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AFFORESTATION AND ITS REQUIREMENTS IN THE SHEKHAWATI AREA OF RAJASTHAN

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The results of detailed surveys during the past two decades by the author, including the data gathered on various aspects of the vegetation, are presented. A brief review of the work done so far on this aspect in Rajasthan—land form classification with its characteristics ecological features, climatological analysis, soil features and their influence on the vegetation, biota and its influence at various levels, quantitative production potential, etc.,—has been given. Based on the above approach, techniques and the requirements of afforestation have been discussed and their successful implementation envisaged.

A relationship exists between the sand and dune region development and grazing pattern. The area possesses high-yielding and nutritive indigenous desert perennial, annual and ephemeral forbs and also grasses.

A plea has been made for (i) reclaming the natural pasture land for maximum production, (ii) large scale afforestation programme of these areas based on a scientific appraisal, (iii) a solution to indiscriminate and overgrazing, and (iv) protection of the existing vegetation and choice of indigenous and new species for plantation.

INTRODUCTION

The dwindling vegetation of Rajasthan has been in a depauperated condition during recent years, and so is its counterpart — the human and animal life in the area. The present paper envisages an integrated summary of the existing vegetation and its environment, based on a reconnaissance and detailed survey during the past two decades by the author, in the Shekhawati area. The data so gathered on various aspects of the vegetation have been used as a basis to discuss certain problems of afforestation and its requirements, with special reference to sand and dune regions of Shekhawati.

Sufficient historical evidence can be adduced to show that the present area and for that matter Rajasthan in general, was once well wooded and fertile, and it was only in the recent past that the desert conditions were accentuated. In recent years the tract has been subjected to such extreme vicissitudes that it has become most imperative to check the perpetual process of sand movement in the area.

General features of the environment and vegetation have also been recorded and discussed on the land-form basis. For afforestation of mobile habitats, a plea has been made both for indigenous and introduced selected plants, envisaging their successful implementation.

Review of Earlier Work

Afforestation and its problems for Rajasthan have been discussed by Chaturvedi (1952), Ganguli (1952), Banerji (1952), Singh (1952), Nair (1954), Bhimaya (1960), Bhimaya and Kaul (1963-1967) Kaul and Ganguli (1962, 1963a-d), Bhimaya *et al.* (1964) and Mulay and Joshi (1964). Tree planting in arid lands and on the road sides was discussed by Goor (1955) and Kaul (1957, 1970) respectively. Side aspects like lopping intensities, top feed species and fodder potential of *Zizyphus* were dealt with by Bhimaya *et al.* (1964), Ganguli *et al.* (1964), Kaul and Ganguli (1963c) respectively. Introduction of *Eucalyptus* and silvical study of *Acacia tortilis* was stressed by Kaul and Ganguli (1962) and Kaul (1963). For the arid land of Rajasthan, nursery practices and its economics were dealt by Pathak (1956) and Kaul and Ganguli (1963b). Dabadghao (1960) described the ecology of grasslands and the principles of their management.

Bhimaya *et al.* (1961), Kaul and Ganguli (1962), Bhimaya *et al.* (1967) and Kaul and Jain (1967 *a, b*), discussed forest economics in Rajasthan, while certain forest ecology aspects were worked out by Raheja (1962, 1965), Kaul and Nambiar (1966) and Kaul *et al.* (1966). Silviculture studies were undertaken by Kaul and Ganguli (1963), Kaul (1965*a,b*), Bhimaya and Kaul (1965, 1966) and Bhimaya *et al.* (1965). Forestry of specific trees of Rajasthan was put forth by Kaul and Ganguli (1962) and Kaul *et al.* (1964).

For sand dune regions, Prakash and Pathak (1957), suggested brick planting in shifting sands while Bhimaya *et al.* (1961), discussed sand dune stabilization in the western Rajasthan. Satyanarayan (1958 *a, b*), made a plea for grasslands in Rajasthan, and listed some indigenous species for the stabilization of sand dunes of the Rajasthan desert. Measures to make sand dunes productive and the performance of *Eucalyptus* species was dealt by Kaul (1968a) and Bhimaya *et al.* (1962). Joshi and Sarma (1964, 1966), suggested certain sand-binder grasses of Jhunjhunu district. Recently, Joshi (1968) dealt with grasslands and range resources studies of the Shekhawati area.

Ecology of sand dune vegetation has been dealt by Gupta and Saxena (1965), Shankarnarayan *et al.* (1965) and Satyanarayan *et al.* (1966), while the importance of shelter belts and techniques of tree planting have been suggested by Kaul (1959) and Raheja (1963).

Area and Climate

Shekhawati, comprising Jhunjhunu and Sikar districts, covers an area of 13,676.8 sq. km and lies between 27° 9' and 28° 37' N latitude and 74° 43' and 76° 9'E longitude in the Jaipur division of Rajasthan (Fig. 1).

Shekhawati area comprises of varied habitats. The area is drained by rainfed streams and rivers viz., Kantli Nadi, Kalli Nadi, Para rampurwali Nadi and Bassi Nadi, which ultimately disappear within the sands of the area. There is no natural lake in the area; there are, however, small brick and mortar tanks in several towns made by

local persons, the two important permanent water reservoirs being the Lohargal tank and the Ajit Sagar Bundh, near Khetri. The area has vast stretches of sand and dunes all over with outcrops of rocks. Harshnath peak followed by Lohargal hills is the highest (914.4 m) near Sikar.

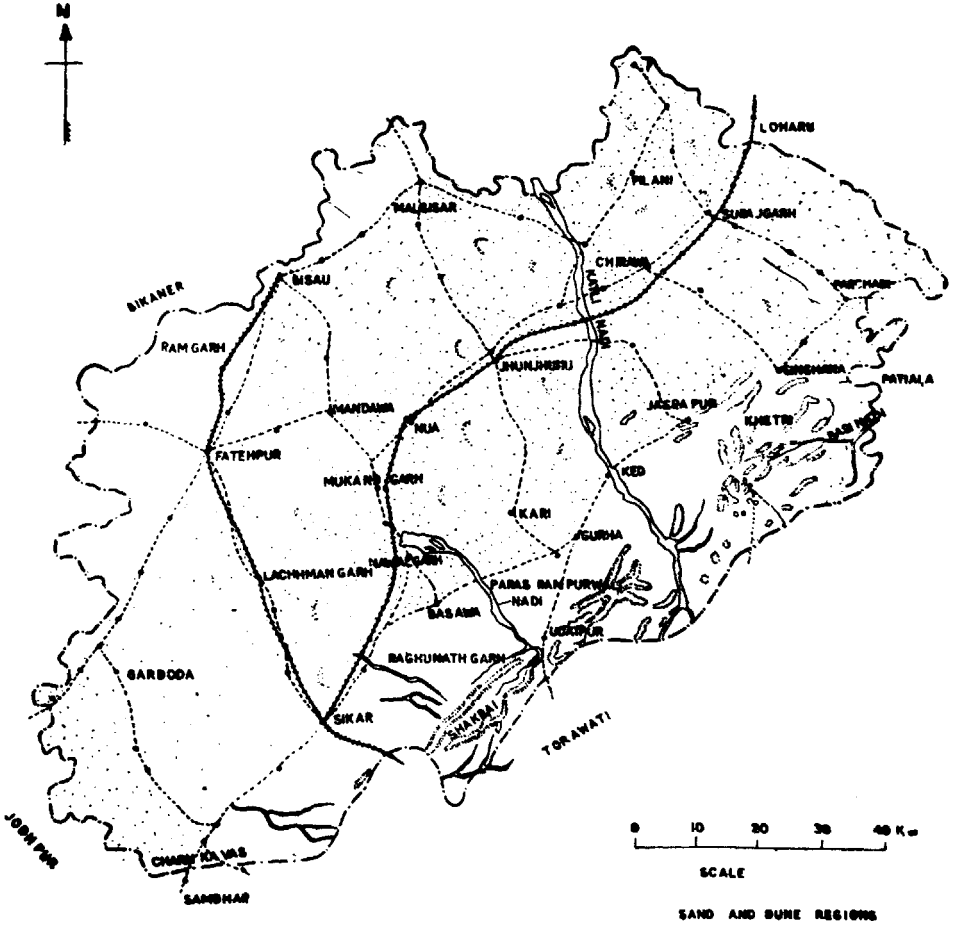

FIG. 1 Map of Shekhawati showing general features of the area. Sand and dune regions have been shown by dots.

The land form classification given below is based on the irregular terrain of the area where distinct topographic zones are recognised. The whole area affords an excellent illustration of the geological action of the wind in modifying the surface features of the area. The land forms can be grouped as follows (Fig. 2).

(i) Hard gritty rocks, hills and loose gravel areas
(ii) Hard loamy ground areas, with low-lying plains and depressions
(iii) Loose sand plain and farm and cultivated areas
(iv) River bed areas
(v) Embryo dune areas

(vi) Barchan dune areas
(vii) Fusing barchanoid dune areas
(viii) Longitudinal and transverse ridged dune areas
(ix) Scattered hummocky dune areas
(x) Stabilized dune areas.

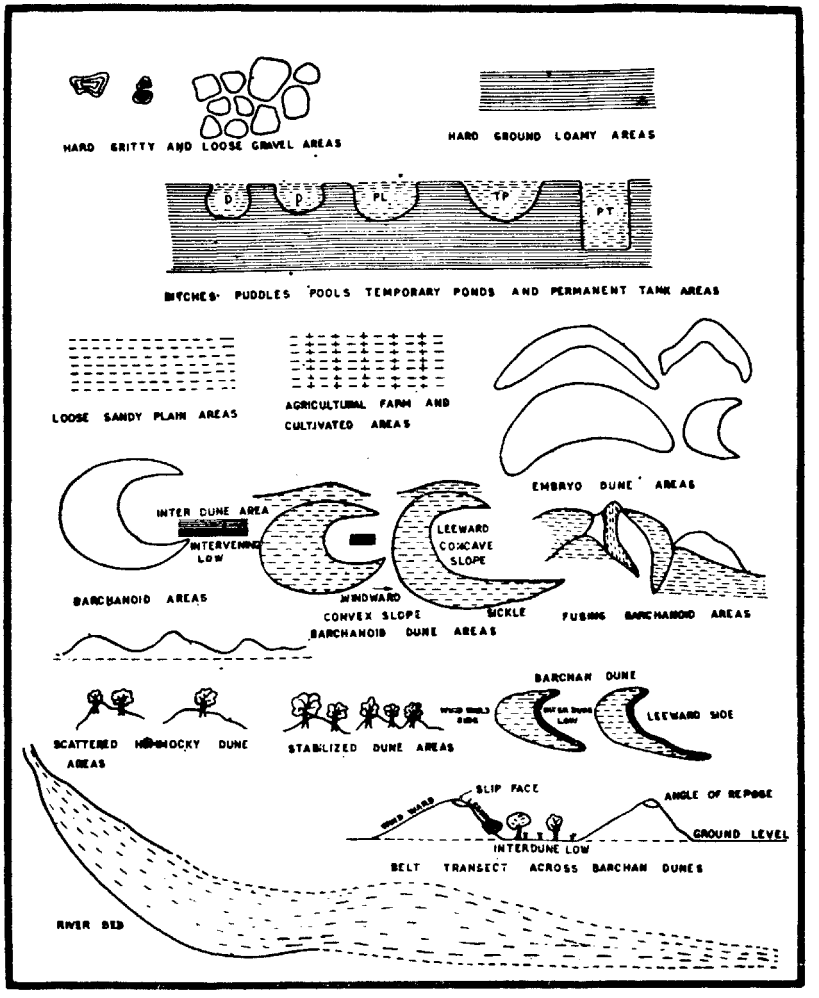

FIG. 2 Land forms of Shekhawati area showing hard gritty and loose gravel areas, hard ground loamy areas, ditches, puddles, pool, temporary ponds and permanent tank areas, loose sandy plain areas, agricultural farm and cultivated areas, barchanoid dune areas, fusing barchanoid areas, longitudinal transverse ridged dune areas scattered hummucky dune areas, stabilized dune areas and river bed. A cross section of barchans is given on the right to show various positions and the 'critical areas.'

The geomorphology of the sand and dune regions is modified all the time due to the perpetual process of change brought incessantly by the relentless action of wind in moving the sand from these mobile areas, and scouring or depositing them elsewhere.

Thus, a process of erosion (sheet erosion and sand abrasion) and deposition goes on side by side in these habitats. In general, the topography is a succession of sand plains and dunes of various shapes, sizes and forms.

Deposition and accumulation of sand in the area is therefore, both in simple and complex forms. The extensive irregular and generally thin drifts are common in vast plain areas. However, against any obstacle or a plant, microdunes (embryo dunes) are formed which are elongated in the direction of the wind. Sometimes microdunes (Nebkhas) are formed round bushes and tufts of vegetation. 'Barchans' dunes are often more than a metre in height and are crescent-shaped. Often series of these dunes cover extensive areas. To start with, erosion first produces small drifts which gradually grow into veritable barchans of various dimensions, ranging in length and width from a few to several metres. The height of these dunes depends on the age of their deposition by the wind. Owing to the prevailing wind direction, which is generally from west to east or south-west to north-east, the faces of most of these dunes are either to the east or to the north-east direction. The barchans are irregularly spaced, with distances between them ranging from a few to several metres. The subsoil on which the dune rests, as well as the soil in between and around them forming the 'critical area' is very compact, hard and fairly level. Dune chains or 'fusing barchanoids' are much higher and more extensive than barchans, but are usually formed when aggregated together or get mounted over one another. This forms a complex dune system. Longitudinal and transverse dune ridges in the area usually serve as boundary lines between villages and cultivated fields. Hummocky and stabilized dunes, however, are not subjected to wind erosion so severely. These habitats usually support rich vegetation. Since the soil is more compact in these areas, removal of vegetation allows the wind to erode areas in wedges which, if the land slopes, serve as a starting point for heavy water erosion forming gulleys and channels. Many of these areas in Shekhawati have already been formed into 'bad lands'.

The characteristic feature of sand dune regions is not its form but the process by which these are formed. With sand (source and supply) and wind (velocity, duration, frequency and direction) the sandy terrain goes on modifying itself. With the addition of water, a third element comes into being, and with the introduction of vegetation the changes are set in a succession of events from season to season and from year to year. The shifting surface of sand vigorously controls the establishment of pioneer plants. As the plants increase in number and size, the sand becomes stabilized, as there are associated changes in the microenvironment, and rapid changes in the plant association.

The surface creep of desert takes place in a characteristic style. Coarsely granulated sandy soils erode mainly by 'saltation' while the pulverized soils by 'suspension'. Lossess from wind erosion and sand abrasion are manifold in these areas. Bare sand, wherever it is present, is not only unproductive but also damages covered areas of crop pasture, woodlands and water reservoirs.

Climatic factors operating in Shekhawati have been based on observatory records obtained from Pilani and Sikar. The data for the ombrothermic diagrams (Fig., 3 a,b) is averaged for the years 1959–1969 for Pilani, while for Sikar it could be averaged only for the years 1950–1956—the data not being available for the years after that. Ombrothermic diagrams are based on the method of Walter (1963). According to

Walter (*loc.cit*), the ombrothermic diagram in a ratio of 1:2 can explain and establish the climate type of the region. The diagrams for Pilani indicate three and a half wet (mid June to September) and eight and a half dry (October to mid June) months. The dry period is further divisible into a cool dry period (October to February) and a hot dry period (March to mid June) on the basis of temperature conditions. For Sikar the diagram shows almost four months wet (June to September) and eight months dry (October to May). For Sikar, the cool dry period and a hot dry period extend from October to February and March to June respectively.

By comparing both the diagrams (Fig. 3, A and B) it can be inferred that the Sikar area of Shekhawati is more wet. The mean annual rainfall for Sikar is 481 mm as compared to 388 mm for Pilani. The major part of the rains is received during July to September, the values being 356 mm and 304 mm for Pilani and Sikar respectively. It is also observed that an alternation of wet and dry year exists in the area, which is not favourable to vegetation.

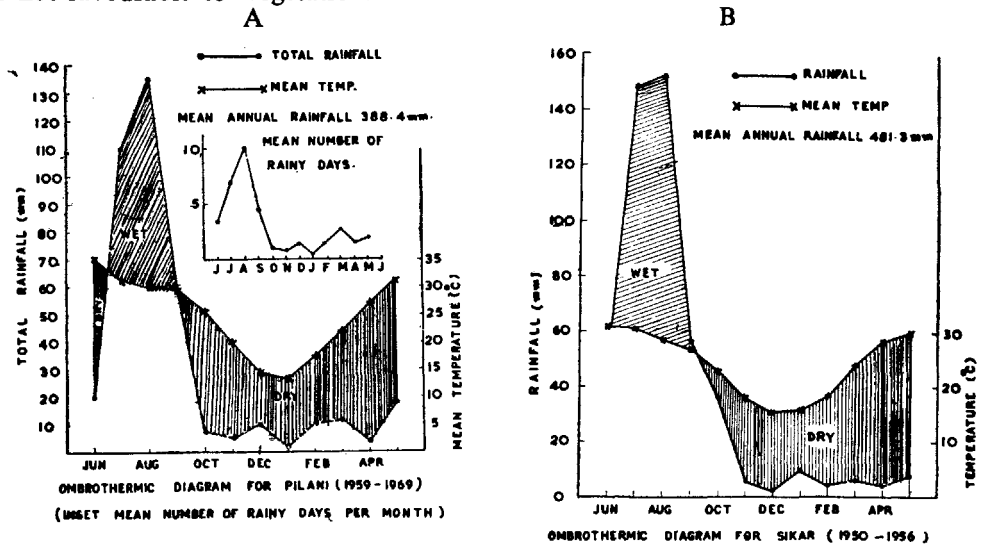

FIG. 3. Ombrothermic diagrams for Pilani (1959-69) (A), and Sikar 1950-56 (B).

SOIL AND BIOTA

The soil characteristics of Shekhawati vary in different habitats. A general summary of soil analysis carried out in different regions is given in Table I.

According to Misra (1967), Rajasthan comprises seven types of soils out of which desert soils total an area of 30,400 sq km. According to his classification the areas of Jhunjhunu and Sikar are covered by grey-brown soil. Shekhawati soils are sandy, porous and loose, and vary from coarse to fine in structure. Alluvial and loam soils vary according to topographic features. Frequently the porous nature of the soils in sandy region results in improved infiltration which allows plants to grow at altitudinal levels on dunes. These plants are much lower than the normal ones. These areas, when wet, are highly productive with grassess and forbs. Since these soils develop under conditions of high temperature and scant erratic rainfall, the fertility of these soils

remains poor. It has also a zone of lime precipitation in the subsoil because of incomplete leaching of soluble salts. Due to intense erosion and development of shifting dunes, the sandy soils develop an ill-defined profile which is azonal. The nature of pedogenic process is mechanical weathering, leading to highly mineral sandy alkaline soils, rich in salts of calcium, potassium, sodium, magnesium etc. Locally, for a short while, incorporation of organic matter by the decomposition of vegetal remains may improve the texture and moisture-holding capacity of the soil, but soon these areas also get disturbed by deposition of fresh sand. Thus, there is no likelihood of any continued development of the soil.

TABLE I

Soil analyses of different habitats from composite samples from 15–20 cm depth

	Fine gravel (%)	Coarse sand (%)	Fine sand (%)	Silt and clay (%)	Total soluble salt (%)	Total carbonates (%)	Total nitrogen (%)	meq(100 g exchangeable Ca	Mg	Na	K	*p*H
Hard gritty (crevices) and loose gravel areas	2.30	60.38	31.27	6.05								8.0
Hard loamy plain areas	1.10	4.70	75.80	18.40	0.86	0.094	0.018	0.73	0.13	0.18	0.20	7.0
Protected loamy areas	1.11	8.81	80.08	10.00		1.520	0.071	0.59				7.6
Road side areas	2.65	10.48	70.29	16.58		3.720	0.079	0.72				7.8
Low lying depressions	1.80	13.90	65.10	19.20	0.59	0.430	0.032	0.83	0.17	0.19	0.21	7.9
Loose sandy plain areas	0.00	38.35	57.80	3.85	0.18	0.065	0.013	0.42	0.06	0.37	0.30	7.8
River bed areas	0.00	3.30	95.90	0.80								7.7
Embryo Dune areas	0.60	2.20	94.30	2.90								7.0
Barchan-dune areas	0.00	14.85	71.50	13.65								7.4
Dune crest areas	0.00	1.20	98.40	0.40	0.10	0.120	0.009	0.62	0.12	0.06	0.22	7.8
Inter-dune lows	1.80	10.50	80.40	7.30	0.15	0.010	0.032	0.66	0.18	0.42	0.30	7.4
Fusing Barchanoid-dune areas	0.00	6.43	90.17	3.40								7.1
Longitudinal and transverse ridged dune areas	0.00	1.00	96.40	2.60								7.9
Scattered hummocky dune areas	0.00	6.43	90.17	3.40								8.8
Stabilized dune areas	0.36	3.47	88.51	7.66		0.740	0.059	0.13				7.2

One advantage of sandy soils is that they allow the water to infiltrate better, which remains as 'sealed moisture' in the deeper layers of sand. Evaporation is thus far less than from soils with higher clay content. Further, sand being poor conductor of heat, only its surface layers get heated while a few centimetres beneath the soil substratum remains moist and cool which helps plants to subsist by keeping their root systems fully alive.

Biota—A gross estimate shows that India has only 2 cft. of timber per capita as against 50 cft. in Canada. Calculations for Rajasthan, or even for Shekhawati, may

reveal a still lower figure. It is an accepted fact that the crux of Rajasthan desert problem is grazing and overgrazing. But, probably, equally or even more important is the cutting, felling, amputating, mutilating and coppicing the indigenous trees and other important perennial cover for fodder, fuel and timber for daily use by the local people. The axe and the goat and to a certain extent the gun have played an important role in bringing the present depleted and depauperated phase of vegetation in the area. To add to this are other animals which damage the existing vegetation at all levels of their development. Prakash (1957, 1964) described the food habits of many desert mammals. According to him 19 mammals in Rajasthan depend on vegetation while others are insectivorous or carnivorous.

According to Purohit (1968), sand dunes and other habitats provide shelter to 38 species of mammals. Thus all the aforesaid biotic agents working in the area never allow the vegetation to grow normally. Gupta (1965) has discussed the anthropogenic influences on the vegetation of Western Rajasthan.

Further, herbivores cause a great loss by grazing, nipping of seedlings and saplings, eating of reproductive parts, leaves and seeds, tunnelling into the root zone, and thus cause desiccation of soil moisture and of root. These are the various ways in which damage to plant cover in the area is effected.

Livestock largely depends on monsoon natural vegetation which exists in a delicate balance with the environment. With excessive biotic interference there has been an upset in nature's balance with consequent deterioration in vegetation and soil.

Vegetation and Productive Potential

In spite of vast expanses of shifting sand and dunes, seemingly lifeless and incapable of producing enough vegetation, hazardous climate, and adverse biotic factors, many plants grow and animals prosper in the area. Shekhawati area comprises distinct plant communities which are in discontinuous patches from habitat to habitat (Joshi 1958 *a*, *b*; Joshi & Bansal, 1968; Nair & Kanodia, 1959 and Nair & Malhotra, 1961). The main perennial complex is mostly of the open type with sparsely distributed trees except for low-lying lands and depressions where it tends to form a closed type of community. Joshi (1958 *a*, *b*) and Joshi and Bansal (1968), have given the list of undershrubs, herbs, grasses and sedges as recorded from belt transect studies of barchanoid dune areas and other sand and dune regions.

The natural perennial complex inhabiting these areas with their main characteristic ecological features are enumerated below:

Acacia nilotica Delile. Prefers better moisture regime. Well suited for temporary marshes of dunes (inter-dune areas) in medium to heavy textured soils.

Anogeissus pendula Edgew. Prefers sandy loam to sandy clay loam soils with a greater percentage of clay. Good for temporary pond bank areas.

Balanites aegyptica (Linn.) Delile. Prefers loamy soil as well as sandy plains. Spreads aggressively by means of subterranean suckers.

Calligonum polygonides Linn. A good sand binder. Good for dune areas.

Calotropis procera R. Br. Prefers sand and dune areas but also found in hard flats and depressions.

Ephedra foliata Boiss. A good liana of dune areas.

Leptadenia pyrotechnica Decne. Good for dune regions.

Maytenus senegalensis Exell. Prefers semi-stabilized or hard ground areas.

Prosopis cineraria (L.) Druce. Prefers coarse textured soils. Good for sandy plain areas.

Saccharum bengalense Retz. Clumps spaced closely grow fast and stop surface creep of sand movement. Good for eroding habitats.

Salvadora oleoides Decne. Prefers sandy loam to sand clay loam. Grows in the form of jungles in certain spots of the area.

Securinega leucophloea Muell. Arg. Prefers loose as well as stable habitats of the area.

Tecomella undulata Seem. Prefers sandy plains and also hard ground area.

Ziziphus nummularia Wt. & Arn. Good for shelter belts.

Plantations in the area, especially in and around Institutions, Government offices, buildings and road sides have been going on for a considerable period of time now, and by and large moderate success has been attained with the care taken to protect the plants introduced with additions and modifications from time to time. *Azadirachta indica* has been a very successful introduction along road sides with *Melia, Dalbergia, Albizzia, Ailanthus, Tamarix* etc., which have all thrived well under protection. *Parkinsonia aculeata* is almost naturalized in the area, and shows good tree forms in certain areas. *Prosopis juliflora* now named as 'Devil's tree' thrives well and has also naturalized exceptionally well in many parts of Rajasthan, but is proving a nuisance by not permitting other vegetation to grow beneath and within its vicinity due to its growth-inhibiting properties (Lahiri & Gaur, 1969). In order to have some more information about this problem, a study was conducted from August to March 1972 at Pilani, and it has been estimated that out of the total 24 species recorded, *Prosopis juliflora* stabilized dune support fewer species as against more species in pure *Capparis decidua* and in mixed perennial complex of *Capparis, Maytenus*, etc., stabilized dune area. Further, the productive potential on dry matter basis also varied from 2.8 to 239.20 g/m^2 under *Prosopis juliflora* to 4.80-657.52 and 42.54-411.68 respectively under the successive types of stabilized dunes. The same order was found with regard to the belowground, litter and extra root values on dry weight basis. At the same time *Mimosa* and *Zizyphus* have grown well in the area.

For sand and dune areas, there are many plants which stabilize sand and dune in the area. These include: *Calligonum polygonoides, Capparis decidua, Calotropis procera, Leptadenia pyrotechnica, Lycium europaeum, Clerodendron phlomidis* and others. Many perennating forbs common to these areas are *Crotolaria burhia, Tephorsia hamiltonii, Boerhaavia diffusa, Convolvulus microphyllus, Indigofera enneaphylla, Farsetia jacquemontii, Citrullus colocynthis, Aerva javanica* and *A. pseudotomentosa.*

The most efficient grass is *Saccharum bengalense.* Other sand-binding grasses are *C. ciliaris, Desmostachya bipinnata, Panicum antidotale, Dactyloctenium sindicum, Brachiaria reptans, Aristida mutabilis, A. adscensionis* etc. Joshi and Sarma (1964), have also suggested certain grasses for the reclamation of these areas.

Among sedges, the most important ones are *Cyperus rotundus* and *C. arenarius*. Other species of *Cyperus* and *Kyllingia* are also seen inhabiting the dune areas, but their root systems are not vast enough to anchor the sand sufficiently.

In order to assess the productive potential at the herbaceous level, observations were recorded by harvest method for certain areas in and around Pilani. Kumar, Joshi and Nigam (1970), evaluated the production of grasses in relation to forbs and sedges for the rainy season of the year 1968 on two sites, and compared with an exclosure (control). These sites differed in their topographic features. The values for the above and underground biomass reach their peak in the month of September on sites I and II (144.30 and 176.80 g/m^2; 23.60 and 14.05 g/m^2 respectively), while in the exclosure the maximum herbage weights were found in October (148.96 and 131.60 g/m^2 respectively). The net community productivity was the minimum on site II (0.21 g/day/m^2) and maximum on site I (1.69 g/day/m^2).

For the year 1969 the productivity of three different habitats—Hard ground (Site I), Sandy plain (Site II) and Stabilized dunes (Site III) was measured. The peak standing crop of biomass was the maximum on site I (125 81 g/m^2) and minimum on site III (78.26 g/m^2). The values for aboveground net community production on sites I, II and III were 217.40, 104.88 and 97.19 g/m^2 respectively. The rate of production (g/day/m^2) works out to 1.59, 0.77 and 0.67 on sites I, II and III respectively. The net production value (g/m^2) of underground biomass was 61.4, 29. 1 and 13.65 on sites I, II and III while the rate of production (g/day/m^2) was 2.04, 0.64 and 0.30 respectively on the three sites. Recently, Kumar and Joshi (1972), have discussed the effects of grazing on the structure and productivity of the vegetation near Pilani.

Methods, Techniques and Requirements

Manifold methods and techniques of afforestation in the sand and dune regions have been tried and are in operation at many places. Skill, patience, labour and funds are indispensable prerequisites for such an undertaking.

The commonest method of checking the relentless march of sand and fighting the destructive power of wind seems to be wind breaks and shelter belts. These can be taken up only after finding out the altitude, velocity and direction of the prevailing wind. One of the means of the stabilization of these constantly and actively eroded areas can be best achieved by natural means rather than artificial ones. From an ecological viewpoint a study of succession in vegetation and soil is essential. Therefore, an ecological study should precede any introduction of a plant species in the area.

In order to establish wind breaks fast-growing species suited to the climate and soil of the habitat are essential. Once the sand is fixed, bushes, undershrubs, shrubs and tree species can follow. In such cases one must always be cautious about introducing new species as some of them grow extensively in their new biotope and eventually become a nuisance. *Prosopis juliflora* is proving to be one such introduced plant.

In order to achieve stabilization of sand and dune areas on a permanent basis two main points to be considered are:

(*a*) Development of an adequate cover in order to control the sand-shifting (surface creep). This will prevent sand-blowing, which is a source of dunes, and protect the soil from shifting, accumulations and removals of sand.

(*b*) Using indigenous species adapted to the existing conditions of the area. It is suggested that selected forbs, grasses and sedges could be tried for control of these mobile areas in two phases: (*i*) Initial sand stilling, and (*ii*) Permanent stabilization.

Out of the two phases the first one is more important and difficult too, because of actively moving sand with very low organic matter and low nutrient status. Further, scant precipitation also is of little help. Therefore, plants having ability to spread and increase in density under the conditions of accumulating poorly defined sand with low-fertility status and scarce moisture content could be used for the initial check.

Further, plants with means of vegetative propagation and the sedges may be the most practical ones for the initial phase on active dunes. When this is effectively achieved and sand movement is stopped to a considerable degree, permanent control of these areas can be accelerated by the invasion of native grasses and forbs.

Vegetation once installed not only prevents soil movement by reducing the velocity at the surface but also binds the soil with roots. However, areas with moving sand have not only their mechanical effects of wind but the physical characteristics of dunes in particular with regard to their height, shape and continuous relentless march of sand which makes it difficult for plants to get established and maintain themselves. An important aspect of such situations is the proper control of the 'critical area' in between and around the dunes which needs utmost care in planning the plantation. At the same time levelling of the crests of dune should go on side by side to prevent these dunes from building higher and higher. It has been observed that after the crest or steep leeward slope is destroyed, the dune has a flatter, more oval shape and does not present an obstruction for the wind. Deep 'listing' with which cloddy soil comes up and 'drag pole' methods can be employed to break the crests of dunes. Inter-dune 'lows' are important places for afforestation as the effects by dry desiccating winds are felt less on the leeward than on the windward side. Plants in this area and also around the dunes will also help to catch the sand on hard-eroded subsoil. Planting time of sand and dune areas depends on rainfall. It is, therefore, suggested that the planting be done in the last part of June for better growth and development in the succeeding rainy season months.

Shrubs when planted maintain an accumulation of growth which will give protection during dry years While the herbaceous species may produce only a small amount of cover, certain selected bushes may prove good.

Permanent stabilization of inland sand and dunes can be more adequately assured by using woody plants in combination with other herbaceous species. Woody plantings should be established only when the dune has been stilled. Initial stabilization of dunes by grasses and forbs is required prior to the planting of woody species.

In addition to the aforesaid, a proper land use is essential if these areas are to be kept under control, and not allowed to be a menace to the surrounding land. It is much easier to prevent sand dunes from developing than to control them after they have been formed.

The Shekhawati area has a dwindling asset of vegetation. Therefore, to restore the area, large-scale afforestation programme must be launched, based on a scientific appraisal of the complex requirements of the various species selected for trial

introduction. We, in India need about 2,000 crores of trees to restore hydrological and nutritional balance. However, there is no such data for our area.

Plants to be selected for the afforestation of the sand dune areas should be such as can well thrive in less water and high temperature conditions. The other point to be kept in view is that such plants should be chosen which are of some economic importance. Professor Toyama of Totteri University, Japan, was successful in producing plentiful diverse crops by sand stabilization (cit. from *Reader's Digest*, August 1970, pp. 101-104). He has proved that the so-called 'defects' of sand could be turned into advantages, and large scale sand-dune farming was economically feasible. In his own words, 'To farm the 2,000 million hectares of dry, barren land of the surface of our planet seems to be one way of solving the problem of feeding the world".

An attempt, therefore, could be made suggesting steps for undertaking the plantation of proper species based on the needs and utility for the people of the area. Plantations not only control erosion by violent winds but also improve humidity and produce wood for economy. Plants to be selected for these habitats should also be large and coarse perennials which could be exposed to the most severe action of the wind with deep-rooted system reaching the vicinity of the permanent water table. *Prosopis cineraria* is a typical plant of this category. Went (1953) has reported that *Prosopis* roots are extended up to 10–30 m to reach the water-table in Mojave and Colorado deserts. Other perennials of the area are *Capparis, Maytenus, Balanites, Salvadora* and others. The second type of plants could be the ones which have prostrate stems creeping over the surface of sand with deep anchoring root systems. Plants belonging to this category are: *Citrullus, Boerhaavia, Zaleya, Indigofera,* etc. The other forb perennials with their vast root systems may also help in stabilizing the dune areas such as *Tephrosia hamiltonii, Convolvulus microphyllus, Farsetia jacquemontii.*

Suitability of grasses has proved of most value in inland sand dune regions for effectively stabilizing them permanently. *Saccharum bengalense* is supposed to be the best check against erosion. Further, its palatability to livestock and wild animals is nil, and hence its insurance against grazing is assured. The other grasses which can be used for sand stabilization are: *Cenchrus ciliaris, Desmostachya bipinnata, Panicum antidotale, Dichanthium annulatum* and *Dactyloctenium sindicum.* For sand dune crests, *Clerodendron phlomidis* and *Lycium europaeum* may be very effectively used as barriers against sand encroachment. To combat wind erosion leaving of completely bare sand-soil is to be avoided. An effective device for doing this is to leave the stocks or stumps and residue of grain crops after harvest to cover and retain the soil clumps for controlling the tendency of sandy soils to blowing.

The idea is to test or determine the value of introduced plants in initial sand stilling and permanent stabilization in our area of inland dune system successfully. Some of the main points which need special mention in afforestation in these areas are as follows:

(1) *Capparis, Calligonum, Maytenus, Calotropis* along with *Leptadenia, Crotalaria, Tephrosia* and others provide a dense compact erosion-resisting cover when many of them are browsed by livestock.

(2) Permanent arboreal or arborescent plantings can be introduced as soon as initial planting for sand stilling becomes effective. Trees once established

do give protection to herbaceous planting, erosion control and also food and protection for wild life.

(3) Rodent and mice control is essential to the success of natural vegetation coming up, more so for small new plantings when introduced.

(4) It is essential for permanent control and also insuring against the hazards of over-grazing and destruction of vegetal cover by livestock etc., to select some such plants which possess characteristic aggressiveness to develop, longevity, and are not palatable. Plants unpalatable to goats may be introduced.

The Birla Education Trust at Pilani has attempted afforestation in and around neighbouring areas during the past thirty years with good results. To start with there was bare sand with its unproductive and sterile characteristic which was damaging whatever little covered areas of cropland and pastures existed. Today the green area with plantations can in no way be compared to what it was 25 years ago. Out of the two dozen important species introduced in the area *Melia, Eucalyptus, Dalbergia, Albizzia, Ailanthus, Tamarix, Acacia, Parkinsonia, Bauhinia, Jacaranda, Delonix, Erythrina, Pongamia, Cassia, Kijelia, Moringa, Cordia,* etc., have all grown well and show luxuriant growth. On an average 200–350 tree saplings plantations have been done in and around Pilani during the last several years. With this there is a hope that the menace of sand creep and march of desert may probably be tackled to a very great extent in the near future. The experiment launched in the area may thus be an answer to the immobilization of the mobile sand in the region.

While *Azadirachta, Melia, Dalbergia, Albizzia, Parkinsonia, Moringa, Ailanthus, Tamarix, Eucalyptus, Prosopis juliflora* and many others have thrived well, the performance of *Saccharum bengalense* in sand and dune areas and *Parkinsonia aculeata* in the Vidya Vihar area have been exceptionally good. *Prosopis juliflora* as elsewhere has grown to huge heights and girths.

However, all these trees when grown in the open and without protection have mostly failed as they have little chance of survival. It is a common sight to see huge chunks of roots exposed to a height/depth of even one metre in areas of active sand movement. When the sand scours, roots are exposed to the air and subjected to sand blasting. Though *Saccharum* has been an excellent effective stabilizer of mobile sand and dune areas, it harbours rodents and mice population in abundance. These are a source of nuisance as they damage the crops in the adjoining areas. Their protection under *Saccharum* (because of its habit) is assured against the top carnivores hence their population goes on increasing. Apart from the enormous number of active, dormant and intermittently active and dormant holes per sq. km, it has been estimated in our field studies that these are capable of excavating more than 60,000 kg of soil per day per sq. km from their burrows in typical summer months of May and June. This excavated soil adds to the already loose sand in dune areas for erosion and movement. An interesting relationship between sand dune development and grazing patterns has, however, been noted in many areas of Shekhawati.

Discussion

The occurrence of a number of species in spite of the extreme ecologic conditions prevailing in Shekhawati is noteworthy. Pastures in the area are mostly composed of

perennials, annuals and low productive perennial grasses which according to Chakravarty (1968), have been estimated as 200–500 kg/hectare. However, the tract has many high-yielding and nutritive indigenous species, forbs and grasses viz., *Prosopis*, *Zizyphus*, *Trianthema* spp., *Tribulus* sp. and many grasses, which if encouraged are expected to play a very significant role in renovating the natural pasture lands for maximum production. For Pilani area in Shekhawati, the annual net productivity (including both top and below-ground growth) values ranges from a maximum of 4763 kg/ha to a minimum of 2114 kg/ha. These values are also quite low. Based on such data on vegetation and its other aspects, an afforestation programme in the area has been envisaged. Plant communities showing degradational variants in Shekhawati have been influenced primarily by the type of habitat, and secondly by the intensity of biotic factors.

There is no doubt that intensification of planting programmes would undoubtedly help achieving success with an increasing productivity of the arid habitats. The question is then of the suitability and adaptability of exotic species which are selected for trials. It should be kept in view that reactions of vegetation on the soil factor are in general more profound than the atmospheric ones, and hence are of particular importance for natural reproduction.

One of the solutions for desert conditions, which are becoming more and more intensified, lies in the protection of the existing vegetation and in planting of some new suitable cover. It is visualized that only a scrub climax can survive due to the various factors operating in the area. A perennial complex possessing characteristics of fast growth, low water requirements, resistance to drought and frost, vegetative propagation by suckers, tolerance to saline and alkaline soils, good coppicers and pollarders, with deep rooting system can easily form a climax community in the area. Therefore, the need of the hour is to guide the movement of plantations to yield positive results and to achieve the object of afforestation i.e. conservation and utilisation of the sandy wastes.

In sand and dune regions the wind, specially when humidity is low, affects the vegetation adversely. Sand binders to immobilize shifting sand and dunes, shelter belts to control wind erosion thereby increasing availability of water indirectly and affording protection and avoiding desiccation, protection of shifting (mobile) sand and dune against biotic interference, creating micro wind breaks on the windward side, and 'lows' are some of the programmes which should be launched to rehabilitate these habitats.

The physical and chemical characteristics and properties of mature, immature and skeletal soils mainly depend on the nature of the parent rock. This is important from the biological standpoint too. Skeletal soils are formed where wind scouring is continuous. Young and immature soils are found in this zone. Therefore, all young soils, skeletal soils, eroded soils, newly deposited soils, immature soils of colluvial origin, are all closely dependent on geomorphological features of the area. The sand and dune soils are mostly of a sandy or sandy loam texture, for physical weathering plays an important part in their formation while their chemical nature is limited by the shortness of the period in which they remain moist during the rainy season after summer. Consequently the biological activity is there only for a limited time of the year.

Joshi (1958 *a*, *b*), Kumar *et al.* (1970) and Kumar and Joshi (1972), have pointed out the oft-repeated practice of sweeping of stabilized dunes resulting in the removal of detritus. It creates a problem of soil development in these habitats where the soil

horizons are either hardened or get very much compact. A characteristic of many such dry lands is the accumulation of salts like Na, Ca, Mg and bicarbonates at or near the surface horizons. These salts reach half way in the soil due to excess of evapotranspiration over precipitation, resulting in their getting precipitated in the upper horizon. This accumulation reach toxic limits and help in the process of calcification which has turned these areas in Rajasthan into 'bad lands'. Details defining what subtances are responsible for this hardening, cementing or compacting are lacking. Further we have to distinguish the effects of processes in the formation of these crusts—the accumulation of the calcareous elements by leaching of surface horizons which is a pedological process and consolidates the calcareous horizons. Information about these calcareous crusts and the role of the vegetation in the process is important before any steps are taken to improve them. Such areas do point out that all desert soils are not of great potentiality.

The extreme nature of biota, climate and soil keep the area physically and biologically unproductive for most part of the year. To combat this, development of existing species of nitrogenous fixing leguminous plants might yield good results.

Soil conservation involves initially the maintenance of fertility which could be achieved by not permitting grazing in these areas until these are properly organized and the plant coverage is thick and strong enough. This will also break the force of wind, prevent erosion and afford soil protection too.

In the sand dune region proper spacing of sand stilling plants is to be kept in mind. Further the character of a successful plant covering is determined by the rate of sand movement it permits, as well as the scour or deposition it manages. At the same time the amount of sand accumulation around a plant is not a true index of the sand stilling qualities although it does give a good measure of its hardiness under severe conditions. Therefore, for that matter many herbaceous species could as well be successful for an initial as well as permanent control of loose sandy areas. Adapted woody species however, may be planted a few years subsequent to the stabilisation of the area to obtain a more permanent type of vegetation. This will give the area anarboreal or arborescent character.

One of the primary functions of the soil is to produce new wealth. This is more so for sand and dune regions which are the concern of people for developing new resources from these areas. Therefore, measurement of soil resources and plant nutrient status is essential before venturing on a large scale afforestation programme. Here is a case of rebuilding resources in depleted areas.

Different methods are followed in different parts to plan the operation of afforestation. Fencing of areas for protection against grazing, wind breaks, shelter belts etc. are some of the methods commonly employed.

In Shekhawati indigenous perennials like *Prosopis, Salvadora, Maytenus, Tecomella, Acacia, Anogeissus* etc., attain great age but grow relatively very slow. These also possess woody trunks and branches. Areas, where use of crop residues is practised, often yield good crops in the succeeding year.

There are some basic questions for shelter belts and wind breaks which pose problems like:

(1) What to plant, when to plant, where to plant and how to plant?

(2) How to control grazing and over-grazing and how to adjust the livestock to the area?

An answer to the above and other basic questions is to be given to the common man of the area to make the programme successful. Further, it has been found that shelter belts do stop march of sand upto 10–15 times the height of the tree planted for the purpose after which it again starts forming sandy habitats (Fig. 4). The meanings to the most commonly practised methods of shelter belts or wind breaks, are yet to be sought in the light of the problem of reformation of dunes as shown in Fig. 4.

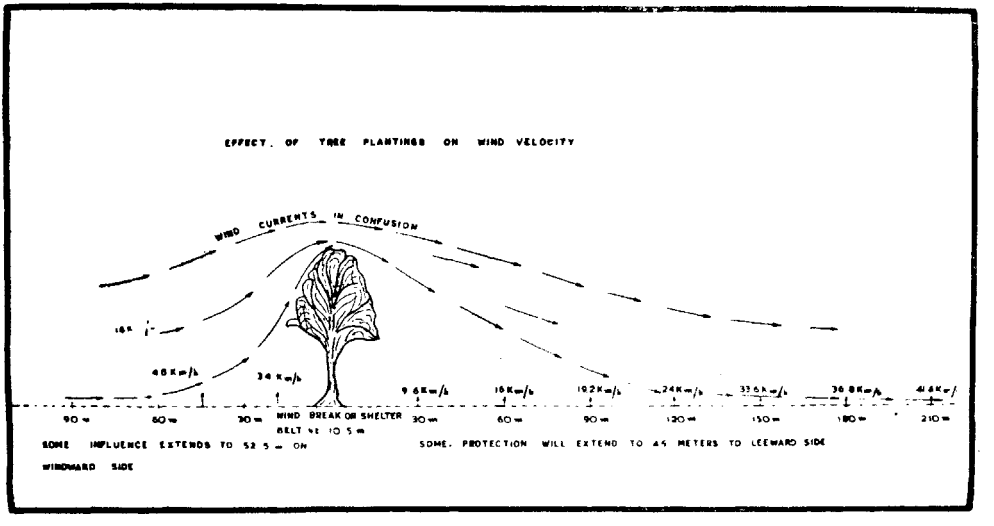

Fig. 4 Showing effect of tree plantings on wind velocity. Some protection will extend to 40 metres or so on the leaward side. (Based on data from the U.S. Forest service).

Planning and implementation of afforestation consists in a combination of practices specially designed to fit the different kinds of ecosystems. Basic and fundamental research therefore, is needed so that the findings may be put to practice. However, introduction of 'wolf trees' like *Prosopis juliflora,* which occupy more space than its value, curtailing better neighbours warrant an early replacement with a better and suitable one.

Thus, no perfect method of complete control is known at present, and no single method can be relied upon. A combination of several methods may be most effective and reliable to combat the erosion evil by afforestation schemes. At the same time, a new approach to training is necessary to tackle this trickly problem of afforestation in the area.

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