 2.9	± 1.2
40	19.4 a	16.9 a	36.7 a
80	22.5 b	24.9 b	45.6 b
120	37.2 c	36.1 c	58.4 c

* Means in a column under a given treatment followed by the same letter do not differ significantly at the 5% level of probability by the L.S.D. test.

also an asphalt barrier produced a higher grain yield during 1977 but, during 1976, a reduction was observed. This might have been due to a combination of excessive nitrogen and water. On an average, however, the production of pearlmillet with barrier was 40-60% higher than without a barrier. Water was used less efficiently in 1976 than in 1977 (Table 4) because poor yields resulted from a heavy infestation of ergot during 1976. With medium and high levels of nitrogen, extra water failed to produce an increase in the yield of grain. At low nitrogen levels, however, the water conserved was used efficiently. Thus, soils with barriers gave a higher yield with low levels of nitrogen than did a soil without barriers and with a medium level of nitrogen. The use of an asphalt barrier, therefore, economised the use of water as well as of nitrogen.

Table 4. Water use efficiency (kg grain/mm/ha) as affected by the use of asphalt subsurface barrier and nitrogen levels

Nitrogen levels (kg/ha)	1976 No barrier	1976 Asphalt barrier	1977 No barrier	1977 Asphalt barrier
40	3.12	3.19	7.50	8.27
	(177)*	(282)	(200)	(290)
80	4.67	4.46	9.13	8.74
	(182)	(276)	(208)	(274)
120	11.06	5.99	15.20	14.41
	(188)	(284)	(210)	(295)

*Figures in parenthesis indicate the water (mm) used by the crop.

3.2.4 Scope of Subsurface Moisture Barriers

The preceding facts adequately demonstrate the usefulness of subsurface barriers as a means of increasing the moisture storage and nutrient conservation in the root zone and, thereby increasing the productivity of sandy soils. Nevertheless, there are several specific requirements which must be taken into consideration before any planning for field scale use of the barriers. These are as follows :

(i) Under the present day techno-economic conditions, it seems that sub-surface barriers are not for all types of soils, for all farmers and for all crops. It has particular promise on sand and sandy soils known for their poor moisture retention and self mulching properties, in high cash crops like vegetables, sugar-beet, groundnut, oil seeds, etc.

(ii) It seems to have special significance under rainfed rather than under irrigated conditions. Its use under latter conditions may be limited to the area where good quality water is available. Under irrigation with saline water it can lead to an accumulation of salts in the soil profile over the surface of the barrier. Accumulation of salts in the root zone can severely limit the crop growth. Further these salts can come up to the surface in the evaporative process, which cannot be easily leached or flushed down below the root zone because of the restricted permeability of the barrier.

(iii) Excavation technique for barrier placement apart from being cumbersome and causing disturbance to the soil involves high cost and labour and so can be used over a limited area. Extensive application of asphalt moisture barrier is possible provided a machine similar to the one developed by International Harvester Company of United States is designed and developed in the country. Until such time subsurface barrier of asphalt or bentonite clay seems to be feasible on small scale localized placement for growing vegetables and fruit creepers.

(iv) The cost of barrier placement with the AMOBAR machine has been worked out as $ 700 to 800/ha, which the manufacturers claim can be recovered in less than four years. With multiple cropping practice in the U.S., this initial cost is paid back even in less than 2 years. The barrier if placed lasts for more than 15 years. Inspite of this merit, the machine may be expensive for an individual farmer, but certainly can be purchased and used on cooperative basis.

3.3 Soil Amendments

Amendments are widely used these days to change physical properties of soils so that they are more suitable for plant growth. They range from chemicals like gypsum and selected fertilizers to bulky materials such as porous minerals, organic peats and wood shavings. The need for physical amendments is being felt more in arid areas where organic matter levels are generally low and soil structure is very weak. In western Rajasthan where the availability of organic matter is low and the peat is not available, pond sediments available from widely scattered ponds could be utilized for increasing their productivity (Gupta *et al.*, 1979;

Gupta and Aggarwal, 1980; Aggarwal *et al.*, 1980).

3.3.1 Use of Pond Sediments

The results of field trials show that the application of pond sediments by mixing upto 30-40 cm soil depth increased the silt and clay content of soil which in turn increased the moisture retention at 0.3 bar tension and also the available water content of soil (Table 5). The infiltration rate decreased with the addition of pond sediments. Consequently, deep-percolation losses were checked and the moisture retention capacity of the soil increased. Wind stable aggregates greater than 2 mm increased with the application of pond sediments. It also increased the total nitrogen, mineral nitrogen and organic carbon content of soil.

The grain and straw yields of pearlmillet increased with the addition of pond sediments (Table 6). The general response was upto 76 tonnes/ha, at which the grain yield increased by 40-50% over the control; beyond this level there was either a marginal increase or some decrease. Water use by the crop generally increased with the application of pond sediments. Water-use efficiency, however, was maximum at 76 tonnes/ha. Application of pond sediments increased the nitrogen content of the soil. The favourable hydro-physical conditions produced by the use of pond sediments increased the nitrogen availability and uptake by plants. The maximum nitrogen uptake was, however, observed at 76 tonnes/ha.

The grain yield of greengram was also found to increase with the use of pond sediments, the maximum being 21.5 q/ha at 76 tonnes/ha (Table 7). Water used by the crop also increased but water-use efficiency was found maximum at 76 tonnes/ha. Total and mineralized nitrogen status of the soil increased with pond sediments application. There was further increase in nitrogen status of soil after the harvest of the crop, showing thereby, enrichment due to legume cultivation. Application of pond sediments also increased the nitrogen concentration in the grain of greengram and nitrogen uptake by the plant. With the addition of 76 tonnes/ha, however, the nitrogen uptake was maximum (83.4 kg/ha), which was about 60% more than that of the control plots.

3.3.2 Use of Farmyard Manure

Farmyard manure, since a long time, has been known to maintain soil productivity but the use of chemical fertilizers, particularly nitrogen, is becoming more and more common for attaining higher yields. Low organic matter levels of the soil creates poor physical conditions which seriously affect seedling emergence, growth and yield of crops (Gupta *et al.*, 1982). The studies were, therefore, conducted to find out a suitable combination of urea and farmyard manure for favourable physico-chemical environment for higher crop production. The results of field trials show that with increase in application of farmyard manure and decrease in urea, there was decrease in bulk density of soil, an increase in moisture retention at 0.1 bar tension and decrease in saturated hydraulic conductivity (Table 8). There-were, however, little differences in moisture retention at 15 bars tension. This, therefore, increased the available water capacity of the soil. Increase in addition

Table 5. Soil properties as influenced by the addition of pond sediments

Pond sediments added (tonnes/ha)	Silt	Mechanical composition (%)			Water retention values (moisture %)			Infiltration rate (cm/hr)	Wind stable aggregates >2 mm (%)	Initial status of nutrients		
		Clay	Coarse sand	Fine sand	(0.3 bar)	(15 bar)	AWC			N (%)	Organic carbon (%)	Mineral N (ppm)
0	3.13	5.87	11.60	79.40	8.6	2.1	6.5	15.0	0.7	0.028	0.21	11.2
38	3.59	6.24	11.20	79.20	9.4	3.1	6.2	14.4	4.6	0.034	0.22	35.0
76	3.71	6.44	10.60	79.00	10.1	3.2	6.9	13.2	4.0	0.039	0.27	37.0
114	3.88	6.67	10.40	78.20	11.5	3.9	7.6	12.6	7.0	0.044	0.31	40.0
152	3.98	6.86	10.10	78.20	11.5	4.2	7.3	10.8	10.0	0.050	0.35	47.0

Table 6. Effect of the use of pond sediments on growth, yield and water use by pearlmillet

Pond sediments (tonnes/ha)	1976				1977			
	Grain yield (q/ha)	Straw yield (q/ha)	Water use (mm)	Water use efficiency (kg/mm/ha)	Grain yield (q/ha)	Straw yield (q/ha)	Water use (mm)	Water use efficiency (kg/mm/ha)
0	10.3	39.8	246	4.18	15.3	73.1	210	7.29
38	12.8	51.5	260	4.92	18.0	76.6	234	7.69
76	15.7	59.5	314	5.00	21.5	79.6	252	8.53
114	16.9	65.8	390	4.33	17.8	64.4	254	7.01
152	17.5	64.8	323	5.41	17.8	77.1	249	7.15
L.S.D. (0.05)	2.14				1.40	3.9		

Table 7. Effect of the addition of pond sediments on N utilization, water use, growth and yield of greengram

Pond sediments added (tonnes/ha)	Grain yield (q/ha)	Water use (mm)	Water-use efficiency (kg/mm/ha)	Soil N			Plant N	
				Total N (%)	Mineral N (ppm)	Increase in N (%)	N in grain (%)	N uptake in grain(kg/ha)
0	15.7	200	7.85	0.031	7.9	10.8	3.23	50.7
38	19.7	230	8.56	0.039	11.2	15.0	3.87	75.2
76	21.5	248	8.66	0.045	13.4	16.0	3.88	83.4
114	18.7	252	7.72	0.050	13.5	13.8	4.14	77.4
152	18.4	332	5.54	0.053	14.5	16.0	4.16	76.5
L.S.D. (0.05)	1.29							

Table 8. Effect of the continuous application of different combinations of farmyard manure and urea on physico-chemical properties of soil and crop production

Combinations for per cent nitrogen supply	Rates of application		Bulk density (g/cc)	Moisture retention (% moisture W/W)		Hydraulic conductivity (cm/hour)	Organic carbon (%)	Total nitrogen (%)	Available nitrogen (kg/ha)	Mean yield (1975 to 1979)	
	Fym (t/ha)	Urea (kg/ha)		0.1 bar	15 bars					Grain yield (q/ha)	Straw yield (q/ha)
$F_{100}N_0$	16	0	1.46	10.6	3.8	5.6	0.35	0.048	164.6	9.27	22.62
$F_{75}N_{25}$	12	44	1.47	10.5	3.2	6.0	0.31	0.046	145.0	10.92	25. 2
$F_{50}N_{50}$	8	88	1.51	9.8	3.6	6.2	0.28	0.042	141.1	12.25	29.25
$F_{25}N_{75}$	4	132	1.51	9.2	3.8	6.7	0.22	0.036	117.6	11.95	27.12
F_0N_{100}	0	176	1.58	9.2	3.6	7.2	0.21	0.032	109.7	11.72	24.52

Fym — Farmyard manure. N — Fertilizer nitrogen.

of farmyard manure also increased the organic carbon, total nitrogen and available nitrogen status of soil and the maximum increase of about 50% was observed with the exclusive use of farmyard manure. The results of four years of experimentation show maximum grain and straw production of pearlmillet with urea-farmyard manure combination to supply 50% nitrogen from each. With this combination there was 30% increase in mean grain and straw yields of pearlmillet over farmyard manure alone or nearly equal with urea alone. This could be due to improvement in physico-chemical environment of soil.

3.3.3 Use of Exfoliated Vermiculite

Vermiculite is a micaceous mineral that exfoliates when heated or subjected to certain chemical reactions. It is a hydrated magnesium-aluminium-iron silicate. Exfoliated vermiculite consists of accordion like granules containing millions of minute air layers, to which vermiculite owes its high insulation value and light weight. It is inert to organic solvents and does not decompose in water.

The application of exfoliated vermiculite to the soil was found to increase the moisture retention at 0.1 bar tension. There was, however, not much difference in moisture retention at 15 bars. This, therefore, increased the available water capacity of the treated soils (Table 9). The use of exfoliated vermiculite decreased the bulk density and saturated hydraulic conductivity of the soil. The reduction in hydraulic conductivity was found to be more significant. It was about 25% at 20 t/ha level and 50% at 40 t/ha. It also reduced the maximum soil temperature at 10 cm depth by about 2 to 3°C. The reduction in soil temperature was maximum at 20 t/ha level. There were, however, no significant differences at other levels of application of exfoliated vermiculite. This, therefore, shows the mulch like behaviour of exfoliated vermiculite in reducing the maximum temperature of soil (Gupta and Gupta, 1981).

The application of exfoliated vermiculite in soil significantly increased the yield of lady's finger crop (Table 9). The optimum yield, however, was achieved with 20 t/ha level beyond which either no significant increase or some decrease was recorded. Integration of grass mulch with exfoliated vermiculite was not found useful in increasing the crop production. This was probably because exfoliated vermiculite itself acted as mulch. Its application at 20 t/ha level increased the average production of lady's finger crop by 40-60% more than the control without vermiculite. The yields were observed to be generally higher in the year 1980 than 1979. This was because of the application of 50 mm of irrigation water during 1980 when there was a severe drought. There were no significant differences in water use of the crop from 60 cm profile with vermiculite application. Though the cumulative water use was nearly equal in treated and untreated plots, the depletion rate throughout the growth period of the crop was higher with vermiculite application (Fig. 3) particularly at 20 t/ha level, showing thereby, the faster utilization by plants grown in the treated plots. There was, thus, higher water-use efficiency of the crop with vermiculite application.

Table 9. Effect of exfoliated vermiculite application on soil physical properties, water use from soil and the production of lady's finger

Rate of application (t/ha)	Moisture retention in soil (% moisture) 0.1 bar	15 bar	AWC	Saturated hydraulic conductivity (cm/hr)	Bulk density (g/cc)	Max. soil temp. at 10 cm (°C)	Lady's finger yield (q/ha) 1979	1980	Mean yield (q/ha)
0	10.3	3.0	7.3	8.6	1.62	46.5	24.1 (138)*	31.4 (199)	27.8
10	11.1	3.2	7.9	7.3	1.58	46.0	26.7 (135)	43.0 (198)	34.9
20	12.4	3.1	9.3	6.5	1.57	44.0	36.2 (133)	50.7 (205)	43.5
30	14.4	3.3	11.1	5.7	1.52	44.0	37.7 (145)	47.7 (203)	42.7
40	15.1	3.2	11.9	4.2	1.52	44.0	38.0 (126)	53.0 (198)	45.5
Mean							32.5 (135)	45.2 (201)	

* Figures in parenthesis indicate water use in mm

	1979	1980
L.S.D. (0.05) Exfoliated vermiculite	6.8	3.7

Table 10. Effect of post emergence cultivations (up to 5 cm depth) on growth, water use and the yield of pearlmillet

Treatment	Bulk density (g/cc)	1977 Grain yield (q/ha)	1977 Straw yield (q/ha)	1977 Water use (mm)	1977 Water use efficiency (grains, kg/mm/ha)	1978 Grain yield (q/ha)	1978 Straw yield (q/ha)	1978 Dry wt. of roots in 30 cm x 30 cm x 30 cm (g)	1978 Weed yield (q/ha)	1978 Water use (mm)	1978 Water use efficiency (grains, kg/mm/ha)
No cultivation + no weed removal	1.61	6.3	16.9	267	2.36	0.5	7.6	1.7	17. 2	310	0.16
No cultivation + weed removal by weedicide	1.64	10.9	17.8	247	4.41	8.2	32.7	3.2	—	296	3.21
One cultivation	1.60	12.3	20.4	273	4.51	11.4	42.0	3.4	0.62	292	3.90
Two cultivations	1.57	10.9	16.4	241	4.52	12.3	34.7	2.6	0.52	290	4.24
Three cultivations	1.56	11.9	20.2	256	4.65	11.3	38.1	2.5	0.43	289	3.91
Four cultivations	1.55	13.8	20.7	263	5.25	11.3	42.3	2.4	—	286	3.95
L.S.D. (0.05)		1.1	1.5			2.85	6.92				

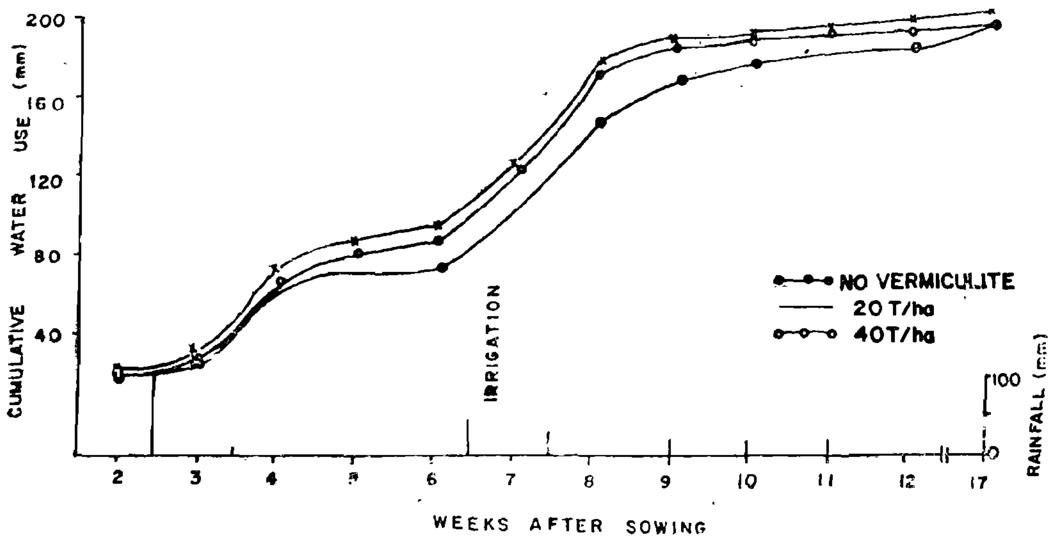

Fig. 3. Effect of the application of exfoliated vermiculite on cumulative water use from 60 cm soil profile.

3.4 Soil Cultivation

Sandy soils with poor organic matter status generally get compacted and thus seriously affect the growth and yield of crops. Wimer (1946) reported favourable responses to post - planting cultivation because of killing of weeds which compete with main crop for light, water and nutrients. The results of two years of field trials show that in uncultivated plots weed removal with weedicide (atrazine @ 1 kg/ha of a.i.) reduced crop weed competition and significantly increased the yield of pearl-millet crop (Table 10). Soil cultivations also reduced crop weed competition. One cultivation after 20 days of emergence reduced the dry matter production of weeds from 17.2 to 0.6 q/ha, lowered the bulk density of soil and thus increased the average crop production from 3.4 to 11.8 q/ha. More cultivations, though, further lowered the crop weed competition and the bulk density of the soil yet either did not increase the production or increased it marginally. This could be due to the damage caused to the roots as is reflected in poor growth and weight of roots. A comparison of uncultivated (weeds removed with weedicide) and once cultivated plots showed that even in the absence of weeds, cultivation was found useful in increasing average yields from 9.5 to 11.8 q/ha. This was probably due to more proliferation and better growth of roots and better utilization of water and nutrients for higher crop production (Gupta and Gupta, 1981). Higher water use of the value of 267 mm in 1977 and 310 mm in 1978 was observed in plots where weeds competed with crop. This led to reduction in water use efficiency of the crop. There was no significant difference in water use of crop under other treatments. Water use efficiency was higher with one cultivation. More cultivations, however, did not increase the water use efficiency substantially.

Nutrients uptake by grain and straw increased with increase in cultivation level. However, the differences were not significant at higher levels. Nitrogen, phosphorus and potassium uptake by the crop in uncultivated (weeds removed with weedicide) and cultivated plots were significantly higher than where weeds competed with the crop. As much as 20.6 kg/ha nitrogen, 2.0 kg/ha phosphorus and 21 kg/ha potassium was removed by the weeds during the growth period of the crop, leading thereby, to reduction in uptake by the crop.

Depth of post emergence cultivation has been found to influence soil properties and root growth (Table 11). Cultivation upto 10 cm depth was found to give the maximum grain yield of 10.8 q/ha which was about 50% more than the control without cultivation and nearly equal to 5 cm depth of cultivation. Deeper depths of cultivation were found to reduce the grain and straw yield of the crop. This seems to be due to the damage caused to the roots. Maximum nitrogen uptake in grain and straw was observed with 10 cm cultivation depth while maximum phosphorus and potassium uptake was observed with 5 cm depth of cultivation. At this cultivation depth there was 25% increase in uptake of nitrogen while it was 50% in case of phosphorus and potassium.

3.5 Mulches

Deficiency of water and high thermal regimes of soil are the two most important factors which adversely affect crop production. The use of mulches have been reported to favourably modify the hydro thermal regimes of soil for crop production (Van Wijk *et al.*, 1959; Moody *et al.*, 1963; Prihar *et al.*, 1977; Gupta, 1978, 1980, 1982). Before discussing the effects of mulches, the moisture and thermal regimes of the soil are discussed.

(i) Moisture regime of soil: During the rainy season (July-August) of the year 1977-78, soil moisture storage below 10 cm depth was maximum and ranged from 5 to 7%. From September to January there was moisture depletion from top 60 cm profile only. There was, however, no change in the profile moisture content below 60 cm depth. From February to June, there was fast elongation of drying front and depth of dry layer (less than 1% moisture) was 40 cm. Lower layers, in general, were found to contain 2 to 4% moisture. As there was little capillarity in this soil, so the moisture loss was probably in vapour phase due to the prevalence of vapour pressure gradients.

Moisture regime of soil with native grass vegetation was generally lower than the bare soil without vegetation. This was due to the moisture utilization by the native grass vegetation.

(ii) Thermal regime of soil: Day time soil temperature (measured at 2 P.M.) was found to continuously rise from January to June (Fig. 4). However, it was maximum at all depths during June. During July there was a considerable fall in soil temperatures because of the cooling caused by rainfall. There was a rise in temperature during September and October after which the soil temperatures

Table 11. Effect of depth of cultivation on yield and nutrient uptake of pearlmillet (1979)

Depth of cultivation (cm)	Grain yield (q/ha)	Straw yield (q/ha)	Water expense (mm)	Total nutrient uptake (kg/ha)								
				N			P			K		
				Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
0	7.2	23.2	77	8.4	7.2	15.6	3.6	2.72	6.3	2.3	23.2	25.5
5	10.6	24.6	77	11.8	6.1	17.9	5.0	5, 0	10.0	3.5	29.5	33.0
10	10.8	23.2	77	13.3	11.1	24.4	5.4	3.46	8.8	4.0	27.8	31.8
15	7.8	21.5	81	11.7	8.1	19.8	4.5	3. 0	7.5	3.3	25.5	28.8
L.S.D. (0.05)	1.77	N.S.										

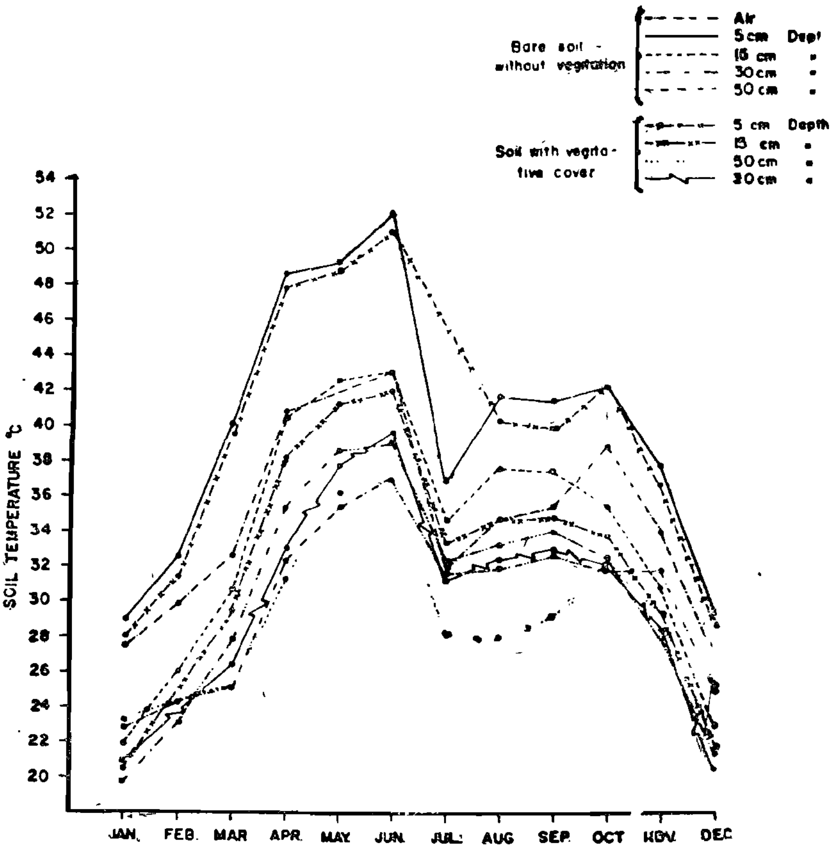

Fig. 4. Seasonal variations in soil temperature.

continuously decreased. Maximum soil temperature in the top 5 cm depth in summer was much higher than the lower depths. It decreased up to 30 cm depth beyond which there was not much change. In winter, however, lower layers below 30 cm were warmer than the surface. Mean maximum temperature of a bare soil at 5 cm depth, in general, was 1 to 2°C higher than the soil with vegetative cover except during July when there was a fall in temperature of a bare soil. During summer months higher day time temperature in surface 5 cm depth led to downward thermal gradients while during winter months upward thermal gradients were observed particularly from depths below 30 cm (Gupta, 1981).

(iii) Heat fluxes: A high variability in day time heat fluxes was observed from week to week (Fig. 5). From 1st to 15th week there were more positive heat fluxes than the negative ones, showing thereby, more heat gains in 0 to 20 cm and 20 to 50 cm soil depths under vegetation. This might be due to more conservation of heat energy in soil under

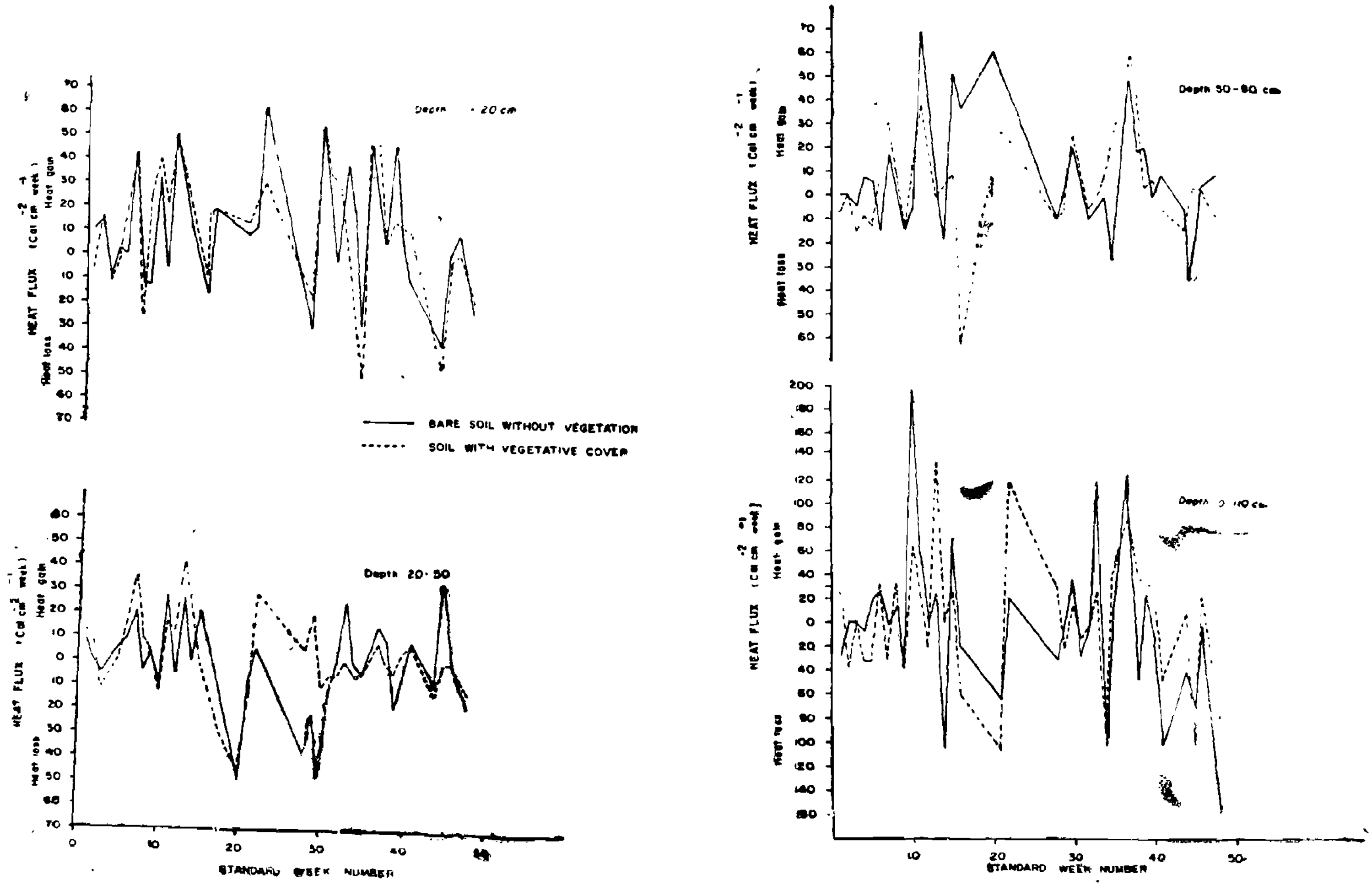

Fig. 5. Seasonal heat fluxes in soil with and without vegetation.

vegetation. At lower depths, below 50 cm, however, the bare soil was found to have higher positive heat fluxes possibly because of more conduction of heat to lower depths by moisture present in bare soil. From 16th to 25th week period (summer months), there were mostly positive day time heat fluxes in 0 to 20 cm depth leading to gain in heat energy in both bare and soil with vegetative cover. During 25th to 35th week, that is monsoon period, positive and negative fluxes were found to operate. During dry periods there was gain in heat while during wet or cloudy periods there was loss in heat. Lower depths under grass cover were found to store heat while bare soil lost most of the heat energy stored during summer particularly after very heavy rain shower. During post-monsoon period there was again some gain in heat energy but during winter months (40th to 50th week), negative heat fluxes were found to operate, showing thereby, heat loss from the soil profile. The heat loss, however, was more from a bare soil than the soil with vegetative cover, indicaing thereby, that the vegetation acted as insulated blanket which conserved heat in the soil.

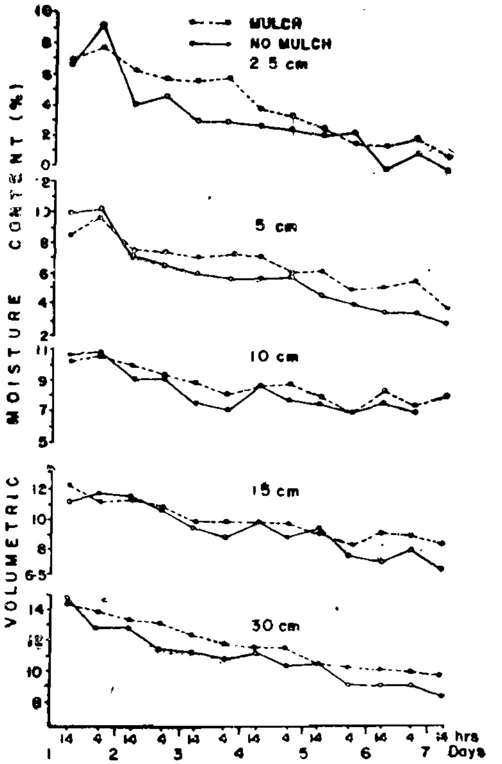

Fig. 6. Diurnal variations in soil moisture as affected by mulches.

3.5.1 Effect of Mulches on Hydro-thermal Environment and Pearlmillet Production

(i) Effect on summer crop

Soil moisture variations: Fig. 6 shows diurnal moisture oscillations occurring in soil with and without mulches. These oscillations were more predominant in surface 15 cm depth below which these were of very low magnitude. In surface layers up to 15 cm, soil moisture status was higher at 0400 hours while it was lower at 1400 hours, showing thereby, the movement of moisture under the influence of thermal gradients. Throughout the period of study (28th June to 6th July) highest moisture status of soil was observed in mulched plots and lowest in unmulched plots. During this period total moisture loss from the mulched plots was about 2 mm less than the unmulched plots.

Soil temperature and seedling emergence: Mean maximum temperature at 5cm depth of mulched plot was about 8°C lower than unmulched plot (Table 12). Maximum temperature in mulched plots generally ranged from 37-45°C while it ranged from 38-54°C in unmulched plots.

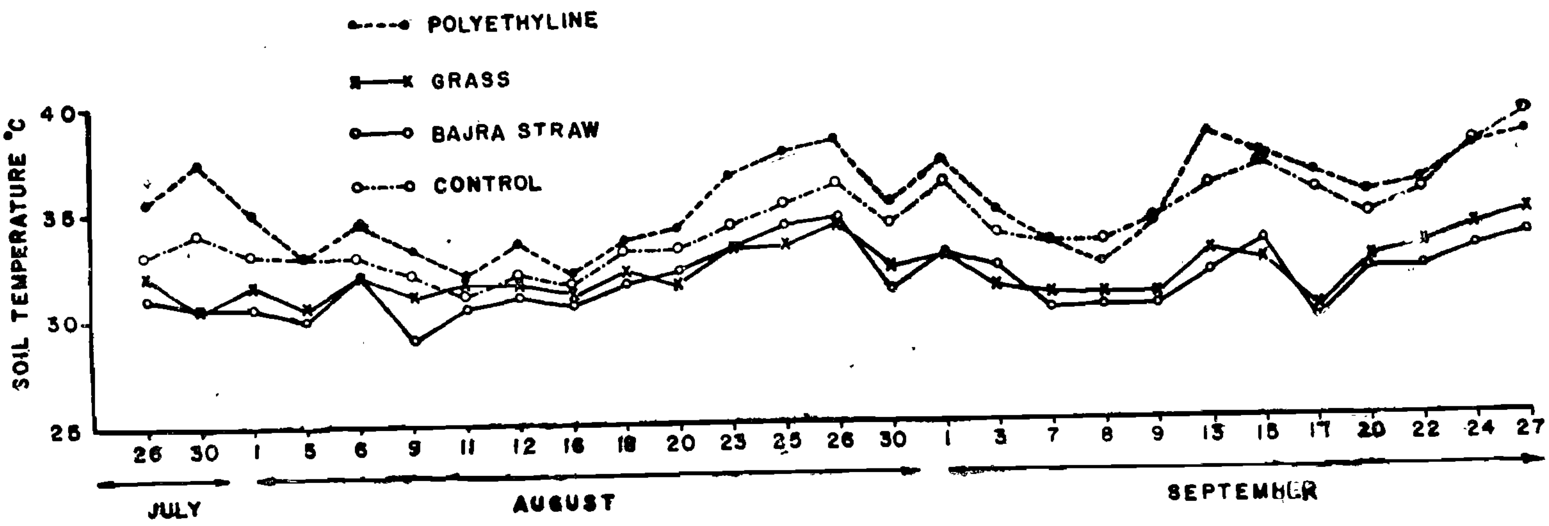

Fig. 7. Thermal regime of soil under mulches.

Table 12. Effect of grass mulch application on soil temperature, moisture loss and seedling emergence

Treatment	Mean soil temperature at 5 cm depth (°C)		Temperature range at 5 cm depth (°C)		Moisture loss (mm)	Seedling emergence (%)
	Max.	Min.	Max.	Min.		
No mulch	48.6	29.4	38-54	25-35	17.0	63
Grass mulch	40.3	29.8	37-45	26-35	14.7	70

There were, however, no differences in minimum temperature of mulched and unmulched plots. Rapid loss of moisture coupled with higher temperatures of unmulched plots reduced the emergence of seedlings (Gupta and Gupta, 1982).

(ii) Effect on kharif crop

Soil temperature : Polyethylene mulch was found to raise the temperature of soil at 10 cm depth by 1 to 3°C, while organic mulches like grass and straw lowered it by 1 to 6°C (Fig. 7). There were, however, no significant differences in soil temperature under grass and straw mulches. Soil temperature generally ranged from 30 to 35°C during the growth period of the crop. Higher production obtained from soil under polyethylene mulch showed that soil temperature up to 38°C was not a critical factor for the growth of pearlmillet crop. It rather helped in improving growth and yield of the crop (Gupta and Gupta, 1982).

Soil moisture : The soil under polyethylene mulch was found to contain 5 to 35 mm and under organic mulches 5 to 25 mm more moisture than the control without mulches during the year 1978 (Fig. 8). However, there were no significant differences in moisture status of soil under grass and straw mulches. Higher moisture status of soil under mulches was due to reduction in evaporation and weed population. Maximum dry matter production of 3.8 q/ha of weeds was obtained from soil without mulch while it ranged from 0.2 to 1.2 q/ha in mulched plots (Table 13), showing thereby, reduced crop weed competition for moisture in mulched plots. This seems to be an important factor for higher crop yields in mulched plots.

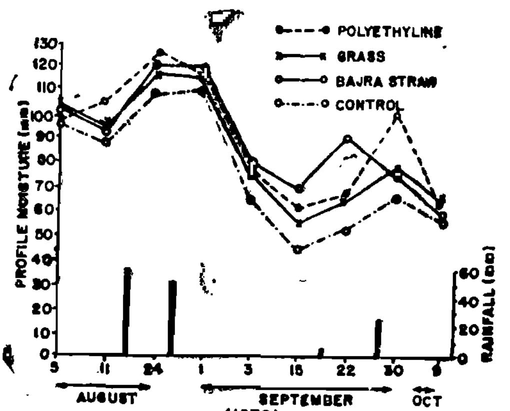

Fig. 8. Moisture regime of soil under mulches.

Table 13. Effect of mulches on weed growth, water use and yield of pearlmillet

Treatments	Grain yield (q/ha)	Straw yield (q/ha)	Weed production (q/ha)	Water use (mm)	Water use efficiency (grains, kg/mm/ha)
Polyethylene	15.5	38.1	0.25	289	5.37
Grass	8.9	27.6	0.92	286	3.11
Straw	7.2	25.1	1.23	276	2.61
Control	6.0	24.9	3.77	294	2.04
L.S.D. (0.05)	0.98	10.12			

Crop yield : Mulches increased the grain and straw production of pearlmillet (Table 13). No wide variations in water use of the crop under different treatments were observed. However, it was higher in control plots without mulch. Water use efficiency of crop was maximum with polyethylene mulch followed by grass, straw and the control without mulch (Bansal *et al.*, 1971; Gupta, 1980). Maximum water use efficiency with polyethylene was due to its imperviousness to vapours and the moisture, thus, conserved, was completely utilized for increasing crop production.

3.5.2 Effect on Hydro-thermal Environment and Legume Production

Soil temperature : Wide variations in soil temperature ranging from 36 to 44°C in unmulched and 32 to 41°C in mulched plots were observed during the growth period of the greengram (Fig. 9). With increase in rate of grass mulch application there was decrease in mean maximum weekly soil temperature with maximum reduction at 12 t/ha level. Grass mulch application at 6 t/ha level on an average reduced the mean maximum weekly temperature by 2 to 3°C

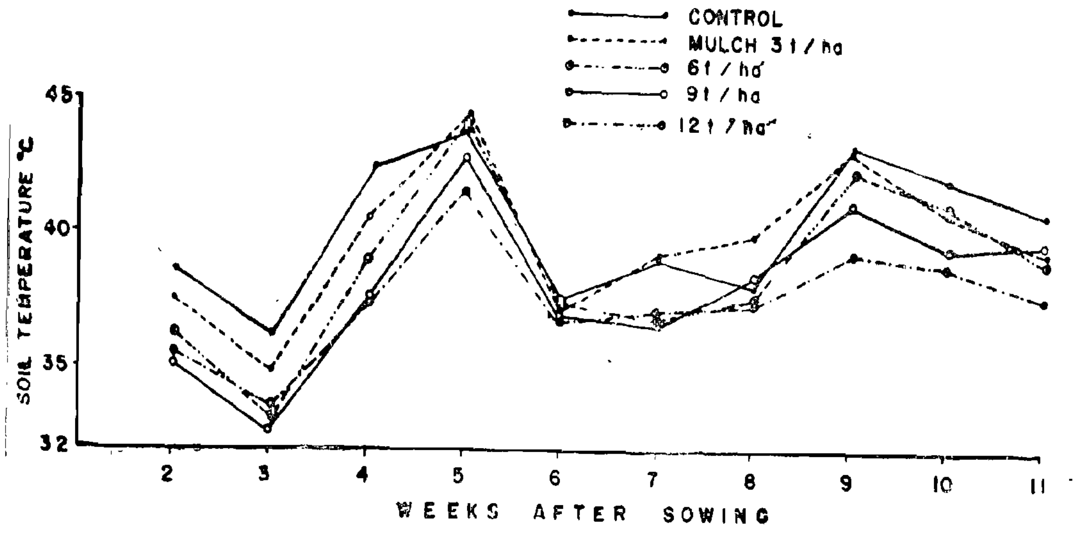

Fig. 9. Mean maximum weekly soil temperature as affected by different rates of mu'ch application.

Table 14. Effect of different rates of grass mulch application on soil environment and production of greengram

Grass mulch application (t/ha)	ET loss from 60 cm soil profile (mm)		Mean max. soil temperature at 10 cm (°C)		Root growth dry weight (g/plant)		Nodule number/plant		Plant water status (%)	Dry matter production (g/plant)	Weed production (q/ha)	Yield (q/ha)		Mean yield (q/ha)
	1979	1980	1979	1980	1979	1980	1979	1980	1980	1980	1980	1979	1980	
0	98.6	128.6	41.8	40.3	0.78	0.63	18	15	70.5	5.2	4.3	8.37	2.43	5.40
3	87.8	131.4	40.1	40.3	1.42	0.48	30	37	71.3	4.2	2.5	8.88	3.48	6.18
6	81.7	126.6	39.1	38.7	1.50	0.77	39	42	74.5	5.3	1.6	10.41	4.36	7.38
9	85.7	122.4	38.6	38.2	1.45	1.12	21	36	72.8	8.6	1.3	8.14	4.80	6.47
12	86.3	128.8	39.0	37.8	1.50	1.53	32	35	75.8	12.1	0.9	9.41	3.60	6.50
L.S.D. (0.05)												0.84	0.46	

and thus increased the root and shoot growth and nodulation.

Water use and crop production : With increase in rate of grass mulch application there was drastic reduction in weed growth (Table 14). There were, however, no significant differences in ET loss from mulched and unmulched plots. Water use efficiency of the crop was, therefore, higher in mulched than unmulched plots. Although there was very little rainfall during July and August of 1980 and the drought conditions persisted, there was higher plant water status and dry matter production in mulched than in unmulched plots. Production of greengram increased with mulch application upto 6 t/ha level beyond which yield decreased. This might be due to some delay in maturity of the crop. Mulch application at 6 t/ha level increased the average production of greengram by 40% more than the control without mulch. Though there was higher crop production during rainfall year of 1979, the crop responses to mulches were more obvious during a deficit year of 1980.

3.5.3 Effect on Vegetable Production

The application of grass mulch at the rate of 6 t/ha reduced the mean maximum temperature of soil at 10 cm depth by about 2°C while polyethylene mulch did not bring about any change during the growth period of the crop (Table 15). There was maximum ET loss from 60 cm soil profile of a control plot without mulch (110 mm) followed by grass mulch (106 mm) and the polyethylene mulch (90 mm). Grass and polyethylene mulches increased the production cf lady's finger by 15% and 46% more than the control without mulch, respectively. Though there were no differences in soil temperature of control and polyethylene mulch plots, a significant increase in crop yield indicates more moisture conservation under this mulch. This also showed that the temperature variations caused by grass and polyethylene mulches did not have any significant effect on the production of lady's finger crop and the temperature as high as 40°C was not critical for the crop growth (Gupta and Gupta, 1981).

Table 15. Effect of mulches on ET loss and yield of lady's finger (1979)

Mulches	ET loss from 60 cm soil profile (mm)	Mean maximum soil temperature (°C)	Yield (q/ha)
No mulch	110.0	40.8	26.3
Grass	106.2	37.8	30.4
Polyethylene	90.0	40.0	38.4

CHAPTER 4

Soil Conservation-Wind Erosion Control

Wind erosion is one of the most serious problems which adversely affects the productivity of agricultural lands in western Rajasthan. Studies conducted at C.A.Z.R.I. (Gupta and Aggarwal, 1978) has shown considerable loss of soil and nutrients from sandy plains particularly during summer months (April-June) when high speed winds frequently blow over this region. As the soils of the region are more vulnerable to wind erosion, therefore, they deserve proper management for its control.

4.1 Extent of Wind Erosion

During 75 days period in summer (April - June) as much as 4 cm and 2 cm corresponding to 615 t/ha and 325 t/ha soil loss was observed at Bikaner and Chandan, respectively. The soil loss was maximum during the period from 13th May to 11th June 1978 when the wind velocity ranged from 27.0 to 38.0 km/h. During the period from 12th June to 26th June, though the prevailing wind velocity was maximum there was reduction in soil loss particularly at Bikaner due to high rainfall received during this period. Data presented in Table 16 show a relative soil loss from different regions of western Rajasthan. There was maximum soil loss at Bikaner followed by Chandan and Jodhpur. Though the soils of Bikaner and Chandan are of the same type, the decreased erosion at Chandan was due to partial stabilisation by native grass vegetation. Minimum loss at Jodhpur was due the presence of nonerodible fractions and the soil binding caused by them.

Table 16. Relative soil loss due to wind from different regions of western Rajasthan

Mean wind velocity (km/hr)	Soil loss (kg/ha/day)		
	Chandan Sand soil	Jodhpur Loamy sand	Bikaner Sand soil
5	0.95	0.26	0.47
10	7.97	1.36	120.75
15	15.62	5.09	140.44
20	76.74	15.64	273.69
25	274.48	20.05	424.75
30	1189.24	230.93	—
40	1276.04	—	1605.25

4.2 Relationship with Wind Velocity

A very close exponential relationship between wind velocity and soil loss was observed both at Bikaner and Chandan (Fig.10) Regression equations are presented for predicting soil loss under different wind velocities at both sites. In the case of Bikaner, there was virtually no wind erosion at wind velocities of less than 5 km/h, while at Chandan wind erosion began at velocities above 10 km/h. This was because the Chandan soil is partially stabilised. With increase in wind velocity up to 15 km/h at Bikaner and 25 km/h at Chandan, there was only a slow increase in erosion. Beyond these velocities, however, increases were much greater. Hence these were the critical velocities for these respective soils. Further the grain sizes of the predominant fractions ranged from 0.10 to 0.25 mm in diameter, therefore, their minimal threshold velocity ranged from 5-15 km/h. As the percentage of erodible grains above 0.10 mm in diameter is higher at Chandan than at Bikaner, this could be another reason for a higher minimal threshold velocity for wind erosion (Gupta *et al.*, 1981).

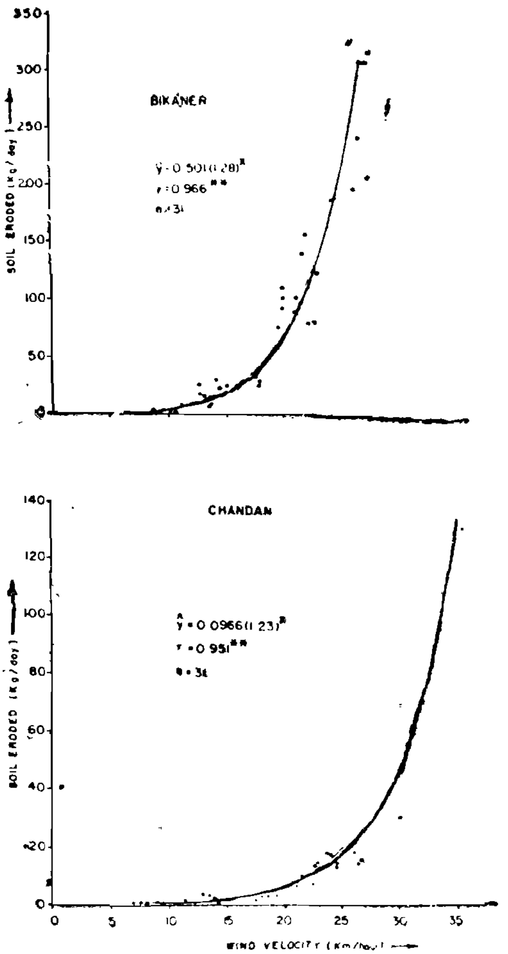

Fig. 10. Relationship between wind speed and soil eroded at two sites in western Rajasthan.

4.3 Soil Fractions Susceptible to Erosion

A higher percentage of particles in the range 0.10 - 0.25 mm was observed in the samples of eroded soils than in the field samples collected from Bikaner and Chandan (Table 17). Particles in the size ranges 0.07 - 0.10 mm and 0.05 - 0.07 mm diameter were found to be less erosive since their percentages in the samples of eroded soil were generally less than in the field soils. Particles less than 0.05 mm were least eroded from the soil. As the field soils consist predominantly of the higher erosive fractions; therefore they are highly susceptible to erosion.

4.4 Nutrient Status of Eroded Fractions

With increase in fineness of soil fractions, an increase in organic matter, nitrogen, phosphorus and potassium was observed. There was maximum concentration in fractions with grains of less than 0.05 mm diameter. This was due to the fact that fine fractions contain colloidal

Table 17. *Grain size (mm) distribution in per cent in field soil and eroded* samples from two sites in western Rajasthan

Site	Soil description	Per cent distribution of soil grain				
		>0.25	0.10-0.25	0.07-0.10	0.05-0.07	<0.05
Bikaner	Field soil	12.8	62.0	11.6	9.7	2.5
	Eroded soil	12.8	69.4	8.2	9.9	0.6
Chandan	Field soil	16.0	66.6	8.5	6.5	1.5
	Eroded soil	14.8	73.5	5.9	5.4	0.4

materials which are extremely reactive and have high cation-exchange capacities. Increase of nitrogen was small but there was a considerable increase of other nutrients. No significant difference was observed in the nitrogen and phosphorus contents of soil fractions having grains with diametres greater than 0 25 mm, particularly at Chandan. The nutrient status of the soil was, in general, higher at Bikaner than at Chandan: this may well be due to a higher organic content of the soil at Bikaner, where climatic conditions are less severe than at Chandan.

4.5 Total Nutrient Loss

Table 18 shows total nutrient losses due to wind erosion. Loss of organic matter at Bikaner was about three times higher than that at Chandan. Similarly, loss of other macronutrients (N,P,K,S) and micronutrients (Z,Cu,Fe,Mn) was two to three times higher at Bikaner than at Chandan. This was due to greater total loss of soil at Bikaner than at Chandan. Though nutrient concentration was maximum in soil fractions with grains having a diameter less than 0.05 mm the total nutrient loss was highest from soil having higher percentage of grains with diameter greater than 0.10 mm. This was due to the maximum erosion of this fraction of soil both at Bikaner and at Chandan.

4.6 Control Measures

(i) Stubbles mulch farming: The practice of using crop residues as stubble mulch began in U.S.A. as early as 1910. It is one of the most significant contributions to dry land agriculture where wind erosion is a serious problem. In mid-west dust bowl of United States, large scale mechanized stubble mulch farming is practiced as a measure of protection to the cultivated farm land from wind erosion. Crop residues of 2 to 5 m tonnes/ha and pearlmillet stubbles of 45 cm height were found very effective in preventing the blowing of sand from sandy soils (Misra, 1971). While working at Bikaner higher soil loss was observed from a bare sandy plain (Table 19) than those covered with pearlmillet stubbles showing, thereby, usefulness of stubbles in checking the movement of sand by providing surface cover, reducing wind velocity and binding soil particles (Gupta and Aggarwal, 1980).

Table 18. Soil fertility loss in different fractions of eroded soil at two sites in western Rajasthan

Site	Size of soil fraction (mm)	Organic matter (kg/ha)	Total soil nutrients (kg/ha)							
			N	P	K	S	Zn	Cu	Fe	Mn
Bikaner	>0.25	132	13	26	29	29	2.47	1,06	270.17	5.11
	0.10—0.25	1131	108	282	634	861	49.35	11.17	5121.11	106.61
	0.05—0.10	160	13	34	113	106	10.35	1.63	1416.71	27.46
	<0.05	202	11	29	72	73	11.62	1.62	1203.25	24.31
	Total	1626	147	372	849	1131	73	15	8011	163
Chandan	>0.25	13	12	11	23	53	1.84	0.81	201.76	2.96
	0.10—0.25	379	48	84	375	446	15.64	5.21	2978.64	54.36
	0.05—0.10	46	3	10	24	29	1.88	0.44	503.37	10.02
	<0.05	66	3	11	22	25	3.04	0.65	448.88	8.15
	Total	505	67	117	445	555	22	7	4132	75

Table 1.9. Sand movement from sandy plain of Bikaner during 75 days period.

Treatment	Total soil loss (t/ha)
Bare	1449
Stubble cover	22

(ii) Wind strip cropping : Strips of perennial grasses of *Lasiurus sindicus* and *Ricinus communis* established at right angle to the direction of prevailing winds reduced the impact and thesrhold velocity of wind to the minimum and thus checked the erosion of wind and increased the production of crops grown in between the protective strips (Misra, 1971). In another study (Gupta and Aggarwal, 1980) it has been found that a 18-20 years old cover of such perennial grasses as *Lasiurus sindicus, Cenchrus biflorus, Panicum turgidum* at Bikaner completely checked the movement of sand. The grass vegetation beside providing surface cover for reducing wind velocity, helped in forming surface crust and binding sand particles. This, therefore, checked the movement of sand. Agricultural lands can, therefore, be protected with grass strips and the marginal lands can be put under complete grass cover for checking the movement of sand towards the productive agricultural lands.

(iii) Sand dune stabilisation : Movement of sand dunes poses a serious threat to the productive agricultural lands, houses, roads and water courses, etc., and, therefore, warrants stabilisation which can best be done with vegetation.

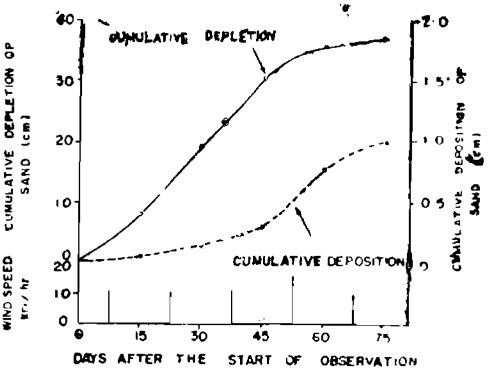

Fig. 11. Cumulative sand movement from typical stabilised and unstabilised sand dune.

Plantation of grasses and trees was found to provide surface cover, bind sand particles and help in the formation of soil crusts which checked the movement of sand (Gupta and Aggarwal, 1980). Bare sand dunes without vegetation, on the other hand, were found to lose as much as 37 cm of the surface sand during 75 days period from April to June (Fig. 11). After the blowing away of 37 cm depth of the dry sand (less than 1% moisture) the rate of blowing was generally found to decrease because of the increase in moisture content (2.0-3.0%) of the unstabilised sand dunes. Moisture content of the unstabilised sands dunes was generally higher than the stabilised dunes (Fig. 12). It has also been found that the sand dunes with coarser fractions at the surface contained higher moisture content because of the more recharge and less evaporative loss. Such sand dunes, therefore, should be chosen for successful stabilisation programme (Gupta, 1979).

(iv) Shelterbelts: Vegetation barriers placed in the path of wind reduce its velocity near the ground by exerting a

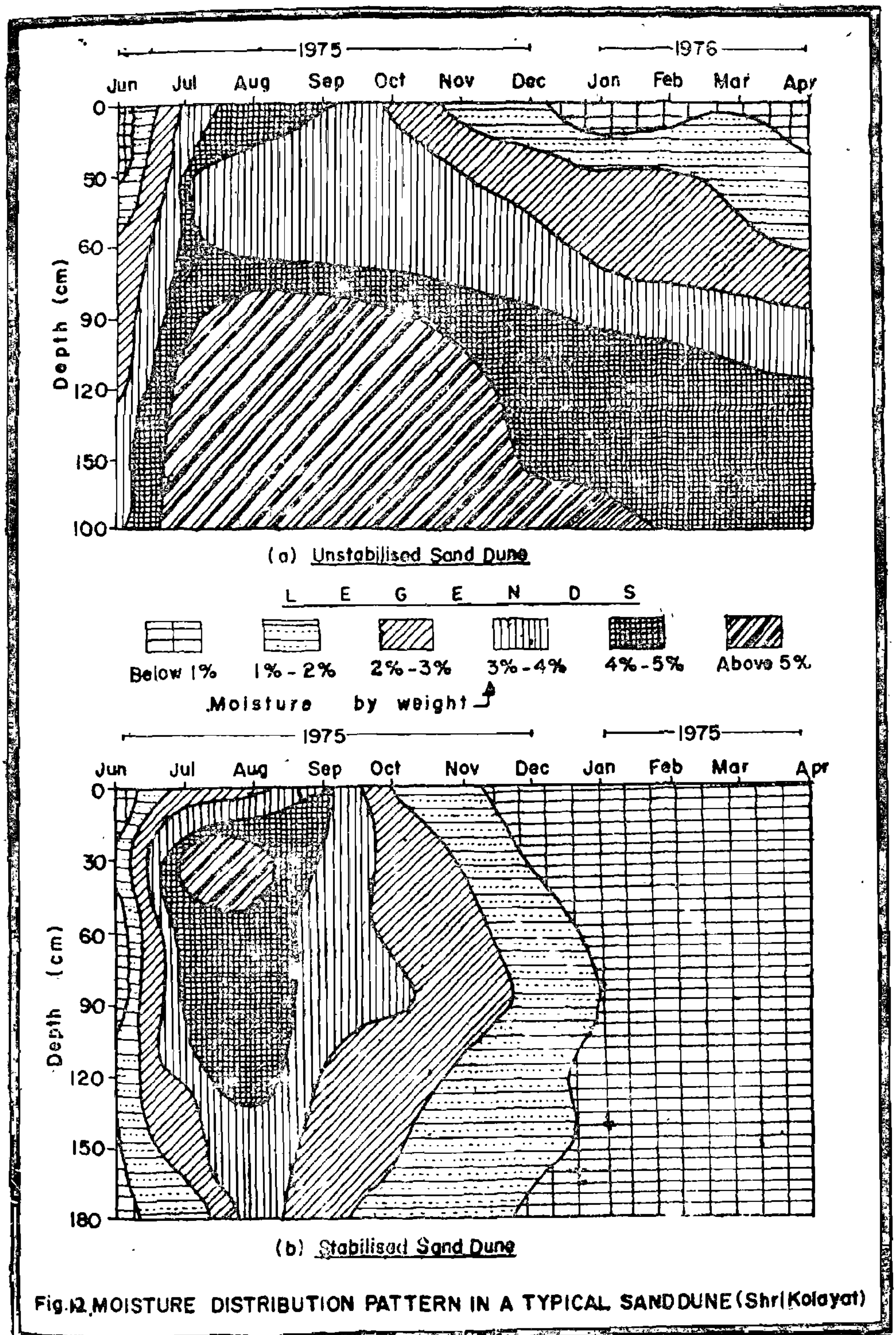

Fig. 12. Moisture distribution pattern in a typical sand dune of Bikaner (Shrikolayat).

drag on the wind and deflecting the wind stream. The effectiveness of shelterbelts in reducing wind velocity depends on many factors such as wind velocity itself, direction, shape, width, tree height and density, etc. From the eight years old plantation of shelterbelts, *Cassia siamea* type shelterbelt was found to be most effective in reducing wind velocity upto 2 H distance (Gupta *et al.*, 1981). The design and tree geometry of the shelterbelts used for these studies are shown in Fig. 13. Maximum soil loss was observed from a bare field without shelterbelt followed by sheltered field with *Prosopis juliflora* or *Acacia tortilis* or *Cassia siamea* showing thereby the effectiveness of shelterbelts in checking soil erosion due to wind (Table 20). The use of shelterbelts in general, brought about 50% reduction in wind erosion. *Cassia siamea* type shelterbelt, however, was found to be most effective in conserving soil during both the years of study. This could be due to thicker branching and more leafiness and, therefore, lesser air permeability provided by this shelterbelt. Higher amount of soil loss was observed during the year 1980 compared to 1979 due to more number of windy days. Ganguli and Kaul (1969) and Bhimaya *et al.* (1958) reported that shelterbelts when planted across and on the margins of agricultural fields effectively protect crops and control sand drifting. The total nutrients loss was also found to be maximum from a bare soil without shelterbelt followed by shelterbelts with *P. juliflora*, *A. tortilis* and *C. siamea* showing, thereby the conservation in soil fertility by the

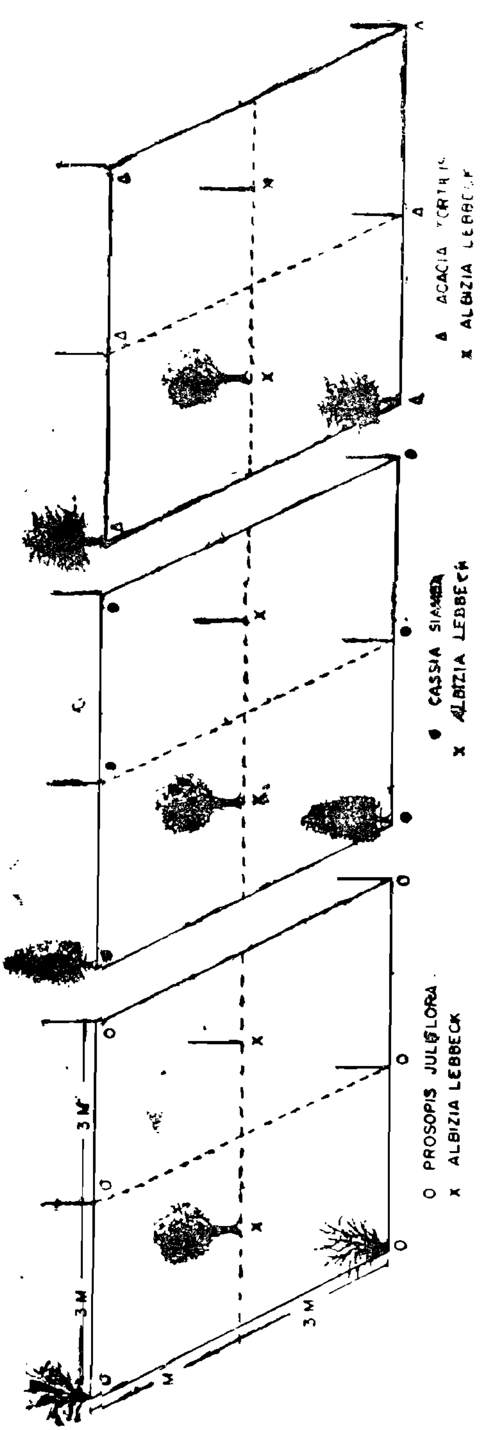

Fig. 13. Tree geometry and design of shelterbelts planted at Jodhpur.

Table 20. Effect of different types of shelterbelts on soil erosion and nutrient loss due to wind

Type of shelterbelts	Total amount of soil loss (kg/ha) (20th April to 26th June)			Nutrient loss due to wind erosion (g/ha)								
				N			P			K		
	1979	1980	Mean	1979	1980	Mean	1979	1980	Mean	1979	1980	Mean
Prosopis juliflora	93.2	609.3	351.2	32.6	213.3	123.0	17.2	112.7	65.0	177.1	1157.7	667.4
Cassia siamea	91.5	277.1	184.3	32.0	97.0	64.5	17.0	51.3	34.1	174.0	526.5	350.2
Acacia tortilis	106.0	494.1	300.0	37.1	173.0	105.0	19.6	91.4	55.5	201.2	938.8	570.0
Bare (without shelterbelt)	262.7	831.0	546.8	92.0	290.8	191.4	48.6	153.7	101.2	499.1	1579.0	1039·0

Table 21. Soil and nutrient loss by wind erosion

Soil treatment	Description of soil condition									
	Clods > 5 mm (%)	Average weight of clod > 5 mm (g)	Average dimensions of clods > 5 mm		Wind velocity (km/h)		Soil eroded (t/ha)	Total nutrient loss (kg/ha)		
			Length (cm)	Width (cm)	Max.	Ave.		N	P	K
Ploughed and planked	12.7	1.75	2.1	1.2	29.1	26.0	40.11	9.79	13.93	49.69
Ploughed only	42.4	111.80	7.9	6.5	29.1	26.50	0.50	0.12	0.17	0.62

shelterbelts in general and *C. siamea* type shelterbelt in particular.

Higher moisture status was observed in 0-15 cm and 15-30 cm layers of soil protected with *C. siamea* than with other shelterbelts. Residual moisture after irrigation was also higher in soil protected with *C. siamea* type shelterbelt, showing thereby, less loss of moisture from field with this type of shelterbelt.

This shows that the plantation of three lines of trees of the type *Cassia Siamea-Albizzia lebbek-Cassia siamea* as shelterbelt across wind direction can be helpful in reducing wind velocity, in checking wind erosion and in delaying the drying of the sheltered soils.

(v) *Tillage* : Excessive tillage of agricultural land when it is dry breaks clods and exposes it to wind action which leads to erosion. Higher percentage (42.4) of the clods greater than 5 mm size with an average weight of 111.8 g/clod was observed in the disked field while such value was lower (12.7) with an average weight of 1.7 g/clod in the disked and planked field (Table 21). Wind erosion during the period of observation (5 days) was as much as 40 t/ha from the field which was thoroughly disked and planked in contrast to a soil loss of 0.5 t/ha from the only disked field. Thus, there was about 80 times reduction in wind erosion from a field which was only disked as compared to the disked and planked one. This reduction was due to more roughness provided by the soil clods (Gupta and Gupta, 1981).

CHAPTER 5

Summary and Conclusion

Proper soil management and conservation techniques play an important role in increasing the productivity of arid lands. Water harvesting was found to be an important technique in increasing water supply to the crops for higher and sustained production during deficit rainfall years. Soils underlain with impervious layers and having 5 to 10% slope were found to generate very high amount of runoff particularly during high rainfall years or years with high intensity of rainfall. This water if properly collected and stored can be used for growing short duration and low water requiring crops and also as supplemental irrigation for saving crops during the periods of drought.

Different materials like asphalt, bentonite clay and pond sediments were used as subsurface moisture barriers at 60 cm depth in 2 mm thickness for asphalt and 5 mm thickness for others. These were found useful for moisture and nutrient conservation. The placement of asphalt as subsurface barrier led to five times reduction in deep percolation loss and two times increase in moisture and nitrogen retention capacity of the soil. With asphalt barrier, therefore, there was increase in moisture and nitrogen status of soil throughout the cropping season. This led to 40-60% increase in the production of pearlmillet (*Pennisetum typhoides*). Therefore, there is scope of the use of asphalt moisture barrier for crop production, nursery plantation and tree establishment.

Different amendments were used for improving soil physical conditions, fertility status and the productivity of desert sandy soils. The use of pond sediments at the rate of 76 tonnes /ha increased the moisture retention at 0.3 bar tension from 8.6 to 10.1%, N from 0.028 to 0.039% and organic carbon from 0.21 to 0.27%, resulting in 40-50% increase in the grain yield of pearlmillet and greengram with associated increase in the N uptake, water use and water-use efficiency. Pond sediments, therefore, can be used for improving soil physical conditions, fertility status of soil and the crop production. It does not involve any expenditure except the transportation and can be used wherever it is available.

The use of exfoliated vermiculite increased the moisture retention at 0.1 bar tension and decreased the bulk density and saturated hydraulic conductivity of soil. Its application at the rate of 20 t/ha optimized the production of ladys finger which was 40-60% more than the control without vermiculite. As the material involves some cost, therefore, it can be profitably used for high value crops like vegetables and also in the establishment of nursery plants and trees.

The contniuous application of farm yard manure in association with urea showed an increase in moisture retention and decrease in bulk density and saturated hydraulic conductivity of soil. The combination of these two nitrogen sources to supply 50% nitrogen from each optimized the soil environment and increased the production of pearlmillet by 30% more than with farmyard manure alone and nearly equal with urea alone. This can, therefore, be used for improving physico-chemical environment of soil and crop production beside economizing the use of fertilizers.

Post emergence cultivation of 5 cm depth after 20 days of seedling emergence was found to substantially reduce weed population, lower soil bulk density and increase root growth and proliferation. This, therefore, increased the production of pearlmillet from 3.4 to 11.8 q/ha with higher uptake of nutrients. In the absence of weeds also one post emergence cultivation was found useful in raising the average production from 9.5 to 11.8 q/ha. More cultivations, however, were not found useful in further raising the level of crop production. The practice, therefore, can be used for improving soil physical conditions, reducing crop-weed competition and increasing crop yields.

Moisture and thermal regimes of the sandy soils were quantified. Bare soil without vegetation contained higher moisture content than the soils with grass vegetation. Mean maximum temperature of a bare soil at 5 cm depth, in general, was 1 to 2°C higher than the soil with vegetative cover. Maximum soil temperatures at 5 cm depth during summer were found higher than the lower depths leading, thereby, to downward movement of heat. In winter, however, the temperatures of lower layers were higher facilitating the upward flow of heat and the vapour flux. A high variability in heat fluxes with generally positive day time heat fluxes in summer and negative in winter were observed.

Different mulches were used for reducing the evaporative loss of moisture and lowering the thermal regime of soil. Application of grass mulch at the rate of 6 t/ha decreased the maximum temperature of soil by 1 to 9°C, reduced the evaporation loss and increased the seedling emergence of pearlmillet crop during the hot month of June. During kharif season (July-September), however, the magnitude of temperature reduction narrowed down to 1-6°C. Polyethylene mulch, on the contrary, raised it by 1 to 3°C. These mulches also suppressed weed growth, improved moisture status of soil and thus, increased the production of pearlmillet and ladys finger crops. With increase in application rate of grass mulch, there was also reduction in maximum soil temperature, increase in water status of soil and plant and improvement in root growth and nodulation. Mulch application at 6 t/ha level optimized the average production of greengram which was about 40% more than the control without mulch. These mulches, therefore, can be used for favourably manipulating soil environment for increasing crop production. The waste plant materials like grass, straw, etc., available at the farms can be profitably used as mulch for general field crops and the polyethylene mulch can be used for high cash crops like vegetables.

As much as 615 tonnes/ha and 325 tonnes/ha soil loss was observed from Bikaner and Chandan, respectively, during 75 days period in summer (April-June). A high exponential correlation between wind velocity and soil loss was observed at both sites. Particle sizes in the range 0.10-0.25 mm were observed to be more erosive, while particles less than 0.05 mm were least erosive. Finer fractions of eroded soil were found to contain higher contents of organic matter, nitrogen, phosphorus and potassium. Total loss of macro-nutrients (N, P, K, S) and of micro-nutrients (Zn, Cu, Fe, Mn) was two to three times higher at Bikaner than at Chandan.

Different methods were used to check the movement of sand. Crop stubbles of 30-45 cm height were found to substantially reduce the movement of sand. Wind strip cropping was found a useful technique for checking the movement of sand. Plantation of grass or a mixture of grass and trees helped in reducing wind velocity, binding soil particles and in forming soil crust and, thereby, helped in checking the movement of sand. Application of soil amendments like pond sediments, farmyard manure, bentonite clay, etc , formed wind stable aggregates and, thereby, checked erosion. Surface mulches, beside providing surface cover, conserved moisture in soil and reduced wind erosion. These techniques if adopted can help in checking the movement of sand and inceasing the productivity of the land.

Plantation of shelterbelts of *Prosopis juliflora* or *Cassia siamea* or *Acacia tortilis* generally reduced wind velocity, wind erosion and the evaporative loss of moisture from the protected fields. However, *Cassia siamea* type shelterbelt was found to be most effective in checking wind erosion and delaying the drying of the soil and, therefore, should be planted in the fields across the wind direction.

Excessive tillage like disking and planking of the dry soil led to the breakage of clods and made the soil more vulnerable to wind erosion. A loss of 40 t/ha was observed from a disked and planked soil while it was 0.5 t/ha from only disked soil. The total nutrient loss was also more from the disked and planked soil as compared to only disked soil Soil cultivation should, therefore, be performed with premonsoon showers so that there is formation of clods which resist the erosion of soil by wind.

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