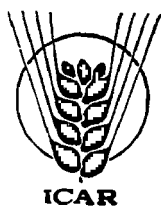


DESERT ECO-SYSTEM AND ITS IMPROVEMENT

Edited by
H. S. MANN



CENTRAL ARID ZONE RESEARCH INSTITUTE, JODHPUR

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P R E F A C E

The Indian Council of Agricultural Research, New Delhi, organised an All India Summer Institute on Desert Eco-system and its Improvement at the Central Arid Zone Research Institute, Jodhpur in October, 1974. The major objectives of the Summer Institute were (a) to impart training to the participants from various Universities, State Agricultural Departments and Research Institutions in the arid zone in various research methodologies, (b) to make them understand the peculiarities of the desert eco-system and the special problems in the planning for its improvement and (c) to acquaint them with the scientific achievements of the Central Arid Zone Research Institute, Jodhpur in different disciplines. Thirty one participants from different regions of the country and disciplines took part in the programme consisting of lectures on different aspects of eco-system and practicals by the staff members of the Institute and special lectures by Guest Speakers. The revised and edited lecture notes have been printed in this monograph.

In organizing the Summer Institute and in bringing out this monograph I have been assisted by a number of scientists and other staff members of the Central Arid Zone Research Institute and I express my gratitude to them.

H. S. MANN

Director

Summer Institute on Desert
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DESERT ECO-SYSTEM AND ITS IMPROVEMENT

H. S. Mann*

INTRODUCTION

The Indian or the Thar desert is spread over four Indian States and in Pakistan. It is vast undulating plain of sand interspersed by hillocks. The Indian desert has been subjected to marine transgressions during the past and now it presents interesting geomorphic formations. In the recent past this desert has sustained well developed civilisations particularly in the Ghaggar and Indus river basins. In spite of the fact that it suffers from paucity of water, erratic rainfall, extremes of temperatures, and is probably the least productive land in the Indian sub-continent, yet it is the most thickly populated desert of the world and has an average density of 46 persons per km. as against 3 in most of the other desertic tracts. Moreover, the growth rate of the human population during the period 1901-1971 has been 158 per cent as compared to 125 per cent in the adjoining area. It also nurtures, in the desert districts of Rajasthan, an enormous population of livestock—13 million; the growth rate of which is also rather alarming. Besides, the desert endures a severe pressure of the wild ungulates and rodents, the density of which is fairly high.

The mean annual rainfall of the region varies from 150 to 500 mm with a coefficient of variation as high as 60-70 per cent. The distribution of rainfall is erratic, occurring mostly in the period, July-September and droughts are quite frequent. The highest summer temperatures range from 44° to 50°C and the winter temperature sometimes drops to—5°C. In spite of the adverse prevailing environment, the desert maintains a highly productive flora (over 530 species) which is well adapted to the xeric condition. Vast natural grasslands of *Lasiurus sindicus* and *Cenchrus* spp. are characteristics of the Indian desert. However, due to over-grazing by livestock and due to the activities of the rodent pests, the pastures and browse shrubs have reached a stage of severe degradation in as much as the plant density has dropped from 112-415/ha. to 6-18/ha. The frequency of perennial, nutritive grasses has drastically dropped and annuals which are inedible/ unpalatable have more or less completely colonised the arid tract,

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severely decreasing its biomass production. Soils have also simultaneously degraded and at certain localities the salinity and alkalinity problems have been aggravated. To cope up the increasing human pressure, the marginal lands are put to cultivation which further the deterioration of the fertility of the land. The major problems of the Indian desert are the shifting of sand dunes, dust storms in summer months, selection of exotic plants for stabilising them, to make inventory and augment the natural resources, to maximise crops having low water requirement, optimum management of rangelands, livestock, and pests; nomads and their sedentarisation.

In its fundamental aspects, the eco-system involves the circulation, transformation and accumulation of energy and matter, through the medium of living things and their activities.

The eco-system is considered to be the basic functional unit in the ecology, as it includes both the organism and non-living environment, each influencing the properties of others and both necessary for maintenance of life. Any area of nature that includes living organisms and non-living substances interacting to produce an exchange of materials between the living and non-living parts as an ecological system or eco-system.

Improvement requires management. Management means to deal tactfully with, to train by exercise, to handle to control etc. Management of the desert eco-system implies control or to manage the area by the use of scientific technology to reclaim, improve and maintain a higher level of productivity.

Natural Resource Surveys

As is evident from the rates of growth of human and livestock populations, the resource—stricken arid land in India is in fact supporting life beyond its carrying capacity. To check the over-exploitation, it is essential to prepare the inventory of the natural resources of the arid and semi-arid lands. With this in view, integrated surveys have been completed for 45,267 km² in Rajasthan, Haryana and Gujarat States. These surveys provide comprehensive information with regard to, a) land use capability classes based on land use data, erosion hazards, both wind and water, types and intensity of sand dunes, soil texture and fertility; b) vegetation types, pastures; c) water resource, both surface and ground water, water quality (salinity), water potential zones; d) socio-economic condition of the desert dwellers, an human-animal-vegetation relationship etc. The integrated surveys, based on aerial photos, lead to the assessment of basic resources of each bio-physical unit to upgrade production and suggest rational appreciacy for development of its natural resources.

Aerial photo interpretation has helped to delineate numerous well integrated buried channels which still receive water from their catchments and all the percolated rain water flows sub-terraneously through these channels. They are, therefore, the perennial source of potable water. Incidentally all the irrigation dugwells are situated along these prior channels. But at their confluence in the lower reaches, there is invariably a concentration of sodium chloride. At some places this salt has come up on the surface resulting into the formation of salt basins like Pachhbhadra and Didwana. At some places, however, the salting occurs at deeper zones which may come up on the surface if irrigation is not properly regulated. It has also been found that gypsum (Calcium sulphate) is found in the upper reaches of the buried channels.

Agro-climate and solar energy utilization

The Division of Wind Power and Solar Energy Utilization had delineated the arid and semi-arid zones. The country has been divided into 64 homogenous soil climatic zones on the basis of moisture regime, thermal index and important soil types. A method has also been evolved for the prediction of soil moisture under natural vegetation without actual measurement.

Using the climatic water budgeting approach, the critical dates of commencement and the duration of crop growing season with no water stress and with moisture stress of different intensities have been determined and maps of India showing these parameters drawn.

The estimates of solar energy available on an inclined surface for utilisation in various solar devices in respect of different stations in the country has been worked out.

A built-in-storage type solar water heater has been developed and installed in the Institute. This heater provides 90 litres of hot water per day at Jodhpur in winter. Its temperature varies between 50°C and 55°C.

Sand dune fixation

Extensive and intensive plant studies have shown that the movement of soil by the process of wind erosion, which is causing considerable loss in soil fertility in the desert areas, can be checked by planting wind breaks, creating shelter belts, resorting to strip cropping and covering and stabilising sandy tracts and dunes with adapted grasses and shrubs like *Lasiurus indicus*, *Zizyphus nummularia* and *Crotalaria burhia*. The technology of sand dune stabilization constitutes

efficient land management practices like fencing, mulching, planting of photo-insensitive and aridity resistant and yet remunerative tree material like castor, *Acacias* etc. The shelter belts could be made across the wind direction on farm to farm basis, constituting species like *Acacia tortilis*, *Acacia nilotica*, *Dalbergia sisso*, *Morus alba*, *Albizia lebbek*, *Ricinus communis* and *Calligonum polygonoides*. Exotic species of *E. camaldulensis* and *Acacia tortilis* have proved very successful for hot Indian arid zone.

Small micro-wind breaks in parallel strips in chess board design may be erected across the wind direction with easily available local shrubs and grass material. These should be sown on the leeward side a little away from the fence. Plants are grown in planting bricks deep in between the furrows so as to protect the plant from the abrasive action of the blowing sand and to place their system in moist sand layer. Apart from general need to stabilize sand dunes in desert areas it is urgently needed to do so in the Rajasthan Canal Command area to control wind erosion. Techniques have also been evolved for afforestation of rocky, and semi-rocky areas.

Soil-Water-Plant Relationship

The studies on Soil-water-plant Relationship and the All India Coordinated Research Project on Dry Farming stationed at Jodhpur are conducted for developing improved methods of farming to reduce instability in agricultural production of this region. These methods include strip cropping and stubble mulching which act as wind erosion control and reduce wind velocity and soil losses; selection of crops and varieties like Bajra HB3, Palsana guar, Aruna and Gujarat HB3 of castor, Sojat Bhavani of forage sorghum, AK 12-24 of Groundnut, Moong S-8 and S-12, Sunflower EC69874 and EC68414, Sarson Harayana No. 1, rate, source, time, mode and method of application; planting pattern for efficient use of water; sprinkled irrigation advantageous over check basin; drip irrigation; quantification of soil-water-plant relationship for efficient water use; and improved cultural practices.

Socio-economic surveys

The socio-economic surveys conducted in collaboration with Division of Basic Resource Surveys provide comprehensive information on population characteristics, social and economic correlations of various caste groups, household structure, rural working force, class of farmers and holding size, animal-vegetation-human relationships, form of settlement etc. Methods to utilise these resources rationally to upgrade production have been indicated in these reports.

The rupture of relationship of mutual dependence between the nomads and the sedentary population has given rise to a host of problems including loss of resources of sedentary population and total collapse of economy of nomads. Welfare schemes executed by the State Government to stabilise nomadic population, which would in turn, improve the deteriorating resource structure of sedentary population met with limited success so far. Studies in the problems faced and caused by nomads in arid zone were therefore undertaken to suggest suitable measures for the welfare of nomadic and sedentary population. The study revealed that nomads of arid zone could be grouped in four categories, viz., Pastoral, Trading, Artisan and Miscellaneous. Detailed rehabilitation schemes for Gadoliya Lohars (artisans), Banjara (trading) and nomadic cattle breeders of Anupgarh-Pugal region have been prepared, keeping in view their kinship structure, cultural values and economic conditions. The Institute has recently adopted one village namely—Daijar, Panchayat Samiti Mandore, for demonstrating the various recommendations of the Institute at Farmer's fields. During the last year the extension activities carried out include (i) introduction and demonstration cum field trials of different crops like Bajra HB3, Maize Ganga 5, Wheat Moti, Potato Kufri Chandramukhi, castor aruna; (ii) fertilizer application for these crops, (iii) introduction of improved varieties of vegetable like tomato pusa Ruby; (iv) plantation of trees and shelter belts; (v) introduction of grasses like Sewan and Dhaman; and (vi) organising stabilisation; Afforestation and shelter belts; Pasture grasses and forage development, demonstrations of effective control of rodents; and programme of techniracy have been planned and initiated.

Range Management

The rangelands of the Indian arid zone support palatable, adapted and productive grasses and shrubs for top feed. Unfortunately, however, mainly due to over-exploitation, over-grazing and poor management, the grasslands are deteriorated to a great extent. Intensive research work on the various aspects of range management and livestock production has been in progress for the last 20 years. The perennial grasses, *Cenchrus ciliaris*, *C. setigerus*, *Lasiurus indicus* in the north-western desert, and *Dichanthium annulatum*, *Setaria nervosum* and *Chrysopogon fulvus* in the southern region are directly sown into the fields after a complete soil working and grubbing out of the weeds and annuals in lines of 50-75 cm. apart at a depth of 1-2 cm. Planting of 2-3 seedling per hill followed by one weeding gave 60 per cent establishment of a pasture. Fertilisation with 22.5 kg/N/ha further increases the forage yield by 15 to 69 per cent. The average seed rate recommended is 2 kg.

per hectare for *D. annulatum* and *Panicum antidotale*, 2 to 3 kg/ha for *C. ciliaris* and *C. setigerus* and 5 kg/ha for *L. indicus*.

Inter-cropping of the grasses with legume (*Phaseolus acontifolius* and *P. radiatus*) gave 20 to 30 per cent increase in the forage production as compared to pure culture of grasses.

The livestock production in relation to improved grasslands indicate a high level of production as the body weights gains of yearling heifers range from 92 to 1964 kg. per year per 100 hectares in different pasture types. Likewise gain in the body weight of ram lambs is also superior to those grazing on depleted natural ranges.

Attempts have also been made to develop a biochemical approach to sheep production to obviate the delay inherent in the time-consuming conventional method of selection based on performance tests. Three polymorphic traits have been determined in the blood of six breeds of sheep: blood potassium type (high and low), haemoglobin (Hb A, B, Hb AB) and erythrocyte reduced glutathione type (high or low).

CROP PRODUCTION

(a) Dry Farming:

Important crops of area are Millets (Bajra) and legume like *moong*. Adapted varieties of these crops have been developed and agronomic practices including water-harvesting, mulching, fertiliser use, alternative crop choice (mid-season corrections) have been developed. New crops like Sunflower and Castor have been found better under late sown conditions.

(b) Irrigation:

Techniques such as sprinkler and drip irrigation have been recommended for optimum use efficiency. With drip irrigation use of saline water is possible.

SOLAR ENERGY UTILIZATION TO CHECK THE DEFORESTATION

The fuel requirement of the relatively dense population of the Indian Arid Zone is usually met with from the locally available brushwood and trees. This is a severe drain on the natural vegetation resources. Majority of fuel wood comes from *Prosopis cineraria*, *Acacia jaquemontii* and *Prosopis juliflora* and deep into the desert from the superior-most sand-binding of *Albizzia lebbek* and *Azadirachta indica* and shelter belts are also not spared by the local populations. A low cost solar water heater and solar oven have been developed; and if these

are widely used the shrubs and trees could be spared to some extent and the process of desertification could be partly checked.

Rodent Pest Management

In the field of rodent pest control one of the effective formulations for their control has been established as follows: Zinc phosphide 2%, wheat or bajra 95% and groundnut oil 3%. It has been further demonstrated that after an initial period of prebaiting the best results in terms of actual kill are obtained when poison—baiting is restricted to one day only otherwise the animals are likely to develop bait shyness. A cheap one-shot baiting technique using berries of *Zizyphus nummularia* has also been standardised for controlling the rodents effectively.

Only a few aspects of problems of the desert and technology to improve its conditions have been dealt with but fairly detailed information on a wide variety of fields is available as a result of continuing work of C.A.Z.R.I. and other organisations. I am sure the participants of this Summer Institute will thoroughly probe into these problems and will involve themselves, on their return, to such work which will result into concrete recommendations for developing the desert eco-system.

CLIMATE

A. Krishnan*

INTRODUCTION

Arid zones are characterised by sparse and highly variable precipitation and high evaporation. Drought due to lack of moisture is the characteristic of aridity. These zones are sharply delineated by the vegetation consisting of plants which are either xerophytes or short lived annuals. Vegetation is sparse since water available is limited. Great adjustments are made by the plants to enable them to grow in this zone. Drought escaping plants grow only when there is no drought. Drought evading plants are economical in use of limited water supply. The plants here have high degree of drought resistance. The crop or pasture production in this zone should therefore aim at the most efficient use of available water and require detailed study of plant-climate relationships so that the best suitable crop or pasture species may be grown in the available growing period.

All these problems require the fundamental climatic element of evapotranspiration. Unfortunately, prediction or measurement of this element has proved to be difficult. This is so because it depends on the physical properties of soil and physiology of plant cover. A simplifying assumption is, therefore, made by the scientific workers in the field by defining potential evapotranspiration in which major soil and vegetation influences are removed by assuming an uninterrupted water supply. Thornthwaite (1948) made a significant contribution by evolving the potential evapotranspiration concept and defining a quantitative measure for it. Thus the computation of monthly potential evapotranspiration which gives the monthly water needs of a place and water deficiency which represents the amount by which the precipitation fails to meet the demands of potential evapotranspiration (PE) after the soil moisture has been used up, would help in quantitatively determining the aridity of a place.

Thornthwaites' criterion for delimitation of arid zone

Thornthwaites' method gives the following formula for monthly P.E. values:

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$$P.E. = 1.6 \left(\frac{10t}{I} \right) \cdot \times L$$

where, t is monthly temperature ($^{\circ}\text{C}$),

I is the heat index which is a constant for a given location and is obtained by adding 12 monthly " i " values which are functions of mean temperature.

a is a cubic function of I and

L is an adjustment for the number of hours of day light and days in the month.

Thornthwaite evolved a simple book keeping procedure for determining water deficiency and water surplus. When precipitation (P) is greater than PE , the actual evapotranspiration (AE) equals PE . When P is less than PE , AE equals P and any moisture stored in the ground available for evapotranspiration (storage change).

Moisture deficit (D) is taken as the difference between PE and AE of the month. If fact the ratio $\frac{AE}{PE}$ is taken as equal to the ratio of actual soil moisture storage to the water holding capacity of the soil (Thornthwaite and Mather, 1955).

Moisture surplus (S) is taken as the excess of P over PE when the soils are at field capacity. Annual values of these parameters can be obtained by adding individual monthly values. Thornthwaites' moisture index is given by $M.I. = \frac{100S - 60D}{n}$ where S is the mean annual surplus, D is the mean annual deficiency and n is the mean annual water need ($P.E.$)

If this moisture index is between -40 and -60, the climate is arid, and if it lies between -20 and -40, it is semi-arid and so on.

Other methods for delimitation of arid zone

There are also other international methods for defining the limit of the desert. Some of the important ones are as follows :-

(1) Koppen's method

Koppen (1923) set out the following limits for boundaries between the desert and steppe and dry and tree climates for regions having rainfall maximum in summer which is generally the case in the Indian arid zone.

Boundary between dry
and tree climate

$$r = 0.44t - 3$$

Boundary between
steppe and desert

$$r = \frac{0.44t - 3}{2}$$

where t and r are mean annual temperature ($^{\circ}\text{F}$) and mean annual rainfall (inches) respectively.

(2) *De Martonne's method*

Demartonne (1928) defined the following index (I) to delimit different vegetational zones.

$$I = \frac{\text{Annual precipitation (mm)}}{\text{Mean annual temperature (}^{\circ}\text{C)} + 10}$$

According to him indices below 5 characterize true desert from botanical as well as hydrographical point of view. Indices above 10 correspond to dry steppe, 20-30 correspond to Prairies and above 30 correspond to forest vegetation.

(3) *Gausse's method*

This method involves use of ombrothermic diagrams and Xerothermic indices (i.e. indices of hot weather or drought). The essential factors taken into account in this climatic classification are temperature, precipitation, number of days of rain, atmospheric humidity, mist and dew. If Xerothermic index exceeds 300, the climate is desert. If it is in the range 200-300 it is hot sub desert. The sub desert is further subdivided into accentuated (250-300) and attenuated (200-250).

An evaluation as to how far different standard climatic classification methods reflect the actual vegetation pattern of Rajasthan was made by Krishnan and Shanker Narayan (1964). This study indicated that the quantitative limits set out by Thornthwaite's moisture indices prove a useful criterion for delimitation of arid zones.

Based on Thornthwaite's classification, Meigs estimated areas of extremely arid, arid and semi-arid zones in the world as follows :

Semi-arid	8,202,000 sq. miles	(21,243,100 sq. km)
Arid	8,418,000 sq. miles	(21,802,540 sq. km)
Extremely arid	2,244,000 sq. miles	(58,11940 sq. km)
Total	18,864,000 sq. miles	(48,857,580 sq. km)

All these three zones together constitute 36 per cent of the total land area of the world, the individual values being extremely arid 4 per cent, arid 16 per cent and semi-arid 16 per cent.

Delimitation of Indian arid zone

Pramanik, Hariharan and Ghose (1952) classified various places in and around Rajasthan into arid and semi-arid zones by drawing a curve

of Koppen's classification and isopleths of Demartonne's indices of aridity.

Climatic classifications of India as a whole or some regions have also been attempted by Subramanyam (1956, 1965), Bhatia (1957), Carter (1954) and Shanbhag (1956) etc. But these studies were all based on the data of only meteorological observatory stations for which long period normals were available. Since the net work of such stations is not dense enough for carrying out detailed delineation of the arid areas in the country, not only normals of meteorological observatories but also long term normals of monthly rainfall of provincial raingauge stations have been utilised in this study. Such rain gauge stations are considerably more in number and cover each district in the State adequately. Thornthwaite's moisture indices were worked out for each of these raingauge stations and observatories and areas with moisture indices value less than or equal to -40 were delineated as arid zone (Thornthwaite, 1948). The State-wise areas of arid zone as well as their percentage coverage in the total area under arid zone in the country including the special case of cold arid zone in Ladakh district of Jammu and Kashmir State have been presented in Table 1.

Table 1: State-wise areas of arid zone in India

State	Area under arid zone (sq.km.)	Percentage area in each State out of total arid zone in India	Remarks
Jammu & Kashmir	70300	—	Cold desert
Rajasthan	196150	61	Hot desert
Gujarat	62180	20	"
Punjab	14510	5	"
Haryana	12840	4	"
Maharashtra	1290	0.4	"
Karnataka	8570	3	"
Andhra Pradesh	21550	7	"
Total area of arid zone excluding cold desert	317090		

West Rajasthan is the principal arid zone in the country constituting 61 per cent of it. Next to Rajasthan, Gujarat has the largest area under arid zone. The detailed descriptions of each of these regions are given below State-wise.

Rajasthan

Information on the district-wise areas of arid zone in Rajasthan has already been presented by Krishnan (1968). The boundary between arid

and semi-arid zone in Rajasthan intersects, Jalor and Pali districts, goes roughly along the boundaries of Ajmer and Nagour and then intersects Sikar and Jhunjhunu districts. This line passes through the towns of Bhinmal, Sojat, Beawar, Mawa, Sri Madhopur and then between Chirawa and Khetri in Jhunjhunu district. The districts in Rajasthan lying wholly in arid zone are Ganganagar, Bikaner, Jaisalmer, Barmer, Jodhpur and Churu. The districts lying partly in arid zone and partly in semi-arid zone are as follows: The actual percentage of area which falls in arid zone has been included in brackets. Nagour (96), Jalor (88), Jhunjhunu (69), Sikar (65), Pali (48) and Ajmer (9).

Punjab-Haryana

To the north of Rajasthan the demarcation line of arid zone intersects Mahendragarh and Hissar districts of Haryana and Sangrur, Bhatinda and Ferozepur districts of Punjab. The percentage of arid zone in the above mentioned districts are as follows: Ferozepur (77), Bhatinda (88), Sangrur (89), Hissar (90) and Mahendragarh (90).

Gujarat

To the south of Rajasthan the boundary of arid zone passes through the following districts enclosing arid areas expressed as percentage in brackets. Banaskantha (18), Mehsana (7), Ahmedabad (6), Surendranagar (29), Rajkot (6), Jamnagar (80), and Junagadh (20). The only district in Gujarat which is completely included in arid zone is Kutch. Apart from this major arid region constituting 91 per cent of total arid zone in India and covering north west Gujarat, West Rajasthan and South West Punjab and Haryana there is also a smaller patch of arid zone (30120 sq. km) in the south covering portions of Rayalaseema and Bellary regions of Andhra Pradesh and Karnataka States respectively. Since data of nearly 100 stations in and around the arid zone in Andhra Pradesh were utilised, it has been possible to demarcate the boundary of this southern arid zone in detail (Krishnan, 1966). In Karnataka, eastern portions of Bellary district, western portions of Raichur district and very small portions of Dharwar and Chitradurg districts fall in arid zone while in Andhra Pradesh north and central Anantapur district, Central portions of Kurnool district and north, west Cudappah district constitute arid zone. The percentage area coverage in each district is indicated below: Anantapur (67), Kurnool (31), Cudappah (9), Raichur (39), Bellary (25), Chitradurg (4) and Dharwar (1).

In Maharashtra State also there are two very small pockets of arid zone, one in West Sholapur district and another covering Sakri in Dhulia district and Satana in Nasik district. But they are extremely small and together cover only about 1280 sq. km (Krishnan, 1966).

Cold arid zone. of Jammu and Kashmir

The only cold arid zone of the country lies in the northern extreme portions of Jammu and Kashmir State. It occupies 72 per cent of Ladakh district except for its south west portion. The climatic conditions over this arid zone located at very high altitude (8000'—14000') is entirely different from the other arid areas described above which come under the category of hot deserts. Hence the area of this arid zone has not been included for working out percentages of the other regions. This cold arid zone can be considered as a continuation of the cold deserts of Ghotan and Kashgar of China.

Thus the main arid zone of the country lies in the north west India with a definite eastern boundry.

Peculiarities of Indian desert

The heart of the tropical desert in the northern hemisphere is contained in the latitude belt 20-30° north. They fairly coincide with the region of dry subsiding air masses of sub-tropical anticyclones. Since they are regions of stable and diverging air masses, conditions are unfavourable for the development of convectional showers in spite of intense heat. Since these regions are generally affected neither by the middle latitude fronts and cyclones nor by the advancing 'lows' from the Intertropical convergence zone from the low latitudes, they form the main desert regions in the northern hemisphere.

However, in the Indian sub-continent, this latitude belt 20°—30°N does not have arid climate throughout. There is a definite eastern boundary of the desert which does not go beyond the longitude 76°E. Apart from that, there is a striking contrast in the north eastern and north western portions of India. The former happens to be the wettest region in the entire world while the latter is a desert in spite of the fact that both have similar position at the northern end of tropical seas and are invaded by surface equatorial maritime air mass during summer which appear to be boxed in by high lands in the north in both the cases. In summer, both are regions of low pressure and location of inter-tropical convergence zone. The north west area is not only the zone of lowest pressure in summer but also a region traversed by moving depressions during winter known as western disturbances. Further, it is the region of highest temperature during spring and summer which should help convectional over turning of the air. Thus according to Trewartha (1962) occurrence of desert in the north west India appear to present a big climatological problem. In order to examine this aspect critically it is necessary to analyse the entire moisture detention pattern in this latitude belt 20-30°N critically. In a paper on water balance of earth van Hylckama (1956) presented a

table showing total moisture detention on or within the land area in units of 10^{16} cu.cm. In determining the total moisture detention for a 10° latitude and longitude quadrant climatic data of all stations in each $1^\circ \times 1^\circ$ quadrant were examined by him and the actual value of detention was determined from a balance between the climatically determined evapotranspiration, runoff and precipitation. The values determined by him for the latitude belt 20° to 30° N in respect of the longitude regions 20° W to 130° E and 70° W to 180° W representing the main land regions of the eastern and western hemispheres respectively of the globe is presented in Table 2 for each month of the year.

Table 2 indicates clearly extremely poor moisture detention in the soil in the longitude belt 20° W to 70° E revealing the distribution of widespread desertic conditions. There is a sharp increase from 70° E longitude onwards more so from 80° E longitude. The highest moisture detention for any $10^\circ \times 10^\circ$ quadrant in the earth also occur in this latitude belt for the longitude range from 80° to 90° . The highest surpluses in these regions occur in July. The moisture detention values are uniformly high in the longitudinal range 80° — 120° E.

Thus the comparatively little coverage of arid zone in the belt 20 - 30° N and the occurrence of arid zone right on the region of the lowest pressure during the main rainy season are peculiar to our longitudinal range. This may be mainly ascribed to the large circulation changes due to Asiatic monsoon which is the best known monsoons of the world. The Indian Ocean is mostly enclosed with Africa to its west and Asia to its north. It is also partly enclosed by Australia and Indonesia to the east and is open only towards the Antarctic in the south. The existence of such an open sea, the lowest pressures during summer over north west India and adjoining west Pakistan and very high Himalayan and Burmese mountain barriers are to a large extent responsible for the exceptional build up of Asiatic summer monsoon. In a classical paper on south west monsoon, Simpson (1921) mentioned the Indian summer monsoon as that of an extensive closed low, orographically bound. He laid special emphasis on the role of the Himalayas and Burmese mountains in increasing rainfall over Indian region. From a study of meridional wind sections in July for 80° W (America), 45° E (East Europe Arabia), 75° E (India), 100° E (East Asia), 140° E and 170° E (Pacific), Ramanathan (1960) indicated that there are no monsoon westerlies in America or the Pacific and the westerlies are the deepest (about 6 km in 10° - 15° N) over India and East Asia. The African monsoon produces westerlies of about 2.5 km. thickness over west Africa and Sudan. Further the inter-tropical front or better known as the inter-tropical convergence zone where the two trade winds meet and converge lies only a little north of equator say within 5 - 10° N

in Pacific and Atlantic ocean. However, in the continental areas the southern hemisphere air stream penetrates well into the northern hemisphere as south westerlies in India and south east Asia (upto 30°N) and to a smaller extent in Africa (upto 18°N). All these factors clearly indicate the peculiarity in the monsoon circulation of Indian sub-continent. Explaining the possible cause for this Flohn (1958) and Koteswaram (1958) emphasized the role of Tibetan plateau, which is an ellipsoid 3000 km by 1500 km. with an average elevation of over 4 km on the general circulation over India in summer. Since this plateau receives copious radiation in summer and re-radiation from this elevated terrain heats directly the middle troposphere, an anti cyclonic cell develops in upper tropospheric levels over the central and eastern part of Tibetan plateau. The predominant effect of this cell is the reversal of normal temperature and pressure gradient between 600 and 300 mb levels (4.5 km to 9 km a.s.l.) correlated with the advance and vertical extension of equatorial westerlies below 500 mb (5.4 km a.s.l.) and formation of deep, strong and persistent easterly jet stream (Koteswaram, 1956). The sudden swing of the westerly jet stream from south of the Himalayas to north of Tibetan plateau and sudden and simultaneous onset of south west monsoon in India are all brought out by the reversal caused by the seasonal warming of Tibetan plateau which acts like a switch. Accordingly, the tropical circulation cell (Hadley cell) of Palmer (1951), a well known atmospheric model, is replaced by two cells of opposite circulation with common heat source near Tibetan plateau. Two jet streams are indicated on this model by Koteswaram (1958) one in the westerlies poleward of northern cell and other in the easterlies equator ward of southern cell. It is by now well known that the easterly jet stream is closely related to the activity of south west monsoon.

Similar changes in the meridional circulation over Indian longitude from those existing in the longitude of Africa (40°E) have also been reported by Rao (1962). Large upper air changes occurring over India in definite time sequence in connection with onset and withdrawal of monsoon have also been found out by Anantha Krishnan and Krishnan (1962).

Special synoptic features of Indian arid zone

In view of this monsoon circulation peculiar to India, synoptic conditions over the Indian desert are also different from other deserts. Probably if a foreigner visits the arid zone of India in mid-monsoon month with good monsoon activity, he may even hesitate to call the Indian arid zone a desert. Though rainfall does not occur much, the humidity condition of the air is high and is almost same as other

places with higher rainfall in semi arid and sub humid zones as indicated in table 3.

Table 3: Relative humidity and vapour pressure at selected stations in arid, semi-arid and sub-humid zones of India (1931-1960)

		Barmer (Arid)	Jodhpur (Arid)	Kotah (Semi-arid)	Indore (Sub-humid)	Bhopal (Sub-humid)
Mean relative humidity %	July	65	65	69	80	79
	August	70	71	75	83	82
Mean vapour pre- ssure in mb.	July	28.7	27.9	28.7	26.6	27.1
	August	28.1	28.0	28.7	25.9	27.0
Mean annual rain- fall (mm)		310	380	841	1053	1209

Thus there is hardly any differences in the actual humidity values. Not only in the surface level but also in the upper levels humidity conditions in Indian arid zone are high. For instances, the precipitable water vapour in gms. over Jodhpur in the main rainy month of July is 5.5 while the corresponding values for the same month in respect of Delhi, Nagpur, Bombay and Trivandrum are 6.1, 5.5, 6.2 and 4.6 gm. respectively. In spite of these favourable humidity conditions, rainfall in arid zone is poor. This is due to low level divergence and associated subsidence of air upto 0.8 km. and also marked divergence between 2 and 6 km. over arid zone (Datta and George, 1964). With the result, clouds coming over the region do not grow in vertical extent and tend to dissipate. It is only when monsoon depressions reach East or West Rajasthan and recurve towards north or north east or when they cross just through the arid zone, the region gets widespread rainfall. The frequency of such depressions moving through arid zone has been estimated by Datta and George (1964) to be 24 during seventy years period 1891-1960. Of these, 14 moved across west Rajasthan following the usual west to north westerly direction and 10 occurring mostly in September recurved over west Rajasthan. The south west sector of these depressions usually get very heavy rainfall. When depressions recurve over the region, the system usually moves very fast and affects the region only for a short period. During those years when no depressions move across Rajasthan and they recurve only in Madhya Pradesh or eastern fringes of East Rajasthan, desert regions get a drought year as it happened in this year (1968), when widespread famine conditions are $\frac{1}{3}$ prevailing in Jaisalmer, Barmer and Bikaner districts.

Another explanation for the receipt of scanty precipitation in spite of good precipitable water vapour over Indian arid zone and the presence

Table 2: Moisture detained in or on surface of land in each 10 longitude zone of 20-30 North latitude belt in units of 1016 cubic centimetres.

(a) Eastern longitude zones

	0-10 E																			
	0-10 E																			
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	
January	0	0.1	0	0	0	3.6	2.3	8.8	30.4	32.7	30.9	24.6	2.8							
February	0	0.1	0	0	0	4.3	3.1	9.1	28.1	30.4	30.7	26.9	3.0							
March	0	0	0	0	0	5.0	3.2	5.9	26.9	31.1	30.0	30.0	3.3							
April	0	0	0	0	0	4.4	2.8	3.5	29.4	37.7	29.5	31.2	3.2							
May	0	0	0	0	0	3.6	2.0	2.0	34.0	48.2	32.6	32.8	3.4							
June	0	0	0	0	0	2.7	1.3	2.4	40.4	62.3	38.1	33.3	3.8							
July	0	0	0	0	0	1.6	0.8	12.9	96.7	72.5	44.5	28.3	3.6							
August	0.1	0	0	0	0	1.0	0.8	19.2	58.6	71.5	46.8	27.0	3.6							
September	0	0	0	0	0	0.7	0.5	18.3	57.0	66.0	42.7	24.4	3.5							
October	0	0	0	0	0	0.6	0.4	13.2	45.5	54.3	38.1	23.0	3.1							
November	0	0.1	0	0	0	0.7	0.6	10.7	37.7	43.7	35.1	22.9	2.8							
December	0	0.1	0	0	0	2.5	1.1	9.5	33.5	37.5	31.9	23.1	2.7							
Annual total	0.1	0.4	0	0	0	30.7	18.5	115.5	518.2	587.8	430.9	327.5	39.8							

(b) Western longitude zones

	180-170 W	170-160	160-150	120-110	110-100	100-90	90-80	80-70	20-10 W	10 W-0
January	0	0	0.2	0	10.0	5.9	5.1	1.7	0.1	0
February	0	0	0.2	0	8.7	5.8	5.0	1.9	0.2	0
March	0	0	0.2	0	7.8	5.5	4.7	1.6	0.2	0
April	0	0	0.3	0	6.5	4.9	4.2	1.5	0.2	0
May	0	0	0.2	0	5.2	4.4	4.0	1.7	0.1	0
June	0	0	0.2	0	5.5	4.5	4.5	2.2	0.2	0
July	0	0	0.2	0	8.1	4.8	4.6	1.9	0.2	0
August	0	0	0.2	0	10.2	4.8	4.6	1.7	0.2	0
September	0	0	0.2	0	11.7	6.0	5.2	2.0	0.2	0
October	0	0	0.2	0	10.6	5.8	5.4	2.1	0	0
November	0	0	0.2	0	9.5	5.7	5.0	2.3	0.1	0
December	0	0	0.2	0	9.7	5.7	5.0	2.3	0.1	0
Annual total	0	0	2.5	0	103.5	63.8	57.2	22.9	1.8	0

of upper air divergence has been given by Bryson et al (1967). It is the presence of large scale dust in air over the area which affects even the radiation regime. According to Bryson, arid zone over India and Pakistan is one of the dustiest place in the world.

Seasonal rainfall pattern in the arid zone of India

In arid zone water is the main limiting factor for crop production. Hence a thorough study of rainfall and its distribution within the growing season is very essential. An outstanding feature in the seasonal distribution of rainfall over the country is that the bulk of the annual rainfall occurs during the south west monsoon season (viz. June to September). In the small arid zone tract in south India the monsoon starts by the 1st week of June while in the main arid zone in the north by the beginning of July. Table 4 shows the normal district-wise annual rainfall in the arid zone and the percentage contribution of the principal seasons.

In the whole Gujarat State and south and central Rajasthan, the contribution of June-September period in the annual rainfall varies from 90-95 per cent. In view of winter rainfall ranging from 9 to 12% of annual values, the contribution reduces to 78 per cent in Punjab and 80 to 85 per cent in Haryana and north Rajasthan. In Maharashtra the contribution decreases from 81 per cent in north to 63 per cent in south. The values become further smaller (48-67) in Karnataka and Andhra Pradesh owing to contribution of north east monsoon to the extent of 21 to 32 per cent of the annual rainfall.

The pattern of aridity index in the arid zone in different States of India

The aridity index can be calculated as the ratio of annual moisture deficiency to the annual water need expressed in percentage. This index delineates areas of different grades of aridity. The mean values of aridity index in the arid zone areas in different States of India are presented in Table 5.

The arid zone of India in the north west India is more arid than a few patches of arid zone in the peninsular India. The highest aridity index of 83 is however, in respect of Ladakh district in Jammu and Kashmir State. The mean aridity indices of stations in the arid zone of Rajasthan and Andhra Pradesh are 78 and 68 respectively.

The coefficient of variation of annual rainfall in the arid zones is very high and usually exceeds 50 as can be seen from the maps of coefficient of variation and probabilities of rainfalls (Krishnan & Thanvi, 1974).

A few stations have as high standard deviation as the average rainfall itself (Rao, 1958). A map showing coefficient of variation of western Rajasthan is presented. The coefficient of variation increases consider-

Table 4: Normal district-wise annual rainfall and percentage contribution of principal seasons in arid zone of India.

State	District	Mean annual rainfall mm	Percentage S.W. monsoon season (June to Sept.)	Contribution of winter (Dec.-Feb.)	N.E. monsoon (Oct.-Dec.)
Jammu & Kashmir	Ladakh	126.1	31	29	
Punjab	Ferozepur	368.5	78	12	
	Bhatinda	403.2	79	11	
Haryana	Hissar	374.7	81	9	
	Rohtak	342.0	84	7	
Rajasthan	Sikar	456.4	89	6	
	Jhunjhunu	404.3	86	5	
	Bikaner	263.7	85	5	
	Churu	325.5	86	6	
	Ganganagar	253.7	83	9	
	Jodhpur	318.7	91	3	
	Pali	415.3	93	3	
	Jalore	404.4	95	2	
	Barmer	277.5	91	3	
	Nagour	388.6	89	4	
	Jaisalmer	164.0	91	4	
	Ajmer	439.6	91	3	
Gujarat	Kutch	322.2	94	2	
	Amereli	358.3	94	3	
	Jamnagar	471.1	95	1	
	Surendranagar	493.7	95	1	
	Junagadh	499.8	95	1	
	Banaskanta	507.6	95	1	
	Mehsana	510.0	96	1	
Maharashtra	Dhulia	493.0	11		
	Nasik	477.0	81		
	Sholapur	449.0	69		
	Satara	473.0	63		
Karnataka	Dharwar	465.0	54	—	29
	Chitradurg	455.0	48	—	32
	Bellary	515.0	57	—	28
	Raichur	542.0	67	—	21
Andhra Pradesh	Anantapur	512.0	58	—	27
	Kurnool	565.0	67	—	21
	Cuddapah	587.0	59	—	29

ably from Sikar, Jhunjhunu region to Jaisalmer region. A map showing Pearsonian coefficient of skewness in western Rajasthan is presented. This shows that there is considerable skewness in the rainfall distribution in the arid zone. Krishnan and Kushwaha (1972) brought out an important fact that while in semi arid and subhumid zones in India etc. the distribution of rainfall for a month or more follows

Table 5: Aridity index in the arid zone of India

State	Mean aridity index (in %)
Rajasthan	78
Gujarat	76
Punjab	75
Haryana	74
Andhra Pradesh	68
Karnataka	68
Maharashtra	68
Jammu & Kashmir	83

normal distribution, the rainfall in arid zone is skew even for the whole season and follows Gamma distribution. They prepared probability charts from theoretical distribution and illustrated how the same can be used for crop planning and flood control work etc.

As regards trends, Banerji (1952) observed that there has been a slight decrease of rainfall during the previous 50 years in Rajasthan except on the Aravallis and also a slight increase in temperature. But the same has been disproved by Pramanik and Jagannathan (1954) and Rao (1958). Krishnan and Anantha Krishnan (1962) also indicated that there is no secular trend in the incidence of droughts.

Climatic shifts

In view of high year to year variability in rainfall and variability of smaller magnitude in other climatic elements, year to year variations occur in the climatic patterns. Subramanyam (1964) emphasized importance of study of such climatic shifts, since they provide clues on secular or periodic changes in climate. Krishnan (1968) studied the climatic classification of Rajasthan during highly deficit year of 1941 and surplus year of 1944. During the former year arid zone conditions prevailed in the whole State except Banswara and Jhalawar regions. During 1944, the arid zone condition was confined only to the north west portion of Bikaner, Phalodi and Ganganagar. Barmer and Jaisalmer regions came under the category of subhumid zone. The semi-arid zone was confined only to the middle belt of Jodhpur, Ajmer, Jaipur, Udaipur and Kota.

Considerable variations in actual evapotranspiration and moisture deficiencies in the arid zone have been illustrated by Krishnan and Thanvi (1969). They also indicated that high water surplus that would run off and recharge aquifers can occur atleast once in 20 years. Similar studies on occurrence of droughts based on five days water balance during 1941-1960 were conducted by Krishnan and Thanvi (1970).

A general description of the weather pattern and synoptic features that prevail over the arid zone of India is given below seasonwise.

Winter (December-February)

During this season when the sun is farthest south (viz. near winter solstice), there is a large high pressure area extending from west Africa to Asia, known as the subtropical high pressure area. This high pressure area is, however, not continuous but has breaks and gets modified by orography and distribution of land and sea. Under these conditions, clear skies, fine weather and low humidity, large diurnal variations of temperature and light north easterly winds are the features of weather. This is changed only when western disturbances pass over the north-west India when cloudy conditions and even rain may occur. The rainfall in arid zone during various seasons has already been discussed. Winter rainfall is 7 to 12 per cent in arid zone of Punjab and Haryana 3 to 6 per cent in Rajasthan and is negligible in other areas. But these disturbances bring in their rear cold waves so that frosts occur often in north west Indian arid zone. For instance a study of frosts at Bikaner indicates that the period during which frosts are common lasts from 18th December to 22nd January and can occur for more than 20 days. Such severe winter had occurred on five years out of 16 years data studied showing a probability of once in 3 years. In severe-most winter, 40 days of frost occurred (Krishnan and Thanvi, 1973). The normal minimum temperature condition in different sectors of Indian arid zone during the coldest month is as follows:—

<i>Cold arid zone</i>	<i>Normal Temperature range</i>	<i>Month</i>
Ladakh	—9° to —14°C	January

*Hot arid zones**North west India*

1. Punjab & Haryana	3° to 5°C	January
2. Rajasthan	3° to 10°C	"
3. Gujarat	11° to 15°C	"
	(Inland). (Coast)	

Peninsula

4. Maharashtra	11° to 15°C	December
5. Karnataka	16° to 18°C	"
6. Andhra Pradesh	16° to 18°C	"

The winter season is very dry except in coastal stations. The mean vapour pressure values are less than 10mb. The relative humidity values, however, appear to be high especially in the morning due to very low air temperatures.

Hot weather period (March to May)

The temperatures begin to increase from March. The high pressure system over north west India gives way to a low pressure area with a trough extending to Chota Nagpür. The desert in north west India becomes the seat of the greatest heat in India. May and June are the hottest months of the year. During these months, dry and hot dust raising winds popularly known as 'Loo' and dust storms (Andhi) occur very frequently. The sandy soil of the area, the scantiness of rainfall due to which soil is not compacted, the occurrence of steep pressure gradient and super adiabatic lapse rates of temperatures between surface and air above are causes of these convective phenomena.

The mean maximum temperatures in different arid zone regions during hottest months are as follows:—

<i>Cold arid zone</i>	<i>Normal Temperature range</i>	<i>Month</i>
Ladakh	25° to 31°C	July
<i>Hot arid zone</i>		
Punjab & Haryana	41° to 42°C	May
Rajasthan	41° to 42°C	May
Gujrat	32° to 41°C	May
	(Coast) (Inland)	
Maharashtra	40°—41°C	May
Mysore	39°—41°C	May
Andhra Pradesh	40°—41°C	May

Though the mean monthly maximum temperature is only 40°—42°C, individual daily values are very high and very often heat waves occur. Individual extreme values during each summer month at Bikaner are as follows:

April	47.2°C (On 24.4.1925)
May	49.4°C (On 28.5.1914)
June	48.9°C (On 10.6.1897)

Temperature of 50°C has been recorded at Pilani. The humidity in this season is higher than that of winter. The vapour pressure suddenly rises in the whole country by 3rd or 4th week of May.

Monsoon season (June to September)

Though the onset of south west monsoon takes place in the peninsular arid zone in the I week of June, the same occurs in north west Indian arid zone only by the last week of June to 1st week of July. The contributions of monsoon rainfall in different arid regions have already been discussed. The day temperatures fall from the range 41 to 42°C in June to 38°C in July and 36°C in August and September. The

diurnal variations are least during this season. As already discussed earlier the vapour pressure values are high and exceed 25 mb. in various parts of arid zone.

Post monsoon season (October-November)

After withdrawal of south west monsoon dry weather prevails and fairly warm weather prevails till end of October. However, in southern arid zone, rains occur due to prevalence of north east monsoon, as discussed earlier. An anti-cyclonic circulation tends to establish over north west India. The vapour pressures fall during this season and are comparable to early summer values.

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GROUND WATER RESOURCES

K. DASGUPTA*

INTRODUCTION

The scanty and erratic rainfall, high wind velocities, high evapo-transpiration losses and extremes of temperatures allow almost negligible portion of precipitation to infiltrate and reach the groundwater reservoir. Such peculiar hydrometeorological conditions cause aridity and such regions are therefore classified as 'arid' regions..

The arid regions of India can probably be grouped into two categories namely; (i) hot arid regions, (ii) cold arid region.

The hot arid regions of India cover almost 2.0 lakh square kilometres which includes a major portion of western Rajasthan, western parts of Gujarat, south western portions of Punjab and Haryana and parts of Karnataka & Andhra Pradesh. The cold arid areas of India cover about 1.8 lakh square kilometres in Ladakh area of Jammu and Kashmir State.

The problem of arid regions are manifold and are of far reaching importance. In the present lecture I would like to focuss your attention to the problems of water resources in arid regions because water is the key factor in the development of such areas. Highly unfavourable hydrometeorological conditions in arid areas not only create shortage of surface water but are also responsible for very low permeability of soils enriched with highly alkaline and soluble salts with very low organic contents resulting in poor vegetation. People in such areas have to depend mostly on the availability of groundwater and entire requirement of water for drinking, livestock and irrigation are met either from groundwater resources or by net work of canals from neighbouring sub humid or humid regions.

GROUND WATER EXPLORATION

For a systematic development of our most valuable resources of arid region 'groundwater' detailed hydrogeological investigations are necessary. The methodology of groundwater investigation has to be different and more sophisticated for the arid regions, as the hydro-geologic settings are entirely different from remaining areas. Due to poor surface and sub-surface drainage, the groundwater in major part

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of the region is highly saline and therefore can not be put to any beneficial use. The majority of the rock exposures are concealed under a thick cover of blown sands and alluvium. Uncertainty about availability of groundwater at depth and frequent occurrence of saline groundwater has discouraged the local people in the past to construct more wells in the region. It has, therefore, become necessary to collect available information about groundwater from the few existing dugwells or scattered geological cut crops and strengthen it by the results of geophysical prospecting. Much of subsurface geology was also not known, as it was very late when oil prospecting was carried out in the Western Rajasthan. The use of electrical resistivity and seismic surveys are, therefore, warranted without which, it will not be possible to explore the hydrogeology of the deeper aquifers of the arid regions. In addition to this, exploratory drilling operations alongwith electrical logging will form the second and even more important phase of the investigation programme. The difficulty of transporting heavy drilling equipment in the desert areas is another major problem, which can be anticipated while implementing the exploration programme.

Till 1950, much attention was not paid for the development of groundwater resources in arid areas of India. However, the results of the groundwater investigations carried out in many regions of the world, particularly in countries like Jordan, Iraq, Iran, Tunisia and U.A.R. in the Mesozoic and early Tertiary formations, it was felt necessary to take up exploration programme in the arid regions of India. With the co-ordinated efforts of Exploratory Tubewells Organisation, Geological Survey of India and Ground Water Department during the last 15 years the hydrogeological conditions of the arid regions became relatively more clear and many potential aquifers could be located. Still there remains a major part of the area, which requires detailed investigations and it is hoped that by the end of this decade, groundwater conditions of the arid region will be well known. There is no doubt that some difficulties may come up in undertaking the investigation programme, like heavy financial implications, and foreign exchange, for taking up such an intensive groundwater exploration in peculiar and complex hydrogeological regions. Recently the importance of the ground water investigations, has been realised and it is expected that necessary equipment, man power and funds will be made available, so that the groundwater conditions are explored and fresh water areas and low salinity aquifers are demarcated. In addition to these operations, it will also be necessary to assess the recharge, whether adequate or negligible for the arid regions, without which a large scale future groundwater development programme cannot be undertaken. It will however, be essential to take up modern techniques of ground-

water assessment and management by using Radio Active Tracers and Isotopes.

GROUND WATER DEVELOPMENT

Although groundwater exploration programme for the arid region is relatively expensive, many potential aquifers could be located in the arid regions. The aquifers are able to yield moderate to high discharge of suitable quality of water through tubewells. As the waterlevels in the areas are deep, the pumping cost is relatively high, rendering groundwater exploitation for irrigation an uneconomical proposition, unless electric power is provided for operation of tubewells. Untill now, major part of the arid areas remain unelectrified because of limited consumption, but it will be now necessary to electrify all these areas, otherwise utilisation of groundwater potential so far proved, can not be successfully done for the socio-economic benefits of the people.

GROUND WATER RESOURCES

The findings of hydrogeological investigations so far conducted by the Central and State agencies are very encouraging. Fresh water and low salinity aquifers have been located, demarcated and their exploitable ground water potential have been assessed. The following table shows the availability of exploitable groundwater potential of productive fresh water aquifers located in desert districts of western Rajasthan.

Table: 1

S.No.	District	Present annual pumpage in mcn	Estimated annual recharge/annual economical mining yield in mcn	Exploit- able potential
1.	Barmer	15-00	90-00	75-00
2.	Bikaner	9-06	31-40	22-34
3.	Churu	26-06	80-00	53-93
4.	Jaisalmer	5-50	143-20	137-70
5.	Jalore	292-38	460-96	168-58
6.	Jhunjhunu	93-11	222-94	129-83
7.	Jodhpur	130-56	228-50	98-06
8.	Nagaur	129-01	353-92	224-91
9.	Pali	212-36	290-23	77-87
10.	Sikar	193-12	289-90	96-78

It is seen from the above table that 1068 mc/m of usable water can be exploited annually for meeting the drinking, livestock and irrigation

requirements. Some of the aquifers of Jaisalmer, Barmer and Bikaner do not get any significant replenishment but the total mineable groundwater storages are so high that even dewatering of few metres of aquifers can meet the water requirement for various purposes for next 200 years.

The ground water conditions of western Gujrat are also encouraging. The sandstones of Mesozoic and Tertiary eras and quaternary alluvium have been proved to be promising aquifers. An artesian belt having natural flowing wells have been located west of Palanpur which offers scope for future agricultural development. In addition, areas capable to yield moderate quantity of water have been located and comprise of Vesicular traps, miliolite limestone and infra-trappean sandstones.

The ground water resources of arid region of Punjab and Haryana have improved due to influent seepage from irrigation channels and return flow of irrigation water. Although the native ground water is saline at depth, there is adequate saturated thickness of fresh water formed due to percolation of irrigation water. The groundwater conditions, therefore of north-western regions have considerably improved except of a part of Mohindragarh and Hissar districts. The detailed hydrogeological investigations have been undertaken in these areas by the State Government and it is hoped that new potential fresh water aquifers, will be located and assessed.

Although scarcity of water, and particularly of groundwater has been reported in cold arid region of Laddak no efforts were made in past to explore the groundwater conditions. A major part of the cold arid region is composed of consolidated sedimentaries of Mesozoic and Tertiary eras alongwith granitic intrusives. It is anticipated that moderate yields can be obtained from sedimentaries provided detailed investigations are initiated.

CONCLUSIONS

The hydrogeological investigations, so far carried out in arid region of western India have revealed that there is adequate exploitable ground water potential, which needs scientific management for conservative and controlled utilisation. At present, the ground water potential of the arid region is in an almost uncontrolled stage of development, from practically unexploited and capable of being considerably developed, to those which are locally over-drafted. Some of the potential aquifers lie in areas, where land and cattle resources are eminently suitable for economical agricultural usage. The main difficulty is of paucity of funds to electrify the tubewells proposed to be constructed for tapping productive aquifers for pastoral and agricultural development of arid

region. It will therefore be necessary for the Government to provide all the essential assistance in the form of subsidy or grants for the electrification and development of these regions so that the standard of living of people is raised and they may attain economic stability. This would also create scope for absorption of surplus people from overcrowded regions of the country and in the formation of a local defence line all along the Indo-Pak border, which at present is a vast sparsely populated, desolate land.

GEOLOGY AND HYDROGEOLOGY

V. B. Khilnani*

INTRODUCTION

Indian arid regions include hot arid areas of western Rajasthan, part of western Gujarat and south-western parts of Punjab and Haryana occupying about 2 lakh sq. kms. area and cold arid region mostly around Laddakh in J & K covering about 1.81 lakh sq. km. Arid regions are characterised by scanty and capricious precipitation, extremes of temperature and high evaporation. Geological settings and hydrogeological conditions of Indian arid regions are described here alongwith the future groundwater development possibilities. The hydrogeology of western Rajasthan and Gujarat have been studied in more details by the State and Central agencies during the last 15 years. Very limited hydrogeological work has been carried out in cold arid region of Laddakh. It is however reported that cold arid region suffers from water scarcity and groundwater resources are also not abundant.

GEOLOGY

The rock formations of Indian arid region range from Archaeans to Quaternary in age. The stratigraphic succession of the geological formations in arid regions of India are summarised in table 1.

HYDROGEOLOGY OF ARID (HOT) REGION

The water bearing rocks of Indian arid zone range from Precambrians (Older) to recent of Quaternary age and include igneous and metamorphic rocks and consolidated to unconsolidated sediments. The hydrogeological properties of different rock units of Indian arid regions are described in table 1.

ARCHAEAN GROUP

Precambrians (Older)

The oldest rock formations in arid zone of western India comprise of mica schists of Aravalli system. The younger formation include

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crystalline limestones of Raialo series and quartzites, calc-schists, mica schists of Delhi system. These have been found to be intruded by Erinpura granites, Jalore and Siwana granites and Malani Volcanics. Exposures of these rocks are observed in districts of Pali, Ajmer, Jalore, Nagpur, Sikar and Jhunjhunu of western Rajasthan. Ground water occurs in the weathered zone, joints and fissures of these rocks. The yield of wells tapping crystallines ranges from 15 to 120 cubic meters per day depending upon the thickness of weathered sequence and fracture porosity. Depth to water is generally shallow and varies from 5 to 15 metres below the land surface. Ground water is generally fresh in crystalline rocks and contains less than 1000 mg/l of total dissolved salts, except in isolated areas of weathered granites of Jalore and Pali districts where quality tends to deteriorate. The ground water occurring in crystallines gets replenished every year from precipitation and influent seepage from ephemeral streams debouching Aravalli ranges. There is scope of future ground water development by way sinking low duty tubewells and revitalisation of existing wells.

PALEOZOIC GROUP

Vindhyan System

The Vindhyan system is mostly represented by the consolidated to semi-consolidated sedimentary rocks in western Rajasthan. The areaceous members of the system are represented by sandstone, mapped as Jodhpur, Phalodi, Bhadura and Nagpur sandstones. Of these, Jodhpur sandstone has been proved to be productive aquifer and yield moderate to high discharge of fresh water. Calcareous horizons include Birmania and Bilara limestones, the later being very productive aquifer. Groundwater occurs in joints, fissures, bedding planes and pore-spaces of sandstones and solution cavities of limestones. The yield of wells and tubewells tapping Jodhpur sandstone and Bilara limestone ranges from 70 to 400 cubic metres per hour of potable water. The remaining formations yield less ranging from 20 to 50 cubic metres per hour. Jodhpur sandstone and Bilara limestone have prospects for future groundwater development as these occupy large areas in districts of Jodhpur, Pali and Nagaur. Recently a project of sinking 300 tubewells have been undertaken as part of drought proofing under World Bank assisted programme. Quality of water is generally suitable for irrigation and drinking purposes. Saline zones are found in Birmania limestones. Nagaur and Bhadura sandstones. Glacial boulder beds in Bap-Pokaran area belonging to Permo-carboniferous period are found but these do not form an aquifer.

MESOZOIC GROUP

...

Rocks belonging to Jurassic and Cretaceous systems of Mesozoic group are exposed in Bikaner and Jaisalmer districts of western Rajasthan. Jurassic system is represented by Patcham, Chari, Katrol and Umia series in Kutch and Dhangadhra and Wadhawan sandstones in central Gujarat.

In Jaisalmer district of Rajasthan, the following succession has been established:—

Cretaceous	{	Abur Beds—Limestone with grits and shales
	{	Parihar sandstones—Felspathic and ferruginous sandstones and quartzites.
Jurassic	{	Badesar Beds—Ferruginous grits and sandstones
	{	Baisakhi formations—Shales with inter calations of sandstone.
	{	Jaisalmer limestone—Olitic and shell limestone with calcareous sandstone.
	{	Lathi Beds—Sandstone with subordinate limestones towards top.

The Jurassic sequence in Kutch achieves thickness of 2150 metres which is attributed to gradual sinking of the basin of sedimentation as the deposition proceeded. Patcham and Chari series are predominantly calcareous while Wadhawan, Katrol, Umia formations are arenaceous with some limestones. Among these, Lathi sandstones in Jaisalmer district and Patcham and Wadhwan sandstone of Kutch and Palanpur form the productive aquifers. Remaining formations are less productive and yield brackish to saline waters. The yield of wells tapping these productive aquifers ranges from 50 to 150 cubic metres per hour of potable quality of water. Although there is hardly any possibility of recharge of these aquifers, there is vast storage of mineable fresh water, which can be exploited for future ground water development.

CRETACEOUS—EOCENE SYSTEM

DECCAN TRAPS

The exposure of Deccan Traps are observed over the western and south-western parts of Kutch and Saurashtra. The traps achieve great thicknesses varying from 1000 metres in the east to 120 metres in the west. Some of the horizons are vesicular in character and infra-trappean beds are commonly encountered. These horizons form productive aquifers. Ground water occurs and moves through the vesicles, joints and fissures and through interstitial openings of infra-trappean sandstones. Yield of wells ranges very widely from 10 to 50 cubic metres per day of fresh

to slightly brackish quality of water. There are however prospects for future groundwater development by way of sinking tubewells for small holdings.

TERTIARY GROUP

This group is mainly represented by the rocks belonging to Eocene period in western Rajasthan by Palana formations in Bikaner, Khuila formations in Jaisalmer which are of Laki age and Jagira and Bandah formations of Kirthan age. The Palana sandstone encountered around Bikaner forms the productive aquifer and is tapped by many tubewells. Yield of tubewells tapping Palana sandstone varies from 30 to 100 cum/h. Quality of water is generally potable but at times it is inferior in periferial areas. Depth to water is deep and varies from 30 to 70 metres below the surface. The tertiary group is represented by shales, with minor sandstone and limestone in Kutch and Saurashtra, particularly along coastal areas. Nari and Gaj beds of lower Miocene period are found to contain saline water.

QUATERNARY GROUP

Pleistocene to Recent

This group includes blown sand and alluvium, Mar and Shumer series in western Rajasthan, alluvium and miliolite limestone of Gujarat and alluvium of Punjab and Haryana. Ground water occurs in the pore-spaces of granular horizons of alluvium and solution cavities of limestone. The thickness of alluvium ranges from 30 metres in Haryana and Punjab. The upper shallow aquifers are found to contain water under water table conditions but lower aquifers are confined. Natural flowing wells have been observed in Kutch with yields of 50 cum/h. of potable quality. The yield of tubewells constructed in Punjab and Haryana regions varies from 100 to 400 cum/h. Except a limited area, around Mohindragarh and Hissar the quality of water is fresh and is suitable for irrigation and drinking purposes. Quality of water in western Rajasthan is generally brackish but is being used for irrigation. Miliolitic limestones of Gujarat has been locally developed to be a productive acquirer capable to sustain moderate yields.

HYDROGEOLOGY OF ARID (COLD) REGION

The geology of arid cold region is mostly composed of consolidated sedimentary rocks of Palaeozoic and Mesozonic groups and intruded by

the granites of tertiary era. These rocks are highly folded and faulted and have been observed to be poor aquifers. Although hydrogeological investigations in this region have not been undertaken by the Central as well as State agencies in details, it has been known from the findings of the reconnaissance surveys that this region has scarcity of surface as well as of ground water. Granites and consolidated sedimentaries yield meagredischarged to wells, mostly from the secondary porosity. Depth to water is shallow and quality of water is generally potable. There is no irrigated agriculture in the region and the drinking water supply is mostly obtained from dug wells or from the streams.

CONCLUSION

Despite unfavourable hydrometeorological conditions in the arid regions of the country have indicated encouraging situation. Few aquifers located in arid regions, are extensive, highly permeable and contain vast storages of fresh water. Although, there is hardly any possibility for replenishment of these potential aquifers, an intensive ground water development can be supported on the concept of optimum mining yield. Other aquifers located on the foot hills of the Aravallis receive adequate recharge and are being exploited for irrigation. There is still adequate surplus potential which can be exploited for increased irrigation. It has been observed that about 25-30% of the area of the arid region of western India contains fresh water aquifers which can be supported moderately yielding tubewells. Remaining area having saline aquifers needs detail hydrogeological investigations comprising of geophysical survey and exploratory drilling for locating isolated, moderately extensive, fresh water aquifers. These aquifers, if located, can not only meet the drinking water requirement but also support pastoral development.

1	2	3	4	5	6	7
Palaeozoics	Malani suite of igneous rocks	Nagaur & Bhadura sandstones Granite & Rhyolites	— — —	— — —	Tanawal series —	limestone, Nagaur & Bhadura sandstones. Tanawal formations yield meagre discharge of good quality water.
Archacons	Delhi System	Erinpura Granite Calc-schists Basal grits, Quartzites	—	—	Dogra Slates	Generally contain zone of saturation. Yield meagre to low discharges to wells through joints, fractures and weathered mantle. Quality is suitable for irrigation & drinking purposes.
Pre-Cambrians	Rialo series Aravalli System	Marble Mica- Schists Quartzites Mica schists gneisses	— —	— —	— —	

Table 1 : Geological succession in arid regions of India and the water bearing properties of important hydrogeologic units.

Group	System	Rajasthan	Gujarat	Punjab	J & K	Water bearing properties
1	2	3	4	5	6	9
Quaternary	Recent Pleistocene	Blown sand & Alluvium Mar & Shumar series	Alluvium Miliolite limestone	Alluvium	Alluvium	Alluvium of Punjab and Haryana, and Miliolitic limestone of Gujarat are productive aquifers having generally fresh water Quality. is inferior in western Rajasthan particularly in Mar and Shumar series
Tertiary	Miocene Eocene Eocene Cretaceous	Bandah & Jogira series Khuila & Palana series —	Nari & Gaj series Deccan traps	—	Granites	Palana sandstone is productive aquifer having fresh water. Granites of Laddak have poor yields. Nari and Gaj beds have moderate yields, but of inferior quality.
Mesozoic	Cretaceous Jurassic	Abur beds & Parihar beds Baisakhi beds Jaisalmer lime- stone	Bagh beds Umia Sst. Chari Sst. Katrol Sst. Patcham Ist.	—	— Infra trappean	Lathi sandstone, Patcham Limestones and Bagh beds are potential aquifers. Rest of the formations yield low discharges of inferior quality of water.
	Upper Carboni- ferous Vindhyan System	Bap Boulder Beds Birmania & Bilara lime- stone Jodhpur	— —	—	—	Jodhpur sandstone and Bilara limestones have been proved to be potential fresh water aquifers. Weathered granites yield meagre discharge. Quality of water is brackish to saline in Birmania.

ECO-CLIMATOLOGICAL FEATURES

A. Krishnan*

Ecology is that branch of Science which deals with the relationship between living things and their physical environment together with all other living organisms within it. Organisms and the physical environment in which they exist is termed as ecosystem. Various climatological parameters including the energetics which is concerned with the energy transformation occurring within the ecosystem play a very significant role in the interrelationships of living things and physical environment in the ecosystem.

THEORY OF ENERGETICS WHICH IS THE CONTROLLING FACTOR IN PRIMARY AND SECONDARY PRODUCTION IN ECO-SYSTEMS

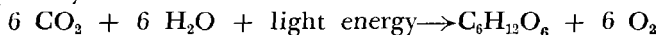
Energy is capacity to do work and various forms of energy are recognised such as mechanical, chemical, radiant and heat energy. Potential energy is the stored energy by virtue of the position of the body, kinetic energy is the useful energy which the body possesses by virtue of its motion. All organisms must work to live and hence they require a source of potential energy which can be utilised. This is found in the chemical energy of food. The combustion (oxidation) of coal in a furnace or of food by respiratory processes, release energy which can be used to accomplish work. Thus chemical energy is converted into mechanical energy.

The sun a vast incandescent sphere of gas releases energy by the nuclear transmutation of hydrogen to helium and is the primary energy source on which life on earth depends. Heat is a very special form of energy resulting from the random movement of molecules, which by virtue of their motion possess kinetic energy. All work including the growth and reproduction of living organisms represents the transformation of energy and ultimately involves heat production. For example an animal while doing work releases the potential energy of glucose (Two thirds of it is converted into mechanical energy to be used in activity and growth while one third is given off as heat). There are also instances of processes where heat is absorbed like the cooling unit of refrigerator and the fixation of atmospheric Nitrogen by certain bacteria.

On the earth, the ultimate source of animal food is plant life which acts as a potential energy store. Fungi, many bacteria and animals

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which utilise for their food organic matter with a high potential energy obtained from the tissues of other organisms are known as heterotrophs. All other organisms which manufacture their own food from inorganic chemicals with the aid of energy absorbed from the environment are known as auto trophs. All green plants, a few bacteria, and many blue-green algae are auto trophs. The vast majority of auto trophs, however, possess the green pigment chlorophyll. In the presence of chlorophyll, provided a source of radiant energy is available, organic matter can be synthesized from water and CO_2 . This process is known as photosynthesis.



There are some chemosynthetic auto trophs also. But the photosynthetic plants are the major source of food and hence energy for heterotrophs. The process of photosynthesis requires radiant energy in the photosynthetically active wave lengths viz. 0.36 to 0.76 micron which represents the visible range. 112 kilo calories of energy are associated with transfer of 12 grams of carbon into organic matter (A calorie is the amount of heat required to raise the temperature of 1 gram of water through 1°C). For formation of 1 ton of dry matter thus, we require 9.3×10^6 K. Cal. On the average the following annual yields in tons of carbon/sq.km. are expected in various ecosystems.

Forests	250
Grassland	35
Farm land	150
Desert	5

These would reveal the enormous energy storage requirements for the different ecosystems.

As against these requirements, the receipts and disposal of solar energy can be summarised as follows:—

Through the solar constant is 2 Cal/sq cm/min only 40 per cent is received on earth's surface, since much of the radiation entering the earth's atmosphere is scattered by dust particules or is used in the evaporation of water. The average amount of radiant energy per unit area per unit time actually available to plants varies with geographical locations. The following are the order of figures quoted:—

Britain	2.5×10^8 Cal/m ² /year
Michigan USA	4.7×10^8 Cal/m ² /year
Georgia USA	6.0×10^8 Cal/m ² /year

For Jodhpur, the values of the total solar radiation (viz. solar and diffuse radiation from sky) are given below in Table 1.

Table 1 : Total solar radiation on horizontal surface at Jodhpur in Cal/cm /day

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Total radiation	399	469	557	627	651	619	513	485	520	497	421	375	511
Diffuse radiation	99	106	108	167	181	242	261	281	136	121	91	99	

This table indicates that the highest solar radiation of 651 Cal/cm² day occurs in May and the least in December. As is to be expected, the diffuse radiation component increases during monsoon when clouds are present.

An average solar radiation of 511 Cal/cm²/day would mean 1.87×10^5 Cal/cm²/year i.e. 18.7×10^8 Cal/m²/year. This shows that the energy receipt in a desert ecosystem is extremely high.

The synthesis of plant materials by auto trophs is known as primary production.

The total amount of chemical energy stored by them per unit area per unit time is referred to as gross primary production. Auto trophs in synthesizing organic matter must perform work and the energy for this is obtained from the break down (oxidation) of organic substances in the process of respiration. Gross primary production minus respiration gives the food energy potentially available to heterotrophs. For instance in the grassland vegetation in Michigan USA, the solar energy received is estimated as 4.71×10^8 Cal/m²/year. Of this, plant uses only 0.058×10^8 i.e. 5.8×10^6 Cal/m²/year which is the gross production. The respiration is estimated as 0.9×10^6 Cal/m²/year giving net production as 4.9×10^6 Cal/m²/year.

The total solar energy annually stored (S) in the biosphere in the world is given as

$$S = A \times B \times C \text{ K. Cal (i.e. estimated as } 1.5 \times 10^{18} \text{ K Cal)}$$

where A is solar energy flux reaching earth's surface 5×10^{20} K cal/year.

B is the proportion of flux absorbed by plants (generally 0.3)

C is the proportion of absorbed light converted into chemical energy (generally .01)

Such quantitative information in respect of Desert ecosystems are required.

This transformation of solar energy to chemical energy of plants follows the laws of thermodynamics viz. I law which proclaims the constancy of sum of mechanical and thermal energy in systems containing energy only in these 2 forms and the II law which enunciates the

concept of entropy and states that in a closed system (a system not exchanging energy with the surroundings) heat can not be converted into work without some other change in the system involving an increase in disorder and balancing the increase in orderliness associated with conversion of heat into work.

The transformation indicated below thus conforms to the laws of thermo dynamics.

Solar energy assimilated by plants	=Chemical energy of growth of plants	+ Heat energy of respiration

Similarly according to laws of thermo dynamics we can state for heterotrophs

Chemical energy assimilated by heterotrophs	=Chemical energy assimilated by heterotrophs (generally 30 to 50 per cent). But may be 75 per cent for carnivores and 10 per cent for herbivores)	+ Chemical energy of faeces produced by heterotrophs and

and

Chemical energy assimilated by heterotrophs	=Chemical energy of growth of heterotrophs	+ Heat energy of respiration

The storage of energy in heterotrophs tissues is termed as secondary production. Faeces and body tissues of heterotrophs eventually serve as food materials for other heterotrophs/autotrophs. Thus finally in ecosystem it may be written as Solar energy entering the system = Heat energy leaving the system.

Thus it can be summarised that the assimilation of solar energy by plants which is a plant environment interaction is the most important factor in the primary and secondary production of the ecosystem. The difference between the daily periodic assimilation and continuous respiration is called Net assimilation rate (NAR).

At higher light intensities NAR is almost constant and is limited by water supply or other internal biochemical processes or supply of CO_2 from atmosphere. The concentration of CO_2 just outside a particular leaf in crop canopy depends on the efficiency of mixing of air in that layer with that above the crop. This mixing efficiency depends on the turbulent character of the air flow above and through the crop. NAR will be higher with higher supply of CO_2 . At lower light intensity NAR is proportional to light intensity and falls to zero at the compensation point which is the intensity at which the synthesis of organic matter

and its break down by respiration takes place at equal rates. Though some leaves will be saturated with regard to light, the same will be a limiting factor for leaves partly or wholly shaded. The increase in leaf area per unit area of soil below it viz. leaf area index causes reduction in light at the lower canopy.

Another most important factor in dry regions viz. arid and semi-arid ecosystems is the interaction of photosynthesis and transpiration. Any difference in the transpiration and the water uptake through the roots results in a change of water stored in the plant. Decrease of such storage results in decrease of pressure of water in plants. It is this change in water pressure that partly controls the opening and closing of stomata, the aperture through which diffusion of CO_2 in photosynthesis and water vapour in transpiration takes place. Thus there is a direct but complicated interrelationship between transpiration, photosynthesis and water supply. It is essentially dynamic in character depending on the rates of flow associated with each process. During midday with high radiation, plants can be seen wilted an account of the fact that the rate of loss of moisture has exceeded the intake rate through the roots and the wilting is due to loss of water pressure or turgor. Such water stresses occur during periods of maximum potential photosynthesis. Such stress is a common cause of reduction in crop yields. Thus energy balance, water balance and determination of evapotranspiration are important factors controlling primary production in ecosystems. These are dealt with in subsequent sections

ENERGY BALANCE AT EARTH'S SURFACE

The solar radiation received by us is mainly in short wave length. The radiation in the wave length region 0.36μ to 0.76μ is the visible light. Where μ is called micron and is equal to 10^{-6} m. The radiation below 0.36μ is known as ultra violet radiation while radiation above 0.76μ is the infra red radiation. The sun emits like a black body of 6000°K while earth like a black body of 300°K . Thus wave length distribution in solar and terrestrial radiations are completely different. The wave length corresponding to maximum intensity of radiation (λ_{max}) is 0.47μ i.e. Blue-Green range of the visible light. But distribution is so asymmetrical that only 26 per cent of the total radiation lies below λ_{max} . Wave length centre of balance such that 50 per cent of radiation is on either side of it is 0.7μ i.e. in visible red. 40 per cent of the radiation lies in the infra red spectrum. The downward scattered and reflected component of radiation is referred to as sky radiation. This comes from all regions in the visible sky. It is intense in direction close to that of sun. The sum of short wave radiation from sun and

sky is known as global radiation. This can be estimated from sun shine data using Angstrom relationship.

$$\frac{R_T}{R_e} = f + g \frac{n}{N}$$

Where R_T is the total radiation, R_e is the extra terrestrial radiation, T_n is the duration of bright sun shine. N is the maximum period of sun shine astronomically possible. These relationships applicable to the arid zone of India have been worked in the Central Arid Zone Research Institute, Jodhpur.

Albedo is the reflection coefficient for short wave radiation and can be measured by albedometer. Some of the albedo values reported in the literature are as follows:—

Light sand dune	30–60 per cent
Sandy soils	15–40 per cent
Meadows & fields	12–30 per cent
Dark cultivated soil	7–10 per cent
Water surface	3–10 per cent

Albedos measured at Central Arid Zone Research Institute, Jodhpur over Bajra crops was 25 per cent and over water 5 per cent or so. Albedos decrease when soil becomes wet. C.A.Z.R.I. is also measuring radiation at normal incidence and portion of radiation received upto green, orange and red bands in the solar spectrum.

As already stated, the terrestrial radiation is in the long wave viz. from 6.8μ to 100μ 95 per cent of solar and diffuse radiation lie in the range 0.3μ to 2.2μ . The range 2.2 to 6.8μ is used by both the radiation to the extent of less than 5 per cent. The water vapour absorbs strongly over certain wave lengths in the terrestrial radiation. With the result, there is considerable downward back radiation back to the earth from the atmosphere. Carbondioxide and dust are also subsidiary absorbers. The difference between radiation from ground surface upwards and the downward radiation from the atmosphere to surface is known as the net out going radiation or nocturnal radiation. (R_L). This can be computed by the following formula of Penman (1948):

$$\sigma T_a^4 (0.56 - 0.092 \sqrt{e_a}) (0.1 + 0.9 \frac{n}{N})$$

Where σ is Boltzmann's constant, T_a is mean monthly temperature in $^{\circ}\text{A}$ and c is vapour pressure of air in mm of Hg.

Though this radiation is called nocturnal radiation, its value is higher during day than during night.

Thus the net radiation (R_n) can be computed by the following formula:

$$R_N = R_T (1 - a) - R_L$$

Where R_t is the total radiation on horizontal surface, α is albedo and R_L is the net terrestrial radiation.

The energy balance equation can now be expressed as $R_N = G + P + H + LE$ where

R_N is the net radiation received at surface

G is the heat flux into the ground

P radiation flux used in photo synthesis (This is small but at times can be as much as 5% of net radiation)

H and LE are the sensitive and latent heat fluxes of air respectively.

The net radiation (R_N) can be measured over the field by net radiometers or can be estimated as described above.

G can be determined by means of heat flux plates or from the observed soil temperature values, volume fractions of mineral, organic matter and water in the soil and porosity values.

The crux of the problem in the arid zone ecosystem is the partitioning of H and LE . With the dry soil more net energy is used for H while in wet soil the component LE representing evapotranspiration is also high. The partitioning is done by using the Bowen's ratio $\frac{H}{LE}$ which is given in terms of the ratios of gradients of sensible and latent heat with height and diffusivities for heat and water vapour. There is generally difficulty in determining the ratio more so under advective condition.

A direct approach to evapotranspiration (E_o) would be by the formula

$$E_o = f(U) (e_o - e_a)$$

Where $f(U)$ is the function of wind speed at a certain height above the vegetation surface either empirically determined or derived from turbulent transfer theory. e_a —vapour pressure of air at that height and e_o is the saturation vapour pressure at temperature T_o of surface. Since surface temperature is unknown and the accuracy of $f(U)$ is uncertain, it is difficult to apply aerodynamical method in actual practice. In this method, aerodynamic flux gradient may be estimated either implicitly (Bulk aerodynamic method) or explicitly (Profile method).

Penman (1948, 1956) was the first to combine these two approaches in a simple equation. Basically in his method evaporation from a hypothetical open water surface is calculated as a function of net radiation and an expression of the drying power of the air. His formula for evaporation from free water surface is

$$E_o = \frac{\Delta H + \gamma E_a}{\Delta + \gamma}$$

Where Δ is the slope of the saturation vapour pressure curve at temperature T_a , H is the energy balance term and E_a is the aerodynamic term. The weightage to the factors E_a and H depend on Δ and γ . It has been found out by Krishnan (1971) that under arid zone conditions of Jodhpur, the aerodynamic factors are much more important than the energy balance factors and that is why the Penman's equation which gives relatively higher weightage to energy balance factors under estimates evaporation conditions. By multiple regression methods, new prediction equations have been developed by him for incorporating revised weightages in Penman's equation and for determining individual climatic factors contributing to arid zone evaporation. In spite of the fact that the total radiation as a single factor has the maximum correlation of 0.70 with evaporation, the best combination of pairs of factors which have maximum association with evaporation happens to be saturation deficit at maximum temperature epoch and wind speed which explain 83 per cent of variance in evaporation. By additional inclusion of total radiation to this pair only 5 per cent more of the variance is explained (Krishnan, 1973).

Penman's method can be used for directly finding evapotranspiration of crop by putting in the formula albedo values appropriate to crops. Improved combination method has been suggested by Slatyer and McIl Roy (1961) by using wet bulb depression instead of saturation deficit and by taking into account soil heat flow in the energy balance term. Another combination model without any empirical constant was suggested by Van Bavel (1966) who took into account surface roughness in the proposed wind function. Another modification of the combination approach has been suggested by Monteith (1963) and Linacre (1967) by inclusion of crop resistance which is a function of crop structure and leaf properties and aerodynamic resistances which are characteristics of crop-atmosphere interface.

The actual evapotranspiration of plants is considerably influenced by soil water supply, plant structure and physiological conditions of leaf and rooting depth etc. (Slatyer and Denmead, 1964). Just after rain or irrigation, when the surface is visibly wet, the rate of evaporation is almost the same as an exposed water surface receiving the same amount of radiation. But after the soil has dried evaporation takes place from deeper layers of the soil and there is a sharp and continuous decline depending on the length and complexity of internal diffusion pathway within the soil. Further when the plant grows in height and leaf area, the ground is shaded and consequently the evaporation from soil surface decreases and the plant transpiration rises progressively with increase in leaf area till the whole surface is effectively covered by the vegetation. Transpiration is sensitive to further leaf development

and is maintained at high level when the plant is actively growing and then declines as the plant matures. Further, as the roots develop, the plants has access to increasing volume of soil water. Any model for actual evapotranspiration (AE) should therefore take in to account the above factors. Water budgeting methods using the AE values should be used to determine the soil moisture at any time during the growing season. An illustration is presented below from the work done at Central Arid Zone Research Institute, Jodhpur.

APPLICATION OF WATER BALANCE APPROACH TO THE NATIVE VEGETATION IN THE ARID ZONE OF INDIA:—

In this approach the following hydrologic equation is used:—

Precipitation = Evapotranspiration + Run off + Drainage + Change in water content of the block of soil.

By measuring or eliminating all but one of the variables, the remaining one can be found. Such water balance studies would not only be of use in establishing relationship between amount intensity, time of rainfall and the amount of water that entered the soil but also will help us in finding out associations between water loss from the soil, the initial amount of water in soil, atmospheric conditions and the characteristics of vegetation. This would ultimately help us in water conservation and better utilisation of incident rainfall.

A comprehensive experiment on the water balance of *Prosopis cineraria* community including soil moisture, microclimatological, ecological and plant physiological observations was conducted at the Central Arid Zone Research Institute, Jodhpur from 1963. The site is a typical habitat for the community. The soil at the experimental site is sand to 15 cm depth (clay content 6 per cent) and sand to loamy sand upto 180 cm. (clay content 8 per cent) at which depth, there is a calcareous kankar pan of lime coated gravel. The soil texture was quite uniform and unaggregated upto 180 cm. with a nearly constant bulk density of 1.5 g / cm³.

The results of the soil moisture observations and water balance of the community for the three years 1963, 1964 and 1965 were analysed. These years had rainfall of 156.9, 536.2 and 234.6 mm respectively as against the normal annual rainfall of 366 mm at Jodhpur. The data indicated that the evapotranspiration in the sandy soils of Rajasthan in months other than monsoon and subsequent post monsoon months is surprisingly low. In fact the rainless season is marked by occurrence of condensation and low evaporation. The data on the water balance of *Prosopis cineraria* community for the years 1963, 1964 and 1965 were computed.

The period 30th July to 28th September (60 days) accounted for 156.0 mm. of evapotranspiration during very much deficient rainfall year of 1963 while the period 10th May to 6th October (150 days) accounted for evapotranspiration of 321.9 mm. and deep drainage of 34.9 mm. during the surplus rainfall year of 1964. During the medium rainfall year of 1965, the period 29th June to 7th October (100 days) had an evaporation loss of 219.5 mm. These data indicate high variability from year to year in the available vegetation growth period. The run off losses constituted 0.4, 23 and 5 per cent respectively during these years. The very high run off loss during 1964 is due to very high intensity of rainfall on the 8th July and 18th August together with good antecedent moisture conditions in the soil. For instance 138.2 mm. rainfall was recorded in just 4 hours on 18th August, 1964. Light rains moisten only surface layers and get evaporated. The real contribution in the inputs during rainless season is by the contribution of water in vapour phase.

From the transpiration measurements, it is seen that *Prosopis cineraria* trees extract moisture not only from a large area but also take the same from the Kankar zone through which their roots penetrate.

In this experiment, a graphical integration method was used to determine the mean water contents in different layers of the soil in various ten day periods. An evapotranspiration model was evolved from this experiment for predicting soil moisture storage under native vegetation during the growing season of the vegetation (Krishnan, 1970). Part A of the model depicts the pattern of ratio of actual evapotranspiration to potential evaporation in terms of stage of growth represented by cumulative evaporation values from USA open pan evaporimeter while part B indicates the pattern of decline in evapotranspiration as soil water storage decreases. It is seen from part A that the ratio of AE to PE increases from 0.40 directly after soil moisture recharge to a maximum of 0.70 corresponding to 200-300 mm of cumulative evaporation and then declines to a steady value of 0.50. The soil storage of available water and additional survival storage referred to as store A and store B respectively work out to be 150 mm and 60 mm under Jodhpur condition. It is seen from part B of the model that the water stress factor becomes less than unity when store A becomes less than 70 mm (47 per cent of available capacity). When store A is reduced to less than 30 mm, withdrawals are made in the model from both the stores A and B. The agreement between the predicted values and those actually measured during 1965-67 is quite close.

Some of the other eco-climatological studies completed at Central Arid Zone Research Institute, Jodhpur are as follows:

Study of moisture regime and microclimatic patterns over unstabilised and stabilised sand dunes indicate that high moisture concentration (>5 per cent) occurs below 1.5 metre depth in unstabilised sand dunes throughout the year. Such a feature does not exist in unstabilised sand dunes. This partly explains the surer establishment and better growth noticed in the plantations done on unstabilised dunes. The soil temperatures reveal similar type of diurnal and seasonal variations as in the sandy plains. The seasonal variations range from 32.2°C at 5 cm. depth to 2.7°C at 5 metre depth (Krishnan and Rakhecha 1966).

A field method for finding hydraulic conductivity and calculating soil evaporations (Rose and Krishnan, 1967)

In the absence of rainfall or irrigation input, the soil water balance equation can be written as:

$$\Delta M = [K_z] \left[\left(\frac{\partial h}{\partial z} + 1 \right) \right] T + \int_{t_1}^{t_2} E dt \quad (1)$$

ΔM in left hand side is the change in water content and can be more fully expressed as

$$\int_{t_1}^{t_2} \int_0^z \frac{\partial \theta}{\partial t} dz dt$$

K_z is the hydraulic conductivity at depth Z , $\left(\frac{\partial h}{\partial z} \right)$ is the time averaged

gradient in soil water suction and $\int_1^{t_2} E dt$ is the evaporation during the

time interval T (viz $t_2 - t_1$). Since evaporation and kg are two unknowns, one constraint is required for finding K_z . This is provided in the method by Marshall's equation for slope of the hydraulic conductivity curve.

For the method evolved under this study, we only require measurements of successive profiles at suitable time intervals of water content and soil-water suction for determining hydraulic conductivity in-situ.

Values are first assumed for the evaporation $\int_1^{t_2} E dt$ during the series of time periods over which (K_z) is to be calculated. Error in these initial assumptions will not affect the results of the iterative analysis, but the convergence to final values of (K_z) is very rapid if assumed values are realistic estimates, perhaps based on some proportion of open-pan evaporation values at the experimental site.

Substituting such assumed values of evaporation into equation (1) yields a series of first estimates of (K_z) calculated at a specified depth z . The choice of this specified depth is flexible, but it should be such that water flux is dominantly in the liquid phase and the gradients in soil-water suction accurately defined. These estimates of (K_z) are then plotted against the mean volumetric water content θ to which they apply, and the theoretical relationship between these variables, calculated, from Marshall's equation, is fitted to plotted values.

Reading off this fitted theoretical relationship provides a second estimate of (K_z) values corresponding to the range of (θ_z) values. Using equation (1), these second estimates of (K_z) in turn yield second estimates of evaporation. This procedure is then repeated until change in the computed values of (K_z) at the specified depth (and of evaporation over the periods T) are insignificant.

The final values of evaporation obtained may then be used to calculate hydraulic conductivity as a function of water content at other depths in the soil profile.

The method was applied to data from the Central Arid Zone Research Institute farm at Jodhpur, India. The soil at the experimental site was sand to 15 cm. depth (clay content 6 per cent), and sand to loamy sand up to 180 cm. (average clay content 8 per cent), at which depth there was a calcareous kankar pan of lime-coated gravel. The soil texture was quite uniform and un-aggregated to a depth of 180 cm., with a nearly constant bulk density of 1.5 g. cm.^{-3}

Measurements of water content profiles were made for 5 consecutive days following a substantial rainfall of 138.2 mm. recorded on August 18, 1964, in the monsoon season, there being no rainfall during the measurement period. Measurements were made with neutron moisture meter.

The iterative procedure described above was used in calculating hydraulic conductivity characteristics, the specified depth used in evaporation calculations being 25 cm., at which depth flux of water in the liquid phase was expected to be dominant transport mechanism over the water-content range covered by these measurements.

Studies on soil thermal regime and heat fluxes

For the sandy to loamy sandy soil of Jodhpur, there are two types of soil thermal regimes (1) summer pattern when soil temperature decreases from 1 cm to 120 cm depth during maximum temperature epoch and increases from 1 cm. to 30 cm. depth and decrease thereafter for minimum temperature epoch, (2) winter pattern when soil temperature during maximum temperature epoch decreases upto 30 cm with an increase thereafter and during minimum temperature epoch increases

continuously from 1 cm. to 120 cm. depth. The former pattern lasts from mid March to mid October with a few breaks during active monsoon period when the winter pattern is brought in temporarily

Conditions are favourable for upward movement of moisture in vapour phase during the morning hours and for the downward flow during the afternoon hours throughout the year. From April to end of October, the gradients are stronger. However, during monsoon, downward vapour pressure gradients in afternoon are much less than those in other months thereby indicating that the general upward movement of water vapour in crop growing season exist during monsoon period.

Though many workers have reported that the annual soil temperature cycle is well represented by the first harmonic alone, it has been found that under Jodhpur conditions, the first harmonic explains only 69 to 85 per cent. The change in soil temperature pattern during monsoon is well reflected only if the third harmonic is superposed over the sum of the first two harmonics. The amplitudes at various depths vary between 4.8 to 9.1°C for first harmonic and decrease sharply enableness us higher order harmonics. The finding of this harmonic analysis enable us to predict the soil temperature pattern at any time during crop season. (Krishnan *et al.* 1972).

A study of weekly mean soil heat fluxes at Jodhpur indicates larger oscillations of fluxes in monsoon than in other seasons. The weeks of rainfall have large negative fluxes while the intervening dry spells have large positive fluxes. These are noticed in each individual layer upto depths of 120 cm.

These results indicate existence of flow of appreciable heat due to mass movement of water and also flow of water in vapour phase in arid zone soil during monsoon. The above features are important in moisture movement problems and estimation of crop water use (Krishnan *et al.* 1974).

Distribution of burrow temperatures in the burrows of the Indian Desert Gerbil, Meriones hurrianae (Prakash *et al.* 1965).

The normal daily ranges of air temperatures, soil surface temperatures and temperatures inside the burrows of desert gerbils (from 50 cm. to 2 metres slant depth) have been studied for different seasons.

	Winter	Hot weather period	Monsoon	Post monsoon
Normal soil surface temperature (°C)	11.9 to 39.0	26.7 to 55.5	31.5 to 45.8	22.7 to 49.3
Normal air temperature (°C)	13.1 to 24.8	28.1 to 39.3	26.8 to 33.4	19.6 to 32.7
Burrow temperature	19.1 to 20.7	33.6 to 37.6	37.6 to 35.8	24.6 to 31.3

The burrow temperatures have generally smaller ranges compared to air and soil surface temperatures. It is interesting to note that the range of temperature within the burrows is maximum when the air and soil surface temperatures have the minimum range. This may be due to occasional flooding of the burrows with rain water. During the maximum temperature epoch (viz 0230 PM in afternoon) burrows are cooler than the soil surface by 19.2 to 20.9°C in various seasons except in the monsoon when the difference is 11.4°C. Thus, the burrows serve the gerbilles as air conditioned chambers to avoid the high extremes of temperatures noticed in the arid regions.

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SOLAR ENERGY AND WIND POWER UTILISATION

H. P. Garg*.

The arid and semi-arid parts of our country throw a difficult challenge to the ingenuity of man in devising means to live, work and to produce more agricultural products under adverse climatic conditions (Krishnan, 1969). Indian arid and semi-arid areas receive high solar insolation so that where conventional sources of energy are not available, the harnessing of solar energy is worthy of serious consideration.

Some of the problems generally encountered in the cold and hot arid and semi arid zones are:

Cold arid & semi-arid zones

1. Very low temperatures in winter.
2. Low humidities
3. Shortage of water
4. Fuel shortage
5. Power shortages
6. Drying of products

Hot arid & semi-arid zones

1. High temperature in summer
2. Low humidities
3. Shortage of water
4. Fuel shortage
5. Power shortage
6. Preservation of food

Many of the problems mentioned above can be solved by utilising solar energy and wind power which are available at the place of use.

1. SOLAR ENERGY UTILISATION POTENTIAL IN ARID AND SEMI ARID ZONES OF INDIA

Solar energy which is freely available at the site of use is a boon to the hot arid and semi arid zones of our country. Roughly on the earth's surface one square metre of horizontal area receives about 1 KW of solar energy under clear sky conditions while its value outside the earth atmosphere and normal to the direction of sun rays is 1.36 KW/m². Thus on the earth's surface in a year, the energy received by a surface of one square metre will be about 2500 KWH which may vary with the amount of actual sunshine hours and the latitude of the place. If the efficiency of the collecting system is assumed to be only 20 per cent, then the energy received by an area of 10 metres by 10 metres in one year will be 50000 KWH. This energy is more than sufficient for any

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household work like air conditioning, refrigeration, cooking, water heating, drying etc.

Table 1 gives the seasonal mean values of total solar radiation (Rao and Gameson, 1972) at 8 stations in the arid and semi-arid regions of the country.

Table 1 : Seasonal means of daily radiation in Cal/cm² day in arid and semi arid regions in India

Station	Arid or semiarid	Winter (Dec-Feb)	Hot weather (Mar-May)	Monsoon (June-Sept.)	Post monsoon (Oct.-Nov.)	Annual average
1. Jodhpur	Hot arid	414	612	534	479	510
2. New Delhi	Hot semiarid	363	576	479	420	460
3. Ahmedabad	"	429	611	466	458	491
4. Poona	"	459	602	435	461	489
5. Hyderabad	"	436	544	372	369	430
6. Bhavnagar	"	442	618	452	481	498
7. Bangalore	"	461	580	392	400	458
8. Srinagar	Cold semiarid (Nearest radiation station)	198	491	536	300	381
						Annual average 465

It is seen from this table that total solar radiation is maximum during hot weather period and minimum during the winter period. In the hot arid and semi-arid regions more than 544 Cal/cm² day is received during hot weather season while more than 364 Cal/cm² day is recorded during winter, monsoon and post monsoon seasons. In Srinagar which is not exactly a cold semi-arid region but is very near to that also shows very high solar insolation during hot weather and monsoon seasons namely 491 Cal/cm² day and 536 Cal/cm² day respectively but receives only 198 Cal/cm² day in the winter season. The annual average solar radiation received by Jodhpur which comes under hot arid part of the country is maximum viz. 510 Cal/cm² day. These figures clearly indicate the possibilities of large scale use of solar energy utilisation appliances in the arid and semi-arid regions of our country.

Solar energy can be collected either through flat-plate collectors or by focussing collectors. Flat plate collectors are of low cost, simple in design, absorbs direct and diffuse radiation, need not to follow the sun but can supply low grade energy i.e. below 100°C. In winter by keeping the flat-plate collectors at optimum tilt we can collect upto 50 per cent more radiation at higher latitude stations like Jodhpur and Laddakh. Focussing collectors which requires sun tracking arrangement can produce temperature upto 4000°C.

2. SOLAR ENERGY APPLICATIONS

2.1 Solar water heating: One of the most successful and widely used application of solar energy is solar water heating. In this application the interruptions due to bad weather may be tolerated. Solar water heaters are in use for more than a decade in countries like Japan, Israel, Australia and in some parts of U.S.A. like California and Florida. In Israel almost every house has got solar water heater and in Japan about 2.6 million solar water heaters are in use at present. Because of the energy crisis and the high cost of fuel, the Miromit firm of Israel has received an order of 100000 units of solar water heater from abroad which will be used in factories, hospitals, hotels and in private homes. The increased use of solar water heating in our country will help in saving fuel like cowdung, wood, kerosine oil and electric power which are generally used for water heating.

In India, based on the requirement, three models of solar water heaters having different capacities namely, domestic solar water heater (140 litres), large size solar water heater (600 litres) and built-in-storage type solar water heater (90 litres) have been successfully developed by the author. The domestic and large size solar water heater, developed by the author ((Garg, 70, 73) at C.B.R.I., Roorkee, uses the tube in plate collector and a separate double walled storage tank while the plate of the built-in-storage type solar water heater, developed by (Garg 1974) at Central Arid Zone Research Institute, Jodhpur, performs the dual function of absorbing the heat and storing the heated water.

The cost of energy (Garg, 1974) developed by these three solar water heaters is given below:—

	Capital cost (Rs.)	Cost per unit of KWH (Rs/KWH)
1. Domestic solar water heater	1000	0.13
2. Large size solar water heater	3500	0.12
3. Built-in-storage type solar water heater	350	0.08

Thus it can be concluded that heating of water using solar energy is always economical.

2.2 Solar cooking: This solar application, though simple in technology, will be of considerable value in fuel scarce regions where the tendency is to burn agricultural and animal waste for cooking purpose, thereby robbing the soil from potential fertiliser.

Solar cookers are generally of two types, the reflector type and the hot box type. The reflector type of solar cooker was developed in early

fifties at National Physical Laboratory, India (Ghai, 1953) which consists of a parabolic disc (about 1 m dia) made of sheet aluminium, a commercial grade material with 75 per cent reflectivity. This reflector has an output equivalent to 300 watts under clear sky conditions and can be used for boiling or frying. The hot box type of solar cooker was developed by Dr. Maria Telkes (1955) in U.S.A. which consists of an insulated wooden box lined from inside with blackened aluminium sheet and covered with two glass sheets of side 75 cms. The top of this box is surrounded by octangular aluminium or looking glass reflector. Recently Central Arid Zone Research Institute, Jodhpur has undertaken a project on development of suitable solar cooker. Two of them would be of hot box type and the third and fourth ones would be using flat-plate collector and reflector respectively.

Despite the apparent simplicity, the efforts in introducing such solar cookers in the Indian villages and in Mexico have failed. The main reasons of failure are social habits, inherent drawbacks of solar cooking like intermittent and varying radiation and mostly inadequate promotional efforts.

2.3 Solar distillation: Lack of potable water is primarily a problem of the arid regions. Frequently there is saline water available in these regions, sea water at the coast and bore water inland. Solar energy can be used to distill saline water. For small amounts of fresh water, the conventional roof type still is probably best. As the energy supply is free, the cost of the water becomes dependent to a large extent on the capital cost and life of the equipment.

The largest stills, according to the U.N. report, are in Patmos on the island of Greece with an output of 5300 gallons per day and in coober peddy in the southern Australia (Morse & Road 1968) with an output of 2340 gallons per day. These stills are extremely simple and comprise a horizontal black tray with a tilted glass or plastic cover over it. The sides are closed and sometimes thermal insulation material is placed below the tray. A shallow layer of water in the tray gets heated by the sun, producing water vapours which condense on the underside of the sloping cover and trickle down a channel into a container. A unit of 1 square metre area will yield 3 to 5 litres of water per day on a clear summer day.

The technology of solar distillation is a proven technology and solar stills can be fabricated by the rural community itself. Extensive research and extension efforts are required to extend the method of solar distillation to rural areas in the arid zones of Rajasthan, Haryana and Gujarat area for human and stock consumption. Central Arid Zone Research Institute, Jodhpur is studying the effect of some of the more parameters (Garg & Krishnan 1973) climatic (Garg, 1974), design and

operating parameters on the distillation output and has undertaken the extension work of solar distillation.

2.4 Solar drying: The classical methods of drying the agricultural and other products involve spreading the material on the ground and to expose it to solar radiation and wind. Though cheap, such methods often lead to products of inferior quality because of lack of control over the rate of drying and incidence of contamination. By applying modern techniques, solar drying can make great progress. Solar drying systems, ranging from cottage produced small capacity cabinet devices to large capacity drying plants, have been developed in many parts of the world.

In National Physical Laboratory, New Delhi drying of coal fines using hot air has been demonstrated. Plane glass mirror concentrators with overall dimensions of 1.83×0.91 m. were designed in NPL and used for making jaggery from sugarcane and palm juice (Khanna, 1957). Similar work has been reported from Khadi and Village Industries Commission, Ahmedabad (Pandya, 1973). A pilot plant has been erected by that Commission which dehydrates palm nira and turns it into gur or syrup. Solar drier can also be used for timber seasoning as is done in CSIRO, Australia (Read, 1974). Solar air heaters have been used for drying paddy at Annamalai University, drying grain for storage at I.A.R.I., New Delhi and drying of maize etc. at Brace Research Institute, Canada.

Recently a solar cabinet dryer (based on the principle of hot box) has been designed and installed at C. A. Z. R. I., Jodhpur (Garg & Krishnan 1974). This solar cabinet dryer has been successfully used for drying of chillies. The efficiency of this dryer was found to be much higher than that of the conventional methods. This can be used for dehydration of small agricultural products such as copra, peas, tobacco, groundnut etc.

2.5 Solar space heating and cooling: The requirement for comfort in the cold arid zone involves heating and in the hot arid zone involves cooling. Solar space heating is relatively a simple method, and a number of solar houses have been built. The heating system comprises collectors, heat storage unit, and appropriate heat distribution and control arrangement. With the present energy crisis and high cost of oil, gas and electricity, solar space heating has become economical as compared to electric heating. In the heating system the demand and supply are out of phase while in the cooling system both are in phase.

A simple but effective solar room heater was developed by Garg (1972) at C.B.R.I., Roorkee. This heater is very much suitable for heating small huts even under sub zero conditions. In this system a number of flat-plate collectors are kept on the roof and the specially designed

storage cum radiant panels are kept inside the room. The radiative and convective heat loss from the heated storage cum radiant panels heat the room air.

The biggest solar house having floor area of about two thousand square feet is in operation at Denver as described by Lof (1963) in U.S.A. This system employs overlapped glass plate solar air heaters of about 600 square feet area and a storage system of about 12 tons of crushed rock pile.

The main advantage in the solar space cooling is that the demand and supply matches each other and the comfort conditions can be provided only by lowering the air temperature by 10 to 12°C. Heat operated coolers (Garg, 1974) suitable for solar energy use are generally of two types: based on the absorption refrigeration cycle and the absorption dehumidification cycle.

Large commercial units or small units where sub-zero temperatures are required such as in refrigeration for ice making or food preservation usually water is used as the absorber and ammonia as the refrigerant. For airconditioning where temperatures above zero degree centigrade are required, the lithium bromide is used as an absorbent and water as refrigerant. In the absorption machine using lithium bromide water refrigerant, a generator temperature as low as 75°C will produce a reasonable amount of cooling and a satisfactory coefficient of performance. This lower generator temperature favours the use of flat-plate collector.

Sufficient cooling can also be produced by dehumidifying the air by adsorption or absorption and then cool in the air by vaporation of water. In this cycle the sorbent can be an absorbent such as silica-gel or an absorbent such as lithium chloride in aqueous solution. In both the cases the sorbent is regenerated by solar heat.

2.6 Solar engine: About a century ago, attempts were made to convert solar energy into mechanical power. Several steam driven solar power plants were constructed and operated but could not become popular because of their high cost. The world's biggest solar power plant is at Tashkent having an reflector area of about 20000 m² and having steam generation capacity of about 13000 kgm per hour.

At National Physical Laboratory, India (Khanna, 1970) small 200 watt stirling engine was operated with concentrators made of small plain glass mirrors.

Commercial solar pumps from 0.1 to several horse power capacity are now available in countries like U.S.A., Italy, France etc. These solar pumps can be used for pumping underground water.

2.7 Electric power generation: In most of the arid part of the country there is power shortage either for lighting or agricultural

purposes. There are many ways in which electric power can be generated from solar energy. Silicon solar cell which is a p—n type semi-conductor can convert solar energy into electricity upto a maximum efficiency of 22 per cent, although the efficiency of the silicon solar cell is at present only about 16 per cent. However, to be really useful, the cost must be reduced by a couple of orders of magnitude.

Electrical power can also be generated by thermoelectric or thermionic devices. For either one of these generators, high temperatures are necessary for high efficiencies, and it is necessary to concentrate the solar energy by suitable mirrors or lenses.

Power can also be generated by conventional vapour cycles using steam or other working fluids. One of the principal advantages of solar power generation is that it is best suited for small installations such as individual homes or small villages. Pumping water for irrigation would represent the type of application where the intermittent nature of the power supply would not be detrimental. For other applications, such as lighting etc. some type of energy storage may be necessary.

3. WIND POWER UTILISATION POTENTIAL IN THE ARID ZONE OF INDIA

The primary requirement of energy in arid zones is for supplying water for drinking and irrigation and also electricity to small farmers. Wind is, of course, a free and inexhaustible source of energy but its economy and practical potentialities depend upon the cost of harnessing it. When an object is placed in the direction of the wind, it exerts a pressure which is proportional to the square of the wind speed while the power in the wind stream is proportional to the cube of this speed. The power (P) developed by the wind is given by the formula:

$$P = KAV^3$$

where A is the cross-sectional area of the wind stream and V is the wind speed. The factor K is a constant, the value of which depends upon the density of the air and on the units used for the measurements of P, A and V. If P is expressed in Kilowatts, A in square metres and V in kilometres per hour, K has the value 13.7×10^{-6} . Then the above equation becomes $P = 13.7 \times 10^{-6} AV^3$

As an example of the power contained in a wind stream, consider a horizontal stream 10 metres (33 feet) square, moving with a speed of 36 km/hr (22.4 miles/hr). The power is $P = 13.7 \times 10^{-6} \times 10^2 \times 36^3$
 $= 64$ kilowatts (48 horse power)

When one considers the possibilities of wind power in any region one has to obtain information from the India Meteorological Department on the prevailing direction of wind, its average value every year, its variation from month to month etc. All this is important and useful,

but may serve only as a guide and not replaced a wind survey to decide on favourable sites. While there may be no choice in the case of the water-pumping wind mills which have to be located near the well, the most favourable site in the locality can be chosen in the case of the wind electric generators. The reason is that wind power is proportional to the cube of the wind speed, so that if one can find a site with an average wind speed of even one or two km.p.m. higher than that in the annual output of energy by 30 to over 50 per cent. Therefore, wind measurements at specially selected sites are important from wind electric generation point of view while the wind speed data over a particular locality will suffice the purpose of wind mills for pumping water.

Since wind mills start pumping water only from a wind speed of 8 km. p.h. (5 M.P.H.), frequency of number of days with daily wind speed equal to or greater than 8 km.p.h. were worked out for Jodhpur, Jaisalmer and Bikaner falling in the hot arid zone of the country (Garg & Krishnan 1975). The average number of days, based on the 12 year data (1949-60) when wind mill is likely to function during each month at these stations, can be read from Table 2.

Table 2 : Number of days when mean wind speed $\geq$ 8 km.p.h. for three arid zone stations of India.

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Jodhpur	13.0	12.7	17.6	19.8	27.6	28.8	28.5	27.1	20.2	9.4	6.1	9.7
Bikaner	1.1	2.5	5.8	9.7	19.6	26.1	25.5	22.3	17.1	5.0	0.3	0.7
Jaisalmer	18.9	16.1	22.7	22.9	28.0	29.6	30.5	30.3	27.4	14.2	7.0	11.2

It would be seen from table 2 that during the period April to September mean number of days exceeds 20 in Jodhpur and Jaisalmer. In Bikaner, mean exceeds 20 days covers only June, July and August. The period with less than 10 days covers October to December in Jodhpur and only November in Jaisalmer and October to April in Bikaner. Thus areas near Jodhpur and Jaisalmer have good potential for pumping water by wind power.

4. WIND POWER UTILISATION

4.1 *Wind mills for water pumping:* The National Aeronautical Laboratory has designed and developed two types of water pumping wind mills (1960), designated WP-1 and WP-2. The WP-2 wind mill is suited for regions of moderate wind speeds and is of the direct acting type. The WP-1 type is suited for windier regions and is of the gear type.

The WP-2 wind mill starts working at wind speeds of 8 km.p.h. The head mechanism, which carries the wind wheel or rotor and tailvane, mounted on a four-post steel tower 10 metres high, directly operates a pump with a stroke of 12.5 cms. The pump is of the reciprocating type and is installed either with a 15 cm or 10 cm cylinder depending on the height through which water has to be lifted. The rotor which is of the multibladed type has a diameter of 4.86 metres and carries 12 blades. The tower and rotor are designed to withstand wind stresses upto 160 km.p.h.

It has already been mentioned that the power output P in Kw of a wind mill is given by the relation: $P = 13.7 \times 10^{-6} AV^3$.

The water that can be pumped in gallons per hour from WP-2 wind mill with swept area 4.88 sq. metres and assumed overall efficiency (Ramakrishnan & Janardan, 1962) of 12 per cent through a total head of 10 metres for various wind speeds will be as shown in table 3.

Table 3 : Amount of water that can be pumped by WP-2 wind mill through depth of 10 metres

Wind speed Km.p.h.	Water pumped (gallon/hr)
8	160
10	260
12	400
15	740
18	1370
21	2180
24	3460
27	4830
30	6670
33	9000

To estimate the quantity of water pumped in one year, the mean hourly wind speeds at that place are required over a year.

4.2 *Wind electric generators:* Wind electric generators could be used in farms for irrigation or supply of electricity for lighting and for running the radio sets, etc. for a small community. When used for lighting, the generators must be used along with storage batteries that serve as a stand by, to ensure a constant supply.

The major difference between the wind mill and the wind electric generator (Golding) is that the wind electric generators are fast running. The rotors for these machines are therefore of the propeller type with a small number of blades—usually 2 or 3—so that the starting torque is low and a relatively high wind speed, as compared to that for a multi-bladed rotor, is needed before the machine begins to provide power. Thus the cut in wind speed for a wind electric plant may be

as high as 16 km.p.h. upto even 32 km.p.h. (at a very windy site) instead of 8 km.p.h. which is sufficient to start a water pumping wind mill.

The annual energy output of six types of generators fabricated by different countries (Venketeshwaram and Sivaraman 1964) and of different capacities have been estimated for Jodhpur for which hourly wind speeds are available. The details of the generators are given in Table 4.

The monthly distribution of the energy output and the annual energy output worked out are given in Table 5.

From this study it can be concluded that by installing the wind mills for pumping water for domestic purposes or for irrigation and medium capacity wind electric generators to supply power in these areas, which are underdeveloped for want of fossil fuels and hydro-power, would make a substantial contribution towards development and prosperity of these areas.

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Table 4 : Details of wind electric generators

Machine details	Dowsett holdings (25 KW)	All-gaier (7.5 KW)	WVG-5 (5.5 KW)	WVG-2 (2.5 KW)	WV-2 (2 KW)	KSV-800 (0.85 KW)
Manufacturer	Dowsett Holdings Limited, U.K.	Allgaier Werke Uchingen Wurt, Germany				Elektro, G.M. b.H., St. Gallerstrasse, 27, Winterthur/2H Switzerland
Diameter of wind rotor (metres)	12.2	10	5.0	3.8	3.5	3.0
Cut-in-speed, km.p.h.	20	16	8	6	5	4
Assumed rated speed, km.p.h.	61	37	41	40	38	32

Table 5 : Estimated monthly and annual energy output of 6 wind electric generators at Jodhpur (In KWH)

	Jan	Feb	Mar	Apr	May	June	July	Aug.	Sept	Oct	Nov	Dec	Year
Elektro KSV-800 (0.85 kW)	21	13	33	28	67	101	78	45	26	10	13	17	452
Elektro WV-2 (2kW)	38	38	55	47	97	137	109	67	42	20	26	32	708
Elektro WVG-2 (2.5 kW)	43	44	66	55	118	172	135	86	51	22	28	37	857
Elektro WVG-5 (5.5 kW)	67	69	108	91	217	319	251	149	86	30	40	54	1481
Allgaier (7.5 kW)	38	62	148	116	350	548	411	171	99	23	22	21..	2009
Dowsett Holdings (25 kW)	14	38	125	76	231	412	293	86	54	10	7	5	1351

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AN INTRODUCTION TO DESERT GEOMORPHOLOGY

Bimal Ghose*

Romance of exotics and unknown excited in man an urge for expedition, and exploration with a geographical vision. As the scientific intelligence of man became more and more developed his simple geographical romance for unknown and unseen changed into a need for exploitation. This motive of exploitation is for new resources with an appeal of emancipation from harsh environment. There are, therefore, formidable memorials to the pioneer desert explorers like Blake (1858), Powell (1875), Gilbert (1875), McGee (1896), Darwin (1891), Bowman (1924), Bryan (1925), etc. etc. They were all inspired with a philosophy of environmental determinism (Cook and Warren 1973).

Pressure of population on resources and land, demand of imperialism, lebensraum, and an urge for expansion within established international boundaries (e.g. Israel) attracted man's interest in arid land research.

How to define arid land

Legion are the concepts of arid land or desert. Simple definition of a desert is a barren land which supports very few lifeforms that are capable of surviving in the extreme conditions. More precise definition are there based on climatic criteria with associated vegetation pattern and hydrological condition. Koppen, Trewartha, Thornthwaite, and Meigs define desert on climatic indices. According to these methods deserts having similar indices are similar. But the definition of a desert purely on climatic indices does not give a proper guideline for optimum utilization of arid land. The climatic indices do convey a meaningful physical state of the atmosphere and its effect. But, as the arid land research is directed to utilization of land and its resources its applicable definition should be in terms of land-use depending on anticipated rainfall. This relation between rainfall and landuse will be different for different altitude, latitude, time of rains and cropping season. Its lower limit may not follow the same isohyet in all arid regions. On one side of this limit animal husbandry is the only feasible form of landuse which is termed as true arid land. On the other side of this isohyet limit cultivation is unreliable which is done only for subsistence. This zone is called semi-arid, a transition zone to the subhumid condition.

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Wind Regime

Deserts are found mostly near the tropics on the continents, where on the equatorial sides these zones are swept by trade wind which blow in clockwise direction around high-pressure cells in the northern hemisphere and in the anticlockwise direction in the southern hemisphere. The patterns of wind circulation determine the patterns of dunes and wind erosion in the deserts.

The trade winds are only a part of the annual cycle of change. As for example in the winter month in the Sahara harmattan blows from the south west, while the westerlies sweep over the northern part of the desert. These winds create terrible sandstorms. In the Sahara the winter months have the most frequent and intense sandstorms. In the summer months the Sahara hamattan is moderated by intertropical convergence wind which is feeble and gentle (Powell and Pedgley 1969). In Australia, on the other hand, the southward migration of the northern tropical wind in summer generates the strongest sandstorms (Brookfield 1970).

Most of the mid-latitude deserts lie in the path of the westerly winds and consequently aeolian transportation of sand and dust has the westerly orientation. Even then there are local winds which modify the sedimentation pattern.

In the deserts of Siberia and Persia there is westward drift of the aeolian deposition (Gabriel 1958). In the Chinese deserts there is a predominant outward flow from a central high pressure zone in winter. In summer it is invaded by south east monsoon. Therefore the circulation of wind is irregular and complex (Petrov 1962). According to Hedin (1904) the dune forming wind in the Tarim Basin is from the east-north-east.

There are many other anomalous wind pattern in the general model of global climate (Cooke and Warren, 1973). In the desert of the Indian sub-continent the dune building wind is mostly the summer monsoon which blows from south west to north east. This region is also invaded in the winter months by wind from the north which modifies the dunes formed in summer. The morphology of the dunes therefore displays an interaction between these two circulations of the summer and the winter winds.

Apart from these winds, marked diurnal changes of temperature, that is, the intense cooling and heating of deserts, generates many local winds which are responsible for complex patterns of dunes not always oriented to the prevailing summer and winter winds.

The Death Valley of California provides one of the best examples of the thermal effect on the local circulation of winds. As it is said, here, the wind circulation has a 'respiratory' pattern. During the day

wind blows in from outside as the temperature in the Valley rises and on cooling at night wind blows out of the Valley (Cléments, *et al* 1963).

Topographic obstructions have a marked effect on the general model of global circulation of wind which is very obvious in the desert regions. The topographic obstructions generate extra pressure and deflection of winds that produce typical land features like obstruction dunes, aeolian pot-holes in the rocky surfaces, depressions as playas etc.

Hydrology

A popular concept is there that precipitation in desert is variable in frequency, intensity, duration and 'spottiness' (Cooke and Warren 1973). Period between two events of rainfall may be longer and total downpour may be smaller. But the degree of variabilities may not always vary very much relatively from that in the more humid zone. Russel (1936) observed in the south-western deserts of the United States that rainfall may be less erratic in its distribution than it is in Wisconsin and other humid regions of that country. The false impression of the apparently greater spotty distribution of desert rains is due to small totals and wide vistas.

The precipitation variabilities are always studied in terms of runoff. But data on desert runoff is very very meager. On the other hand it is difficult to estimate runoff from climatic data which reveal only precipitation residual. The total precipitation is highly subject to rainfall rate, infiltration, deficiency of water of the surface material, and the topography. These are all unknown variables of which the effective runoff is a function. In deserts of similar order higher and less spotty rainfall will therefore not necessarily increase the runoff in similar way.

Cooke and Warren (1973) have studied in the Mojave Desert of California ten years' record of the runoff in relation to daily precipitation above 19 mm, 25.4 mm and 34 mm. Their observations are that "if runoff occurs when daily precipitation exceeds 19 mm, its frequency will be once a year in many places and once in two years almost everywhere; if the 25.4 mm level is taken the frequency would be approximately once in every three years; and if there is runoff only when daily precipitation exceeds 34 mm, then it will be experienced only once or twice in a decade."

In Mojave Desert where maximum rain occurs in winter, runoff is more likely as both the temperature and evaporation are low during this period.

Detailed studies of rainfall and runoff in the arid land will reveal fantastic hydrological conditions and that runoff is not directly related to the amount of daily precipitation.

Very little is known about the movement of water from watershed to channel in a desert. But it is known from the movements of the water-borne particles that water moves down the catchments mostly in thin sheets or rills.

Except in the cases of allogenic drainage, flow of water in the channels is intermittent or ephemeral. Most of the streams are underfit, that is, they are too small for the valleys through which they flow. The underfit valleys like the Luni, and the Jawai in Rajasthan are the testimonies of a geologically recent climatic change from humid to arid.

Processes leading to geomorphological changes:

Yield of sediment expressed in $\text{metre}^3/\text{Kilometre}^2/\text{year}$ is one of the measures of the geomorphological activity in a desert. This indicates the amount of loose material produced and removed either by aeolian action or by fluvial or by fluvio-chemical. All the typical landforms in desert reflect the action of these processes. Of course judging from global erosional processes, sediment yield from deserts is very small as compared to humid regions. But the sediments in the humid regions are more quickly transported to the lower levels while in arid regions they accumulate in the forms of dunes, alluvial fans, talus on the hill slopes and pediment surfaces and under the fluvio-chemical processes, as salt basins and evaporites along the underfit valleys or ephemeral streams.

The principal factors that create landforms can be classified as endogenic and exogenic. The endogenic processes are those which are volcanic and tectonic. The exogenic processes are those which are associated with ice, water and wind. Endogenic activities uplift initial landmass like mountains, continents and islands above the sea level. The exogenic processes modify the initial land surface by denudation, transportation and accumulation of debris. From the event of emergence of initial land surface to the stage of absolute denudation, planation and accumulation of debris or sediments at the lowest levels is according to Davis (1922, 1954), the cycle of erosion. According to him, until another endogenic earth movement takes place in the peneplaned region next event of cycle of erosion will not take place. But if before completion of one cycle of denudation tectonic movement takes place, the previous cyclic process will be interrupted and a new one will begin. Incised meandering valleys, river terraces etc. are all indicative of such polycyclic rejuvenated landforms.

In the deserts which are tectonically stable, like those of Australia and Kalahari, the events of endogenic disturbances are very rare, whereas the deserts of California and Chile being tectonically unstable endogenic activities are more frequent. In this respect the Thar Desert

of the Indian subcontinent is tectonically stable and there is no evidence of endogenic disturbances since the Tertiary period. However, in a given area the inter-action between these two processes shapes the morphology of land. Tectonically disturbed desert will experience frequent earthquakes, faulted, tilted and folded rocks; dislocation, reversion and blocking of drainage channels. Therefore there are great diversities of the desert landforms. Generalizations are not possible.

The Geomorphological system in Deserts

Cooke and Warren (1973) have rightly said that "a general model is clearly desirable in any introduction to desert geomorphology. It is needed as a means of categorizing the literature in a meaningful way as a source of hypotheses that can be tested by observation, to define the field and the relationships of its component parts and to help in identifying areas about which little is known or areas in which knowledge is vital to hypotheses". The birth of geomorphology as a discipline is from the themes like sequences of evolution and/or climatic interpretation. These are of course very useful academic themes but these are not always fruitful for all purposes of arid-land-research.

The sculpturing of earth surface is a function of energy input. Chorley (1962) states that it is a dynamic open system in which work is performed, energy is dissipated and entropy increases (Leopold and Langbein 1962). This has a measurable morphological expression. Energy comes from solar sources and from tectonic and gravity. Solar energy, on reaching the earth surface, is used up in a multitude of ways. Some is reflected back to the space, some is used up in performing thermo-chemical weathering of the rock mass and the rest is used up in energizing the atmosphere for circulation of rain and wind. These are the important agents of land denudation and sculpturing.

Geomorphological aspects of distribution of water and salt

All problems of earth science in respect of arid zone can be summarised as (1) the dearth of water, (2) salinity and (3) menace of drifting sand and active dunes. With this context survey of basic resources, research on applied geomorphology and remote sensing are done. For quick appraisal of resources, several methods of remote sensing through aerial photographs were evolved and applied for survey and research in applied geomorphology. The water and salinity are discussed here with a geomorphological outlook

Several methods have so far been adopted to locate underground water in arid lands. In Rajasthan, water divining, geophysical probing and lithological investigations have so far been done to provide water to this thirsty land. All these studies involve lot of expenditure without comparable success. In many cases deep tubewells bored on the basis of such studies unearthed only perched and fossil water at great depths which is not sweet, nor does it assure perennial supply for obvious reasons.

So far the salient contributions made in this field of applied geomorphology was to discover the courses of disorganised and buried streams which have their headwater connections with the Aravalli and other catchments. The distribution of all such streams were reconstructed by remote sensing without any costly geophysical aid or field traverses. This discovery proved that rain water from the catchment areas flows subterraneously along these buried channels which are the potential and perennial sources of sweet water within easy reach of poor farmers (Ghose, 1964, 1965).

This method was adopted to locate shallow subsurface water in many parts of arid Rajasthan and in the CAZRI campus also. After geophysical survey one site was located in the CAZRI campus for tubewells which was not approved by us on the basis of our theory. Recently, another tubewell has been bored in the new area of the CAZRI campus which was previously preferred by us. The water discharge from the latter is definitely more which proves the theory.

The economic implications of this discovery are that the flow of fresh water through the buried streams can be located without any expensive and speculative field survey and geophysical probing which very often deliver deceptive data. Since this water is available at shallow depth farmers can afford to dig their own wells.

There are numerous salt basins in Rajasthan. Soil and water in many places are contaminated with salt that inhibits plant growth. But no measure can be effective unless reliable information of the cause and distribution of salts are known.

Holland and Christie (1909) conducted some experiments at Pachbhadra and they propounded a theory that the origin of Pachbhadra salt is the Rann of Kutch, which is frequently inundated with brine that dries up in dry seasons leaving an efflorescence of sea salt on the surface. According to them this salt is transported by wind and is dropped in the inland salt basins (and supposedly not on the adjoining areas). Considering all points of geochemistry, and aerodynamics, this theory has many weaknesses (vide proceeding of National Institute, 1952).

Contradicting this theory, Godbole postulated that all these salt basins are the relics of an extended arm of the Arabian Sea. When it receded

pools of marine water were left behind which eventually transformed into salt basins. This theory does not tally with the chemistry of all the basins, nor it is in conformity with the geological history of earth movements. Certainly the level of the Arabian sea did not rise as high as the Aravallis to create the Sambar lake which lies astride this range.

The theory which has been propounded at CAZRI (Ghose, 1964) is that all these salt lakes are the sites of confluences of the erstwhile drainage systems. When these were flowing to their brims in a humid era silt load carried by water deposited at the confluences which were gradually silted. This process created conditions of waterlogging and all the salts accumulated near these points. Aridity set in and rivers ceased to flow above the ground, but subterranean trickling was there followed by capillary rise and evaporation of water resulting in the increasing concentration of salt. This is the story behind the origin of salt basins and saline soils of Rajasthan. There are some spots where the salinity is not apparent on the surface. But if these spots are subject to profuse irrigation it will take no time to bring the underground salt on the surface and to finally write off that land from agricultural account. On the basis of this theory all these spots which are not yet saline can be pre-detected and the farmers may be adequately warned to take special care in irrigation.

This theory precludes the necessity of soil survey and chemical analysis of soil to demarcate the distribution of saline soils. Even after soil survey, distribution of salinity cannot be precisely demarcated nor it can sense the existence of subsurface salinity which might eventually manifest itself following liberal irrigation.

It has been discovered that evaporites like gypsum etc. are genetically related to the disorganised and buried drainage system (Ghose and Singh, 1968). In order of solubility, the order of deposition of the evaporites in the buried channels is the head followed by carbonates, calcium sulphate (gypsum) and highly soluble chlorides at the confluence. As for example the gypsum deposits at Thob and salts of Pachbhadra are on the same buried channel. With the help of this theory one will be able to discover the deposits of evaporities by remote sensing without any expensive field survey.

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AERIAL PHOTO-INTERPRETATION AND PHOTOGRAMMETRIC TECHNIQUES AND THEIR APPLICATION IN GEOMORPHOLOGICAL STUDIES.

Surendra Singh*

A. AERIAL PHOTO-INTERPRETATION

Photographic interpretation is defined as "an act of examining photographic images of objects for the purpose of identifying the objects and deducing their significance." (American Society of photogrammetry, 1952).

Types of aerial photographs

Aerial photographs may be of four types:

1. Vertical or Zenithal: Photographs whose optical axis make an angle of less than 3° with the vertical or perpendicular.
2. Divided Verticals: Photographs taken simultaneously by the same aircraft with two cameras, of which one is vertical and the other is inclined at least 8° from the perpendicular. (These are generally small scale photographs).
3. Low Obliques: All photographs, whose optical axis makes an angle greater than 8° with the perpendicular, but in which the horizon is not visible.
4. Panoramic (High Obliques): Oblique photographs in which the horizon is visible.

Sizes of aerial photographs

Aerial photographs are of different sizes: 12×12 , 13×18 , 18×18 , 18×24 , 24×24 , 30×30 , 24×48 cm., the sizes which are generally preferred being 13×18 , 18×18 and 24×24 cm.

The scale of the photographs vary from 1:500 to 1:60,000, the scales which are commonly used for normal work being between 1:5,000 to 1:30,000.

Basic considerations in photo-interpretation

(a) *Elementary characteristics*: Aerial photographs cannot be usefully employed without a knowledge of their characteristics. These are marked on the aerial photographs themselves, in a code form as a foot-note. These characteristics are:

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The nature of the mission: number, designation of the region (project area) surveyed, the Organization which has taken the photos etc.

The date of flight.

The time of the day.

The focal length of the camera.

The scale of negative.

The aerial number of the photograph, indicating the run and the number.

Area covered by the photographs and the photo index.

Orientation of the photographs.

Stereoscopic examination.

Calculation of scale.

Some photographs also indicate altitude, type of camera, film roll number, exposure number etc.

Besides the above legends, all aerial photographs carry four marginal and one central marks, which enable the intersection of vertical and horizontal lines to locate the optical centre of the photograph, which is referred to as the principal point. The marginal marks are known as the fiducial marks. Recognition of these marks is of great importance for all further operations.

(b) *Principles of objects recognition*: Most persons have little difficulty in recognizing features pictured on oblique photographs, for such views appear relatively "normal" to the human eye. On the other hand, a vertical or near vertical view from an altitude of several thousand feet can be quite confusing, particularly for individuals who have never ridden in an air plane. An experienced aerial photo interpreter exercises *mental acuity* as well as *visual perception*, and consciously or unconsciously must evaluate several factors in identifying features on vertical photographs. Prominent among these are:

1. *Shape*: This characteristic alone may serve to identify some objects. For example, a traffic intersection, an airfield, or a foot ball stadium.
2. *Size*: Both relative and absolute size are important. Thus a metal road will not be confused with a cart road, nor a small hut with a large building. Size of course, is a function of the photographic scale.
3. *Photographic tone*: Objects of different colour have different qualities of light reflectance and therefore register in varying shades or tones on a photograph. Obvious examples are cultivated versus fallow fields, or coniferous trees versus broad-leaved tree crowns.
4. *Pattern*: If the spatial arrangement of trees in an orchard is compared with that of natural vegetation, a contrast in patterns will be evident. As another example, a pattern produced by contour

plotting might reveal information on topography, type of soil, or the nature of the crop being cultivated.

5. *Shadow*: A truly vertical photograph of the isolated objects, such as a telegraph pole might present a difficult identification problem, except for the characteristic shadows cast by these objects. By the same token, shadows may also be obstructive to the interpreter by obscuring ground detail, e.g., shadows along tall buildings or beneath dense canopies of vegetation.
6. *Topographic location*: Relative elevation, including drainage features, can be an important clue in predicting soil conditions or the probability of encountering a particular vegetative association. The natural occurrence of willow trees on flood plains or river sandbars provides a good example.
7. *Texture*: The degree of coarseness or smoothness exhibited by photo images can be a useful key to identification. Texture, just as object size, is directly correlated with photo scale. Contrast the texture of grass with that of a corn field, or saplings with large over-mature trees.

(c) *Study of Patterns*: A photo interpreter must tackle the following questions in the course of analysis and deduction:

1. Is the pattern location related to: (a) land, (b) water, (c) regional and (d) local?
2. Is the frequency of its occurrence: (a) continuing (b) transient (c) repetitious?
3. Is it seasonal, i.e. (a) spring (b) summer (c) autumn (d) winter?
4. Is it (a) common or (b) uncommon?
5. Is it apparently (a) natural or (b) cultural?
6. Is the pattern (a) random or (b) systematic?
7. Is the tone of the pattern: (a) consistent, (b) lighter, or (c) darker?
8. Does the unit vary in (a) size, or (b) shape?
9. Is the pattern a unit in itself or subject to breakdown or identity?
10. Is the pattern near or related to similar pattern?
11. Is it or (a) the same, or (b) different datum?
12. Is it related to (a) similar, or (b) dissimilar water bodies?
13. Is it related to (a) similar, or (b) dissimilar landforms?
14. To what major natural or cultural activity does it apparently relate.

(a) *natural*: (1) coastal waters, (2) lakes and rivers, inland waters, (3) forest and cover, (4) mineral, (b) *cultural*: (1) agricultural, (2) residential, (3) commercial, (4) industrial, (5) transpiration, (6) storage, (7) military, (c) oceanography, (d) meteorology, (e) specify other.

15. Note and evaluate effect of following: (a) surrounding areas on tone, size, and shape of pattern, (b) distance or nearness on tone, size

and shape of pattern, (c) scale on image tone, size and shape of pattern, (d) tilt, bearing or dip on tone, size and shape of pattern, (e) exposure, filters, or degradation on tone, size and shape of pattern, (f) recording sequence on tone, size and shape of pattern.

KNOWLEDGE OF ENVIRONMENTAL FACTORS AND PHOTOGRAPHIC IMAGE CHARACTERISTICS

(i) The quality of aerial photograph is an important aid to obtain reliable data. The property of the aerial photographs is apt to change due to technical factors like tone, film, paper, photographic chemicals, techniques of photo processing, printing and exposure. To eliminate such unavoidable defects, it is necessary to reduce or intensify the tone of photographs for normal contrasts for accurate photo-interpretation (Ghose and Singh, 1965).

(ii) The scale of the aerial photographs is of prime importance in photo-interpretation. The photographs of 1:15,000 and 1:20,000 scales are well suited for vegetation, land use, forestry and geological photo-interpretation and that of 1:31,000 and 1:40,000 scale have been accepted for the interpretation of land form, soil and also for soil-landscape relationship.

(iii) The primary knowledge of the terrain factors of the area like soil, rock, vegetation, soil moisture, geological events, drainage patterns, ground relief, depositional and erosional landform features is essential to obtain reliable data from aerial photographs.

(iv) The climatological and meteorological factors like atmospheric haze, clouds, sun angle and the seasons of the year are also to be taken into consideration for photo-interpretation.

(v) The effects of the tilt and tip on the shape of the ground object, effect of relief on the displacement of the image of the ground object, variation in the flying height causing scale error and also the chromatic and spherical lens aberration are sometime avoided for systematic photo-interpretation.

METHODOLOGY AND VARIOUS STAGES IN PHOTO-INTERPRETATION

The art of photo-interpretation depends on deductive and inductive methods. The photo-interpretation is the critical examination of the aerial photographs followed by field check, depending on the type of survey and the degree of details required. The photo-interpretation involves the following stages:

(i) Indexing and rapid scanning of the photographs and to lay them into respective runs to get a compositive view of the area to be surveyed.

- (ii) Selection of right and left hand photographs to avoid pseudo-scopic effect.
- (iii) Placing the aerial photographs on a photo carriage at a proper distance.
- (v) Determination and transfer of principal points on each stereo-pair and to join them to get an air base.
- (v) Setting up the mirror stereoscopic with the eye base of the instrument parallel to the stereoscopic base of the photographs to get a perfect stereo-model.
- (vi) Preliminary photo-interpretation of the photographs for identification and deduction of significance of the images of ground objects.
- (vii) Selection of query points and marking of traverse routes in different photo patterns.
- (viii) Field traversing along the selected query points to collect the data on various geomorphological aspects and to compare the data already collected from the aerial photographs.
- (ix) Final photo-interpretation, preparation of photo legend and analysis of samples collected from the field.
- (x) Transfer of data from the air photos into the base map on the required scale with the help of Zeiss Sketchmaster and Radial-line method.
- (xi) Preparation of final maps using appropriate symbols and writing of report.

FUNDAMENTALS OF AERIAL PHOTO-INTERPRETATION AND ITS ADVANTAGES AND DISADVANTAGES

- (i) *Fundamentals of aerial photo-interpretation*
 - (a) It is never an end in itself. The photo serves as a source of information in various investigations.
 - (b) Aerial photo-interpretation must be based on scientific principles and not on hypotheses.
 - (c) It should only be applied by specialists in their own field of science. These specialists have to be trained in techniques and methods of photo-interpretation in order to understand its possibilities and acquire experience.
 - (d) It should only be applied to improve the results of the investigation and to facilitate work.
- (ii) *General advantages of aerial photo-interpretation*
 - (a) The methods and techniques can be used for any terrain, even in unknown areas.
 - (b) The results of the investigation are often more accurate.

(c) The work can be done in a relatively short time and consequently the work capacity of individual specialists is greatly increased.

(d) The work is carried out more economically and efficiently, much information can be collected even before the field investigation starts.

(e) The cost of investigation is considerably reduced.

(f) New possibilities to study special problems have been created, in particular for large and thinly populated areas.

(iii) *General disadvantages of aerial photo-interpretation*

(a) Many persons, without a thorough knowledge of aerial photography or of the field of application, use them wrongly, bringing the interpreter into discredit.

(b) It is often not recognized that introduction of aerial photo-interpretation implies a change in the normal procedure of field investigation.

ADVANTAGES OF AERIAL PHOTOGRAPHY

In land and vegetational surveys of any size, the use of aerial photography, usually in combination with ground work has certain definite advantages over ground methods used alone. These advantages which vary in degree with local requirements and conditions of operation are as under:

1. Increased accuracy in delineation and mapping of planimetry; the larger the scale of the photograph the greater the degree of accuracy obtained.

2. Provision of an extensive and clear-cut view of ground conditions with a relatively high degree of detail, thus showing at a glance those areas that require immediate attention (e.g. in the case of soil erosion) are of sufficient value to warrant a more intensive examination on the ground.

3. By the use of a stereoscope, air photographs can provide a three-dimensional view of the physical features, vegetation etc., on the land surface. This is an important asset in any type of land-use survey and particularly in a forest survey, as the third dimension, the height of the trees is indicative of stand, age, volume, site and quality.

4. Increased speed in obtaining and mapping information. The combination of aerial photography and field work can give detailed results in a comparatively short time.

5. Provision of a permanent record of conditions at the time of photographing. This record can be brought upto date when required by re-photographing the area, probably at a much lower cost than the original operation.

6. Under certain conditions, aerial photography is more economical than other methods for securing comparable data.

7. Provision of coverage of relatively inaccessible areas that are difficult and costly to reach by ground methods. This is, of course, a special advantage in the reconnaissance and mapping of extensive undeveloped forest regions, where ground surveys can at best cover only a small percentage of the area and as the basis for the opening up the new country where the initial location of transportation lines may have a vital bearing on the future development of the region and well being of its population.

8. The possibility of recording temporary conditions over wide areas, such as the effects of a natural catastrophe, damage by pests, the state of floods and volcanoes, as well as the changing conditions of field cultivation and forest management.

LIMITATIONS OF AERIAL PHOTOGRAPHS

1. Aerial photographs will not supplant ground surveys (by land ground surveys, it is meant land form, land-use and vegetational surveys and not survey for preparation of maps). Aerial photographs and field work (ground survey) are best used in combination and the amount of ground work necessary will depend on a number of factors, chief of which are the accuracy and detail required, the complexity of the region and the scale of the photographs.

2. Air photographs may not give the desired information on any specific problem unless the photography is directed by an expert who has a clear understanding of what is required and of the relationship between operational variables (e.g. cameras, photo scale, etc.) and photographic results.

3. While aerial photographs are used extensively in the preparation of topographic and planimetric maps, the photographs themselves can seldom be considered as accurate maps.

4. Aerial photographs will not eliminate ground surveys methods. In fact, they cannot be used without ground control; an aerial photograph is just a picture until it is measured, interpreted, oriented, and compiled into a map or a photo map on the basis of information on ground control supplied by field surveys. Such a field survey may consist of measured distances on the ground and locating bench marks etc. Once oriented on the basis of ground control, the aerial photograph becomes a map on which is compiled the greatest amount of detail on natural and cultural features that can be devised.

Verticals

Vertical aerial photographs are generally used for preparing accurate planimetric and topographic maps, for land-use surveys, in forestry for

management and logging surveys, and for general purposes. The advantages of vertical aerial photographs are:

1. In general, they give the best possible view of the country.
2. May be viewed stereoscopically?
3. Are best adapted for mountainous country?
4. Will produce the most accurate map?
5. Will permit the transfer of information from photograph to map with relatively high speed and accuracy?
6. May be used for plotting contours?

The chief disadvantage is that the cost is higher than for other types of photograph.

Obliques

Oblique aerial photographs, particularly low obliques are used in Canada, for forest inventory purposes. The advantages of oblique aerial photographs are: *High obliques*: 1. Will cover a relatively large area in a single photograph, though much detail in the background may be too poorly defined to serve any useful purposes. 2. Cost is about one-quarter that of verticals of equivalent scale. *Low Obliques*: 1. Cost is about one-third that of verticals of equivalent scale. 2. Will provide a particularly good view of forest vegetation? 3. Are well studied for periodic re-photography required to record change in vegetation cover? 4. Owing to the relatively steep angle at which the photographs are taken, in comparison with high obliques, their use in mapping moderately rough country might be developed.

B. AERIAL PHOTOGRAMMETRY

Photogrammetry is defined as "the science or art of obtaining reliable measurements by means of *Stereoscopic parallax* of photograph" (American Society of Photogrammetry, 1952).

Types of Parallax: If a nearby object is observed alternately with the left and right eye, its location will appear to shift from one position to another. This apparent displacement, caused by a change in the point of observation is known as parallax. Parallax is a normal characteristic of overlapping aerial photographs and it comprises the basis for three-dimensional viewing. The apparent elevation of an object is due to differences in its image displacement on adjacent prints.

Two measures of parallax must be obtained in determining object heights on stereoscopic pairs of photographs. *Absolute stereoscopic parallax* (X-parallax) is the sum of the distances of corresponding images from their respective nadirs. It is always measured *parallel* to the flight

line.* *Differential parallax* is merely the difference in the absolute stereoscopic parallax at the top and base (ground level) of the object being measured. The basic formula for determining object heights or differences in elevation from parallax measurements is:

$$\text{Height of object (ho)} = \frac{H \times dP}{P + dP}$$

Where H = height of aircraft above ground datum.

P = absolute stereoscopic parallax at base of object being measured.

dP = differential parallax.

If object heights are to be determined in feet, the height of the photographing aircraft (H) must also be in feet. Once the exact photo scale has been ascertained, the flight altitude can be found by multiplying the RF denominator by the camera focal length. Absolute stereoscopic parallax (P) and differential parallax (dP) must also be expressed in the same units ordinarily, these units will be hundredths of millimetres or thousandths of inches.

For reasons of convenience and ease of measurement, the average photo base length of a stereo-pair is commonly substituted as the absolute stereoscopic parallax (P) in the solution of the parallax formula. This procedure produces reasonably accurate results if : (1) photographic tilt is less than 3 degrees, (2) both negatives of the stereo-pair were exposed from the same flight altitude, (3) both nadirs, or principal points, are at the same ground elevation, and (4) the base of the object to be measured is essentially at the same elevation as that of the principal points. In short, use of the average photo base as "P" presents no difficulties for near-vertical photography of relatively flat terrain.

Variations in the elevation of the two principal points of a stereo-pair will result in differing measurements of corresponding base lengths. In such instances, the use of the *average* photo base length supplies an estimate of the absolute stereoscopic parallax for an imaginary datum midway between the actual principal point elevations. A more serious situation is presented when the elevation at the base of the object

* If the paired photographs are assumed to be vertical (i.e. tilted less than 3 degrees) and taken from the same flight altitude, Y-parallax or displacement at right angles to the flight line is considered non-existent. Furthermore, principal points can be substituted for nadir locations in measuring absolute stereoscopic parallax.

being measured differs by more than 200 or 300 feet from that of the principal points. Here, a new value should be calculated for "P", as described below:

1. Set up the stereo-pair as for normal viewing. Flight lines should be superimposed and images separated about 2.2 inches. Both prints should be firmly fastened down to avoid movement.
2. Measure the distance between the two principal points to the nearest 0.01 inch with an engineer's scale.
3. Measure the distance between corresponding images on the two photographs at or near the base of the desired object. Subtract this distance from that obtained in (2) to obtain the absolute stereoscopic parallax at the base.

Differential parallax (dP) is usually measured stereoscopically with a parallax bar or stereometer employing the "floating mark" principle. Actually, the concept of differential parallax can best be illustrated by direct scale measurement of highly-displaced images. Eg., the height of a monument has to be calculated. The nominal scale of 1:4,800 is first corrected to an exact scale of 1:4,600 at the base of the monument. A 12-inch camera focal length as used and the flying height above ground (H) is 4,600 feet.

Average photo base length (P) for the stereo-pair is 4.40 inches. Absolute stereoscopic parallax at the base and top of the monument is measured parallel to the line of flight with an engineer's scale; the difference (2.06-1.46 inches) is dP, the differential parallax of the displaced images.

Substituting the foregoing values in the parallax formula, we have:

$$h_o = \frac{4,600' \times 0.60''}{4.40'' + 0.60''} = \frac{2,760}{5} = 552 \text{ feet}$$

This is an unusually precise estimate, for the actual height of the monument is 555 feet, 5 inches. Had the nominal scale of photography (1:4,800) been used instead of the corrected, the height would have been computed as 576 feet, an error of 21 feet. Errors of similar magnitude would result from inaccurate parallax measurements. Thus the necessity for precision can hardly be overemphasized.

An accurate determination with an engineer's scale would be virtually impossible and dP has to be measured under the stereoscope with a parallax bar or other "floating mark" device. Assuming a flying height of 13,750 feet, average photo base of 3.60 inches, and a differential parallax of 0.40 millimeter, the total height of a tree, for example, is calculated as below:

$$h_o = \frac{13,750 \text{ feet} \times 0.40 \text{ mm}}{91.44 \text{ mm} + 0.40 \text{ mm}} = \frac{5,500}{91.84} = 59.9 \text{ or } 60 \text{ feet.}$$

Most stereometers yield dP readings in millimeters while P is more commonly measured in inches. Although conversion to identical units is not difficult, the solution of the parallax formula can be simplified by use of conversion factors.

C. APPLICATION OF AERIAL PHOTO-INTERPRETATION IN GEOMORPHOLOGICAL STUDIES

The aerial photo-interpretation is particularly advantageous in the classification, investigation, and evaluation of the land as a resource, because the landforms are the most conspicuous features which can be directly seen under the stereoscope in three-dimension. The landform features resulting from fluvial, aeolian, glacial, glaciofluvial, lacustrine and marine actions can be readily identified, accurately interpreted and systematically mapped from the aerial photographs. The genesis and the potentiality of the landforms can be studied from the photo-interpretation without involving much time and cost.

Geomorphological maps depicting the landform features formed by various geomorphic processes can be prepared from the aerial photographs by method described by Ghose and Singh (1966). These maps are also used by the other earth scientists to derive the information of their own fields. The dune maps are also prepared from the aerial photographs because it is easy to demarcate the shape, size and boundary of different types of dunes. The dune map showing the orientation and distribution of sand dunes prepared from the air photos forms the basis for rational management of dunes. Pandey *et al.*, (1964) with the help of aerial photo-interpretation have studied types and systems of dunes in the central Luni basin and they have recognised five types and two systems of dunes.

The aerial photographs are extensively used to study the present and prior drainage patterns and their orientation. The drainage patterns like parallel, dendritic, subdendritic, trellis, rectangular, radial and linear can very well be identified and interpreted by their major characteristics of density, degree of uniformity, degree of integration, degree of control, orientation and angularity. The destructional and constructional drainage and their patterns can easily be studied from the aerial photographs. The courses of the dead drainage channels which are not visible even on the ground, can be reconstructed from the aerial photographs. The drainage map showing the present and prior drainage systems compiled from the air photos can be used for assessing and exploiting the ground water.

The soil salinity and alkalinity are also serious problems in the land use planning. The interpretation of the aerial photographs has revealed that the origin and distribution of soil salinity and alkalinity are associated with prior drainage system (Ghose, 1964). The courses of the prior drainage channels reclaimed for agriculture are turned into 'usar' due to prolonged irrigation, because they are the locations of subsurface brines. The major amount of salt has accumulated along the confluences of the dead drainage channels. Thus the aerial photo-interpretation gives an accurate picture of the origin and occurrence of saline depressions which are common features in arid regions. If these pockets are avoided, the rational and scientific land use and irrigation planning can be done with the help of the aerial photographs.

The extent and the intensity of the erosion which affect the land use to a great extent can be studied from the aerial photographs. Different erosional and depositional features created by water and wind consisting of gullying, rilling, sheetwash, blowouts, sand sheeting and sand drifting are discernible on the air photos which can be interpreted and classified according to their intensity. Thus the boundaries of the areas affected by different types and degrees of erosion can be accurately delineated and mapped. Ghose *et al.*, (1968) have used this techniques in the study of erosion and its effect on the land use in the central Luni basin of western Rajasthan. The amount of the vertical dissection along the river banks and piedmont plains can be estimated by photogrammetric method. The boundaries of the areas affected by the various types of erosion can be transferred on the base map and the erosion assessment maps can be prepared on the various scales according to the suitability of the areas. The erosion maps prepared from the aerial photographs form the basis to delineate the priority areas for conservation measures.

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LAND USE MAPPING BY AERIAL PHOTO INTERPRETATION TECHNIQUE

Amal Kumar Sen

Abstract

Land use survey and mapping deals with the classification of lands according to their present utilisation. This is an obvious requirement to assess the use and misuse of land. Use of aerial photographs expedites land use survey and increases the efficiency of mapping. The paper deals with the methods and techniques of aerial photo interpretation now being used in the Central Arid Zone Research Institute of India for land use mapping in Indian arid zone. The basic principles and scale requirements of the photographs are described first. The recognitions of land use in photographs are based on "*edge gradient*", "*fishing expedition*", "*probability test*" and "*convergence of evidence*" studies. These are described in the text. Three sets of interpretations are needed prior to field survey. These are studies on *regional aspects*; *pattern elements* and *photo elements*. These studies enable to prepare a photo map and a 'key' of interpretation and field checking. Once the photographic images identified are correlated with the type of land use in the field, the sequence of events which form a particular land use unit can often be mapped by means of photo-interpretation.

The paper concludes with notes on methods of the photo interpretations and photo characteristics of major land use units of arid zone of India as standardised in course of works during the last eight years.

Land use map

Assessment of use and misuse of land is the prerequisite to plan the utilization of resources. Land utilization survey and mapping is the obvious requirement to make such estimates.

A land use map shows the distribution and extent of different lands, as classified, according to their present use. The level on which the different land use classes are classified and cartographed is based on the type of survey undertaken, viz., reconnaissance, detail-reconnaissance or detail. It also depends on the materials, data and informations available. A land use map tends to evaluate the lands actually used on the one hand and also the lands available for further use on the other. The map should be helpful to predict the use and misuse

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of land and to recommend its suitability for better use like farming, forestry, pasture growing, settlement etc. under different systems of management. Hence the ultimate purpose of land utilization survey and map is to arrive at systems of land use and management best suitable to the kinds or resources and capabilities of the land composing it.

Depending upon the data, material and informations available; the intensity of survey and the resulting details two broad types of land use maps are distinguished.

(a) General land use maps: These are small scale, often 1: 2,000,000 or less but never exceeds to 1: 1,000,000 scale maps and prepared on the basis of available data. Mostly the data are collected from revenue or settlement records of government departments. Choropleth maps are often designed and the areas under different categories of land use and sometimes their changes are shown in graphical forms. The extent and pattern of land use classes cannot be depicted in these maps. But these maps are often helpful to visualise the different types of present land use, their comparative analysis and thus provide good indications to formulate the mapping units to be drawn for land use surveys and consequent mapping.

(b) Land use maps based on survey and remote sensing device : Based on the intensity of survey, topographical maps and aerial photo interpretations and collection of field data, local informations etc. three types of land use maps can be prepared from the resulting details viz., reconnaissance; detail reconnaissance and detail land use maps. These are large scale maps being 1: 250,000; 1: 100,000 to 1: 50,000 and 1: 15,000 or more in general in cases of reconnaissance, detail reconnaissance or detail maps respectively. These maps show the extent and degree of land use classes and thus depict the actual pattern of land use. These are helpful to delineate or find out problem areas, planning and execution works.

Land use classification in desert eco-system

The efficiency of land utilization maps depends on scientific selection of the mapping units. The land use practice differ in different eco-systems. Influenced by a set of physical and biotic environment—a system with its own peculiarities may be recognised and mapped within which mode of human adaptation tends to develop particular types of human activities. This is eco-system. On the basis of this definition an eco-system is evident along the western margin of the land mass in the sub-tropical belt of the globe. This is desert or arid zone eco-system, which has the problems of its own. Categorization of land utilization units in arid zone should be based on the considerations of these problems. Considering the land use, the problems of Indian arid zone can be summarised as follows (Sen 1974).

- (i) Aridity and drought.
- (ii) Low water table-low yield and low fertility of soil.
- (iii) Absence of surface drainage.
- (iv) Salinity hazard-increase of salinity with depth.
- (v) Extensive sandy and rocky lands.
- (vi) Movement of desert sands and sand dunes.
- (vii) Sparse and scanty vegetation—Absence of forest-less arable land.
- (viii) Large cattle population and livestock.
- (ix) Nomads and semi-nomads.
- (x) Temporary and deserted villages.
- (xi) Absence of fuels.

With these the followings should also be added :—

(a) In the arid zone the cultivated lands are in general not regularly cultivated in all the years. Many of the lands are cultivated in rotation after putting into fallows from 1 to 5 years. These are short or current fallows. The short fallows should be considered as cultivated lands.

(b) Many of the lands in arid zone are kept fallows for want of water. They are cultivated only in the years of very favourable rainfall. These are long fallows and if the irrigation facilities are made available those can be converted into permanent cultivated lands.

(c) The grazing lands in arid zone not only comprise of the land under permanent pasture but waste lands and long and short fallow lands as well.

(d) In arid zone there is a dearth of forests. Forests, where exist, are either thin, open or light forests. Natural forests are rare. But afforested areas and plantation areas may exist in the form of wind belt, shelter belt etc. Hence the classification of forest under arid zone condition should differ from that of other eco-systems.

(e) The classification of settlements of arid zone require separate treatment.

All these problems are of unique character, require special treatments and necessitate the demarcations of the followings in the land use maps.

(1) *Pasture and grazing land :*

- (a) Permanent pasture.
- (b) Other pasture lands.

- (2) *Waste lands* :
 - (a) Sandy waste, (b) Rocky and gravelly waste and (c) Saline waste.
- (3) *Water features* :
 - (a) Wells : (i) Deep, (ii) Moderately deep, (iii) Shallow, (iv) unused;
 - (b) Tank—(i) Permanent, (ii) Seasonal.
- (4) *Settlements* : (i) Permanent, (ii) Semi-permanent and (iii) deserted.
- (5) *Cultivated lands* : (i) Permanently cultivated, (ii) Short fallows and (iii) Long fallows.

Considering these problems and on the basis of experiences drawn while conducting land utilization mapping in the arid zone a scheme for classification of land use units for land use maps had been worked out (Table 1).

Table 1 : *Tentative scheme of land utilization units proposed for arid zone.*

1. Settlement

- (A) Rural settlement :
 - (a) Villages with compact settlement (unplanned).
 - (b) Villages with scattered settlement (unplanned).
 - (c) Linear compact villages.
 - (d) Temporary villages.
 - (e) Deserted villages.
- (B) Urban areas :
 - (a) Administrative.
 - (b) Residential.
 - (c) Mining.
 - (d) Agricultural.
 - (e) Religious centre.

2. Water features :

- (a) Rivers.
- (b) Playas and depressions—salt lakes.
- (c) Wells : (i) Deep, (ii) Moderately deep and (iii) Shallow.
- (d) Tanks : (i) Permanent and (ii) Seasonal.

3. Waste lands (also come under grazing land):

- (a) Sandy waste including shifting sand dunes.
- (b) Rocky waste.

- (c) Saline waste.
 - (d) Gravelly waste.
4. Pasture land and grazing ground :
 - (a) Permanent pasture (Oran).
 - (b) Waste lands and current fallows (suitable representation is to be made so that both are indicated).
 - (c) Hay, thorn, weeds and shrubs—where the grasses are periodically out.
 5. Forest land :
 - (a) Natural forest : (i) Thin and (ii) Dense.
 - (b) Afforested land.
 - (c) Plantation (road side, railway side etc.).
 6. Cultivated land :
 - (i) Single cropped area; (ii) Double cropped area; (iii) Current fallow (also fall under pasture land and grazing ground); (iv) Long fallow.

Aerial photo-interpretation techniques to prepare land use maps.

Basic principles :

For planning purposes a land use map should depict the distribution and extent of different land utilization units of the area under consideration. Field surveys are conducted to prepare such maps. But this is a time consuming device. To expedite the survey and to increase the efficiency of mapping aerial photographs are now being extensively used to prepare land use maps. Land use mapping concerns the classification of lands according to use. The different land use units can be interpreted in aerial photographs by studying the pattern and variation of the image characteristics of the objects in the photographs. The correct interpretation is based on three basic considerations viz.

(a) Similar land use in photographs is likely to appear in similar pattern. Any two land use units arising due to different cultivation practices, like double cropping, irrigation, different crops cultivated or due to grazing, or waste lands derived from rocky, saline or sandy nature of terrain etc. have similar characteristics and appear in the photographs in similar patterns.

(b) Dissimilar land use is likely to appear in dissimilar patterns.

(c) Once the photographic images are correlated with the type of land use in field, the sequence of events which form a particular land use unit can often be delineated by means of photo interpretation

and many important aspects of land use like cropping pattern or type of waste land or type of settlement etc. can be inferred.

Successful interpretation of lands and their uses entails evaluation of man's adaptation to environment. (Frost, et. al. 1960). The land use features of an area are created by human needs and anthropogeographical processes, understanding of which enables the photo-interpreter to classify land use units according to their properties. Wells, for example are constructed in the agricultural lands for irrigation. If the photo-interpreter can recognise the relation between the agricultural land and the wells, which he can determine by examining the size, shape, pattern and relationship of the wells and lands, he can easily and more efficiently demarcate irrigated and non-irrigated lands in detail. Similarly types and forms of settlements can also be demarcated by studying the relationship and pattern of the images.

Prerequisites: The mapping of land use requires the knowledge on various land use in practice as well as the terrains and socio-economic conditions of the region under study. To gain knowledge of these aspects is the prerequisite for photo interpretation for land use mapping. Hence it is necessary—

(a) To study the revenue records. This will help to understand the land use system of the region and enable the photo-interpreters to chalk out, in general, the units to be mapped. Photo-interpreters will however, work out the units in more details.

(b) To study the terrain and socio-economic conditions from existing maps and documents. This will help subsequently to analyse the terrain more efficiently by photo-interpretation.

(c) To conduct a rapid traverse throughout the terrain to understand the different systems of land use, so that the tentative mapping units are framed prior to interpretation work.

Photographic-factors—choice of photographs: Vertical stereoscopic photographs with 60% side lap and 20 to 30% end lap are used for land use mapping. Vertical photographs are often assembled in mosaic, on which the natural and cultural landscapes of the region can be easily identified and mapped.

It has already been said that the primary technique of photo interpretation for land use is based on image classification of the object. Hence the photographs which bear maximum contrast in images or tonal contrasts are best suited for land use studies. Hence photographs with good tone density and adequate tone range are needed. In India panchromatic photographs taken with a minus-blue filter are used. Colour photographs, however, have proved more efficient in many of the western countries. Infrared photographs are often valuable in demar-

cating irrigated lands and classifying waste lands in details. But in India these two photographs are not still available.

Scale factors : There is no single scale of photography which will satisfy all the requirements of land use studies. For identifying various details different scales of photographs are needed. In case of detail land use maps-scale 1 : 10,000 to 1 : 25,000 is suggested. In case of semi-detail 1 : 30,000 to 1 : 40,000 is recommended. If crop rotation, type and forms of settlement of urban land use is to be shown the scale should not be less than 1 : 15,000. The scale requirement for various details has been presented in table 2.

Table 2 : *Scale requirements for various details.*

A. *Cultivated and cultivable features*

Scales 1 : 60,000 to 1 : 30,000

- (i) Outline areas of cultivated lands including short and long fallows.
- (ii) Outline areas of fenced cultivated lands.
- (iii) Outline general areas of extensive and intensive agriculture.

Scales 1 : 30,000 to 1 : 15,000

- (i) Specific land uses in areas of extensive cultivation.
- (ii) Long and short fallows.
- (iii) Irrigated lands—types of irrigation.
- (iv) Outline areas of double and multiple cropped lands.

Scales larger than 1 : 15,000

- (i) Specific crops.
- (ii) Specific use of farm builders.
- (iii) Types of farming like strip farming etc.

B. *Waste lands*

Scales 1 : 60,000 to 1 : 30,000

- (i) Outline areas of waste lands.
- (ii) Outline areas of sandy or rocky wastes.

Scales 1 : 30,000 to 1 : 20,000

- (i) Outline areas of saline wastes.
- (ii) Outline areas of gravelly wastes.
- (iii) Water logged areas.

C. *Settlements—rural*

Scales 1 : 60,000 to 1 : 30,000

- (i) Outline areas of transportation by types like railway, canal, road (metalled or unmetalled or foot tract, camel tract etc.).
- (ii) Outline of the built up area of villages.
- (iii) Scattered, compact or linear forms of settlements.
- (iv) Planned or unplanned settlements.
- (v) Rural industry.

Scales 1 : 30,000 to 1 : 20,000

- (i) Rural public, semi-public and residential buildings.
- (ii) Forms of buildings or house types.
- (iii) Commercial buildings.
- (iv) Types of rural industries.

Scales larger than 20,000

- (i) Functional classification of buildings.
- (ii) Identification of different quarters (like 'para' or 'Niwas' based on cast segregations or other social factors)
- (iii) Specific characters of rural non-agricultural features.

D. *Settlement—urban*

Scales 1 : 60,000 to 1 : 30,000

- (i) Total built up area.
- (ii) Major transportation lines.
- (iii) Major physical characteristics.
- (iv) Hinterlands of the urban area.

Scales 1 : 30,000 to 1 : 20,000

- (i) Total built up area into urban and suburban parts.
- (ii) Kinds of transporational areas.
- (iii) Outline of open spaces and recreational areas.
- (iv) Outline of main industries.
- (v) Outline of functional areas.
- (vi) Street pattern.
- (vii) Effective urban area.

Scales larger than 20,000

- (i) House types.
- (ii) Identification of areas developed in different times—History or time scale.
- (iii) Individual structures and installations.

E. *Water features*

Scale requirement 1 : 60,000 or more

F. *Forest*

Scales 1 : 60,000 to 1 : 30,000

- (i) Outline area of well defined forests.

Scales 1 : 30,000 to 1 : 20,000

- (i) Thin forest and (ii) Plantation areas.

Scales 1 : 20,000 or more

- (i) Stock mapping.

G. *Pasturing* : Permanent pasture (scales 1 : 40,000 and above).

Others—as in 'wasteland'.

Methods and techniques of photo interpretation for land use mapping

Principles : The following procedures can be used for land use mapping. At the outset we must remember the following considerations :—

(i) All the elements of land are registered on the photographs. Their identifications and interpretations depend on the logical classification of images, which is done through study of the texture (in a photo image, the frequency of change of tones is called 'texture'). Some descriptive objectives are fine, medium or coarse. Structure (this refers to the arrangement of dot particles or tones; descriptive adjectives are like stripped or mottled) and form of the images (photo image—the representation of an object produced by optical or chemical means or both) and their correlations. This study and correlation of structure and texture of the images or variation of tones is often called '*edge gradient*' study (Rabben *et al* 1960).

(ii) Certain aspects can be identified directly from the photographs and the others are deduced by systematic studying and correlating the photo elements of the images, like shape, size, tone, height, shadow, relationship, images etc. The identification of problems through this system of interpretation is known as 'direct' interpretation. This is also known as function of '*fishing expedition*' and '*probability*' (Rabben *et al* 1960).

(iii) Many objects are interpreted and identified by means of logical search and resorting to probabilities by studying and correlating photo-elements and existing knowledge and documents. This comes under the study of '*indirect*' interpretation and is known as '*convergence of evidence*' (Rabben *et al* 1960).

(iv) Photo interpretation or photo mapping does not mean complete elimination of field work. Sample checking is always necessary.

The study of land use is mostly 'direct'. But indirect analysis is also needed to identify and interpret many a items like types of settlements; cropping practices etc.

Handling of photographs

(a) In the first step the aerial photographs in question should be studied. A mosaic, preferably semi-controlled, is always helpful. A good practice is to lay down overlapping run of the photographs and to scan the group before stereoscopic examinations.

(b) Second practice is to delineate effective area (Rabben *et al* 1960) of photographs, which include all images closer to the centre of that photograph than to the centre of the other. It is the area in which objects can be viewed with the least relief displacement. This is generally done by radial line or slotted template methods. In traditional surveys, only the middle section of each photograph is used. In order not to damage the photographs transparent overlays are used as working maps for plotting.

Now the photographs are ready for stereoscopic analysis to classify and interpret the images.

Study of regional aspects

First task is to analyse and classify the regional aspects in the photographs and to prepare a map accordingly. A physical map or an erosion map or a slope map can be prepared. The identifications of these are important as they have significant bearings on land use practices. Similarly drainage maps, including wells and canals may also be prepared. This has a bearing to understand the irrigation practices in the area under question. The climate of the area is known or to be obtained from literatures. The influence of climate is evident in aerial photographs in erosional, drainage and vegetation patterns.

To sum up, in this group of study a photo-interpreter is involved to get himself acquainted with the factors affecting land use. Most of the items or informations are to be obtained from the study of the existing literatures or maps. But many of them can be studied also from aerial photographs. It is, however, essential to work out the different relief features from the photographs as the land use often differs in different physiographic units.

Study of pattern elements

Having thus classifying a regional unit, which has the most significant bearing in land use of the area under question, the photo interpreter should study the broad local pattern to classify the major

land use groups. In reconnaissance mapping the unit as a whole is considered but in case of detail or detail reconnaissance mapping often a grid is employed (grid is proportional to scale of map to be cartographed) to study in more details. Agricultural lands are often distinguished by "check board pattern" which indicates the individual holdings. Similarly "checkboard pattern" with wells or canals indicate irrigated crop land. Built up areas or settlements are distinguished from density pattern. Radial pattern of roads help to identify trading or marketing centres. Wastelands can be distinguished on the photographs by lands covering small or image areas in a continuous manner having irregular or diffused boundary. Permanent pasture lands or orans are often marked by a pattern having irregular or often triangular boundary. Urban areas are often marked by pattern having sharply angular corners.

In short, several patterns can be distinguished in photographs which can be easily delineated. Each pattern element suggests certain land use. The type of land use can often be deduced directly by 'fishing expedition' or 'probability' techniques. Alternately a 'key' for the patterns identified is drawn up and check in the field on a 'transect' or sample basis and thus a broad reconnaissance photo map of land use can be made (Sen, 1972, Sen and Gheesa Lal, 1974).

Study of photo-elements :

In this stage, the photo-interpretation is involved to classify and analyse the images in details in each 'pattern' as distinguished in the first interpretation. Here we are to deal with logical classification of images for which a careful stereo-study is needed. A mirror stereoscope with binocular attachment should be used for the interpretation work. The photo elements which indicate land use are shape, size, tone and colour, texture, structure, shadow and height etc. Each element should be studied independently and then correlations of the results are needed. If all the findings agree, then land use can be identified and mapped with reasonable accuracy.

i) *Shape*: Shapes of the image distinguish orchards, plantations and forests. Shapes of the images are also helpful to distinguish used and unused land and help to identify cultivated and fallow lands. pasture lands have irregular shape.

ii) *Size*: Size is also an important photo element to identify land use. Irrigated lands are of large size. Regular cultivated fields are often small. Pasture lands have large areas. Forest areas are large. Size and shape should be studied and correlated carefully.

iii) and iv) *Colours and tone*: This refers to the brilliance with which the sunlight is reflected and registered in the photo image. Tones

are helpful to identify and distinguish cultivated, short fallow and long fallow lands; saline lands; waterlogged areas; recent and old quarters of built up areas in settlements etc. Saline waste lands can be identified by greyish white or ash coloured tone.

v) and vi) *Structure and texture*: This refers to the rapid alteration of colour tone and arrangements of dots and are very helpful to identify many difficult items. With the correlation of structure and texture of images it is possible to identify even, one year, two years or three years fallow lands. These along with colour has successfully enabled us to classify short and long fallows. Through the study of structure it is possible to classify rocky and gravelly waste lands. Texture is a good indication to classify saline and sandy waste lands, shrubs and woodlands etc. For forest classification (medium, dense, thin) these photo elements give good indications. Terraced lands can be identified by analysing structure of the image.

vii and viii) *Shadow and height*: Heights and shadows are important to distinguish orchards, plantations or forests. It is also helpful to identify different crops when aided with shape and size study. Thus sugarcane, rice, bajra etc. can be easily distinguished in medium scale photographs. Shadow helps to determine the height of trees and give indications to classify forest lands.

Correlation of the photo elements: Correlation or the relationship of the images and other objects of the photographs like roads etc is to be made after all the photo elements described above are studied. By correlation we may reach to an accepted agreement. Different crops require different management practices. This is often reflected in the sizes, shapes and arrangement of the fields. The irrigated crops downstreams of tanks and around shallow wells or tubewell can be recognised very easily in this way. Orchards or cultivation of vegetables around settlements can also be distinguished in this way. Recently reclaimed areas have regular shape and size. Beached terrace contour bund fields can also be identified by correlation work.

It is necessary to prepare photo interpretation chart for verification, if required.

Key: When the above interpretation is completed, it should be checked with literatures and legends prepared earlier for verification and corrections. The images identified along with the type of land use deducted for each images should be charted or drawn up to prepare the key of the interpretation. This 'key' is required to be verified in the field on 10% sample basis in case of detail reconnaissance and 15% in case of detail mapping. Random sampling is done in case of reconnaissance mapping. The sampling may be done along transect line basis. This however depends on the efficiency and experiences of the interpreters.

Correlation with field survey: Field survey is to be carried out only to establish the relationship of the images identified and the corresponding land use on the ground. Once the relationship is established and confirmed no further field work is necessary. The findings can be extended to areas having similar or identical pattern and photo elements.

Final interpretation and mapping: The field studies should be followed by final study of the photographs. The previous interpretation is corrected if necessary and completed. The details marked in the photographs along with land use boundaries can be transferred to the base map, if available by vertical sketch master or by similar photogrammetric equipments like radial line plotter, stereotop etc. In our Institute we often use a 'musk' and a proportional compass which is made in proportion to the scale of the photographs and the base map (Sen, 1967). If no instruments are available and the details are made in all the photographs, map can be prepared by radial line or slotted template method on the same photographic scale. With the help of some 'control points' (control point: any system in a horizontal or vertical control system that is identified on photograph and is used for correlating data shown on that photograph) the planimetric map (a map which presents only the horizontal portions of represented features) prepared by radial line method can be converted into a 'map' having geodetic control. This then can be reduced to the required scale. The map thus prepared, require cartographic compilation and editing for finalisation.

Photo interpretation of major land use groups in arid zone

The remainder of the paper deals with the photo interpretation of two major land use units of arid zone, viz. cultivated land and waste land. On the basis of the land use survey and mapping conducted so far in different parts of arid region of India, particularly in Jodhpur, Jalor, Barmer, Bikaner, Pali and Nagour districts of western Rajasthan with the help of aerial photographs the following photo characteristics of land use are tentatively standardised.

Cultivated land: In arid zone cultivated land includes short fallows (current fallow) and long fallows too. The last one being cultivated only in the years of very favourable rainfall. They are mostly cultivated only at the interval of 10 to 15 years. Cultivated lands along with short fallows can be distinguished by regular and check board pattern. The photo patterns are very clear. The current cultivated plots have medium to dark tone. In between, lands, having regular and sharp boundaries are noticed in air photographs having light grey to

grey tone. These are identified as short fallows. Two or even three tonal variations are marked in these short fallow lands. The slightly heavier tone areas are the lands which have been cultivated in the previous year. The lands that have been cultivated two years back have lighter tone. This has been confirmed from the cultivators and field investigations. The marginal lands of this check board pattern area often cover large or small areas in a continuous manner. Limit of the area is irregular and they often present diffused boundaries. These are long fallows and practically waste lands. The tone of the image is light grey to white; it is often bright, the texture of the image is light and structure is often fine. All these are due to the sandy deposits on them. These long fallows are cultivated lands. The cultivation of these lands may lead to the encroachment of sand in the adjacent cultivated land from these areas. This may deteriorate the regular cultivated lands. The irrigated and double cropped areas are marked by dark colour. The presence of wells and extent of distributary channels from the wells help to delineate boundaries of double cropped lands and irrigated lands in the photographs.

Waste lands: Waste lands are surface features of the land and as such they appear clearly in photographs (Moutapa 1972).

Study of pattern aspects and photo elements enable in the arid zone to distinguish hills, sloping hill sides, gravelly lands, sand dunes and depressional areas in the photographs. These comprise waste lands in Indian desert (Sen 1972). Uncultivated sandy plains and saline lands can also be identified and mapped by photo-interpretation. In Indian arid zone we have distinguished four types of waste lands—rocky waste, gravelly waste, sandy waste and saline waste. The photographic characteristics of these waste lands are as follows:

a) *Sandy waste:* Specific photo-pattern is large area covering in a continuous manner often interrupted by hummocks (sand dunes) of varying size. The images are marked by contrasted tones. Sandy plains are best identified by medium grey tones. Sandy hills or dunes are identified by complex or unusual forms. Close examination of stereoscopic pairs are necessary. Dunes are often marked by stripped structure and coarse texture; size and shapes are irregular. Sandy waste lands often indicate diffused boundary. Aerial photographs of desert region will not show vegetative cover on dunes. Dunes are sometimes mantled by grasses which cover darker tones than barren sand. A dune on a sandy plain may appear white against a dark background.

(b) *Rocky waste:* Image structure is mottled, texture is medium to coarse. Specific photo pattern is large area covering in a continuous manner interrupted by hills and rocky outcrops. Scattered trees and

shrubs are identified. Distinct or clear boundary of the unit is often identified. The images present contrasted colour and tones.

c) *Gravelly waste*: Specific photo pattern is large or small area in a continuous manner. Tonal variation is medium to light. The presence of the gravels are marked by close arrangement of dots, coarse texture in the photo image.

d) *Saline waste*: It is easier to identify and locate saline wastes on the photographs due to appearance of greyish white or ash-coloured salt formation on the surface of the land. In arid zone the 'playas' or saline depressions often form saline waste lands. These can be easily identified in the photographs.

A survey of waste lands without aerial photographs will be a very costly and tremendous task.

Conclusions

- a) Use of aerial photographs can expedite land utilization survey and mapping.
- b) It increases the efficiency of mapping work.
- c) It enables preparation of tentative land use maps before the survey is undertaken in the field.
- d) Three interpretations are necessary to prepare the ("key") for mapping. After field checking a final interpretation is also necessary for correction and final mapping.
- e) It minimises field work as this may be confined to sample areas of the same units identified by photo interpretation.
- f) In the laboratory stereo-photo maps can be prepared for an area of about 100 sq. km., within a fortnight. For subsequent field checking of the units five days work are quite adequate for detail mapping. Unaided by air photographs, field traverse alone cannot furnish such details in such a short period.

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BASIC RESOURCE SURVEYS IN RELATION TO RESOURCE DEVELOPMENT OF ARID LANDS

C. T. Abichandani*

Introduction

Soil reclamation or to use a more rational terminology land reclamation demands a prior thorough knowledge of land and its characters. For correct land reclamation approach one must know, physical features of land, soils of the land, vegetation characters in terms of crops, forests and pastures, climate and water resources both surface and ground. Soil or land reclamation is done with object of putting the land later into productive use for sustained higher production. Land reclamation may be done for putting the same under irrigation, on the other hand the purpose may be salinity and sodic reclamation or it may be for pasture development or dry land cultivation. Removal of water logging in an area may yet be another objective.

NEED FOR BASIC RESOURCE SURVEY

To implement any programme of land development therefore it is necessary to gain prior information on basic resources of the land so that the scientific, technical, economic, administrative and social services required for the reclamation and subsequent development programme can be designed well in advance to meet with objective of reclamation programme.

Basic resources of any region put a limit to the developmental activities and any planning without adequate knowledge of basic resources involved in development may lead to disastrous results. There have been unfortunate examples where reclamation and development schemes have failed because of lack of knowledge and limitation imposed by basic resources. In East Africa two attempts to establish agriculture in areas with low rainfall and one in high rainfall area failed because the areas were not suited for the purpose. An example may be cited from this country itself. It is now well known that for the development of surface waters, adequate knowledge of associated ground waters and, the possibilities of deep drainage are well understood so that subsequent water logging and salinity problems are avoided.

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This has been the difficulty in Punjab, Haryana and elsewhere, which has rendered large stretches of land prone to flooding and salinity.

A thorough knowledge of basic resources involved in any land development venture is therefore essential. In some areas one particular resource may be a key factor in development, elsewhere in certain other areas various complimentary factors may be involved. This can however be achieved only if planned information is available about each of the possible basic resource factors involved so that various possibilities are judged together in relation to immediate and long term requirement of the reclamation project.

Basic land resources that have direct bearing in land reclamation and development are varied. These include, physical features, climate, water (surface and underground), soil, vegetation, domestic animal and wild life. In large reclamation and development projects, scenery, tourist and recreation attractions, terrain feature that help development of transport and other infra structure are also to be taken into consideration. In addition to above natural hazards, like heavy wind storms, large droughts, floods, volcanic activities and other severe atmospheric disturbances have also to be accounted while considering different reclamation and developmental phases.

Basic resource factors differ from capital and other kind of resources as the former are relatively fixed in geomorphic location and extent and are not as flexible as the other input resources. Of the most important basic resource factors are the human beings for whose benefit the developmental activities are being undertaken. It would therefore be essential to have knowledge of human resource *visa-vis* other basic resources of the land. Region for development may have a mixed population of nomads, semi-nomads and sedentary population. These are largely interdependent on each other. Relationship of different communities with each other has to be studied prior to taking up any developmental programme, so that drastic changes not immediately acceptable to the social structure of human being living in the tract are not imposed on and if this is considered necessary, the confidence of the population living in the area is *gained and rehabilitation* programme worked out well in advance to meet the changes that the reclamation and development programme may bring about.

BASIC RESOURCE SURVEYS

Knowledge of basic resources that must be obtained before undertaking reclamation and developmental programme are the inventories of physical feature, climate, soil, water both surface and underground, vegetation, domestical animals, wild life and human factor. Thus, this

becomes an integrated approach to basic resource surveys. We now call this the 'Integrated Basic Resource Surveys'. These surveys therefore involve the efforts by various disciplines like (i) Geomorphology for conducting surveys of physical feature which include landform surveys and surveys of erosional hazards, (ii) Pédology & Soil Science, which include soil surveys, present land use and potential land use capability classification, (iii) Climatology, which must describe the present climate, the changes in climates and must give us information on wind regions, wet periods and drought periods and probabilities of their occurrence, (iv) Hydrology and Geohydrology, which must make a resource inventory of both surface and ground waters, their potentialities for exploitation and locate points of exploitation; hydrologic characters of soils have also been studied and listed, (v) Plant Ecology, which must catalogue the vegetation resource of the areas and their potential production; must also differentiate between useful and potential plant species as different from unimportant plant species, (vi) Animal Studies, which can give information on domestic animals and wild life including beneficial and destructive wildlife so that their preservation and control can later be worked out. This discipline should also be in a position to give information on animal and insect pests so that vegetation can later be saved from their ravages, (vii) Silviculture, which can work out the fuel, energy and timber availability, (viii) Nomadism and associated grazing practices if any and lastly (ix) the important human factor involved in the region, which has to benefit from the reclamation and development project.

Let us now take each of these separately and see how these are related to the reclamation and developmental programme.

PHYSICAL FEATURES AND LAND TYPE VARIABILITY

The land you wish to develop may be flat, slopy, hummocky, undulating or rolling. Land may be prone to severe wind erosion hazard or water erosion hazard. General statement of above nature is not adequate. Areas where different physical features and erosional hazards exist have to be mapped and described. Degree of erosion determined and focii of erosion located so that the problem can be attacked at source and developed land assured of measures that can meet the future challenge of these erosion forces.

Take example of Rajasthan desert. This region gives an impression of relatively flat terrain and appears uniform in relief. But the surveys have shown that there are many different land types with their own peculiar problem of potentialities and utilization. Apart from differentiation such as stony hilly, rocky outcrops, sandy alluvium, water borne gravel deposits, sandy plains, sand dunes

swamps and salt pans, there are differences in the nature of rocks and water and wind deposited material, that needs different approach for reclamation and development. The difference of these physical features are reflected in soil texture, soil profile, chemical composition, salt deposition, wind and water sorting action, vegetation, above ground environment, and presence and absence of usable waters.

Land use potential of any area is determined by combination of above factors at any particular site. It is only when these factors are fully known, that the knowledge that what happens at a particular site can be gained and principles of reclamation and development worked out. Sites that have similar characters belong to same type and are expected to respond in same way under a particular climatic environment. Such resource inventories will allow systematic selection of sites for subsequent study so that the results obtained on these places can be translated and put into operation on such similar sites in the surveyed area.

SOILS

Soils are product of interplay of factor like parent material topography, climate, vegetation and time. In any area to be taken for development, soils have to be described in detail and their location mapped. In a programme for reclamation for irrigation project, the irrigability class of each soil situation has to be described. There may be wide range of soils with different textural classes and different water intake rates and permeabilities. It would therefore be misleading to assume any uniformity of soil behaviour to irrigation or response to crop planning. Therefore a knowledge of difference between soils, their erosion susceptibility, significance to fertilizer application, conservation, rates of erosion and depletion and water relationship are necessary to develop management programme. It is not only adequate to describe each soil situation but it is also essential that its location, extent and variability in each area is mapped. The knowledge that is gained by preparing soil inventory as above can be used for classifying soils according to their use capability. Soil may have a high erosion hazard and it may be necessary to put it in the first instance under long term natural vegetation before other protective measures are developed, and land put under intensive cultivation.

Let us take an example of light sandy textured soil of western Rajasthan, which in near future is to come under canal command areas or under tubewell command area. With high wind erosion hazard prevalent in the area, unless suitable shelter belt protection is provided, it may be difficult to establish profitable agriculture. Development of land for cultivation however cannot wait for establishment

of shelter belts to provide protection. Measures may have to be taken in the initial stages to provide micro shelter belts. Soil characters to support the permanent shelter belts and temporary micro shelter belts have to be studied and described, soil depth to kankar pan, nature of kankar pan, physical features of top soil have all to be studied and mapped so that a Silviculturist and Crop Agronomist can plan tree plantation accordingly.

We may yet take another example of a saline site to be taken up for reclamation. Before the plans are drawn up for reclamation, soil characters have to be accurately described and soils with different characters mapped. Salt profiles have to be studied and data collected on the origin of salinity in the soil, so that the future planning can be so arranged that the reclaimed land does not revert back to same conditions and reclamation cycle may not have to be restarted.

Take yet another example of ravine reclamation project. Before any reclamation work is attempted, different ravines have to be classified and location of different ravines mapped. Some ravines may have stabilised at a particular level, some may still be in the erosional phase, yet some may be in the depositional phase. It is essential to know as to what is the soil character in each of these types, what is its erodability class, what are ravine slopes like. In a soil conservation project on slopy or rolling lands, also it is necessary to know the erodability character of soil, map the location of extent of depth of soil and nature of slopes, so that water diversion structure can be accordingly planned.

CLIMATE

In arid and semi-arid lands, apart from canal and ground water irrigation, rainfall is directly the most important factor limiting production. Deficiencies of rainfall in certain locations can be overcome by engineering projects to provide irrigation. Before any planning of agriculture is to be taken up in dry areas, it is necessary to know the nature of rainfall, total in each season, time of occurrence, time of cessation, probabilities of its start at any period, drought periods, wet periods, extent of drought, short or long, evaporation rates, so that effectiveness of rainfall for successful agriculture can be gauged. Take examples of the State of Haryana. You find that nature of rainfall in Karnal, in Hissar and in Mahendragarh area is different, diurnal variations are different, start periods of rainfall are different and probabilities of occurrence are different.

In western Rajasthan, an area of low rainfall, the effectiveness of this rainfall is low because of high wind velocities and high temperatures. In this area rainfall varies from 120 mm to 500 mm

from west to east, but the amount fluctuates considerably from one year to other. Following table will clear this point.

Station	Average rainfall mm	Highest rainfall mm	Lowest rainfall mm	Co-efficient variability	No. of years Record
Jodhpur	355	1157	25	53	76
Bikaner	295	757	28	48	73
Jaisalmer	275	470	0	65	68

It is evident from these figures that any development in these areas will have to take into effect the large variability in the rainfall. In some dry areas crop failures, become a common feature because of low and erratic rainfall, while in other areas land flooding may be a common feature, even though the rainfall may be low. The climatic pattern, when properly described will greatly help in the crop planning and land use capability of different land types.

Hydrology and Geohydrology

Before any land reclamation or development programme is taken up, it is essential to understand the surface hydrology and ground water hydrology, relationship of one to another and prepare an inventory of potential areas of water development. It is essential to describe the hydrological character of the sediment, so that the runoff characters can be predicted from the rainfall data and site characters.

The hydrological characters are of great importance for planning an irrigation net in any reclamation project. Water logging ills in Punjab, Sind and elsewhere are a direct cause of underestimating the study of the hydrological properties of soils. This has, however, not occurred in our countries, but in other countries as well. I know a case of Galodnaya canal in the Galodnaya steppe of USSR. The area reclaimed for irrigation by this canal had ground waters below 7-10 metre. Hydrological properties of soils had been studied and it was recommended that the canal should be lined, otherwise it will create water logging problem. This was not headed to by planners and project executors. With the result that six months after the canal opening 3 km on side and 5 km on other side of the canal were completed and flooded. Not only this, other things happened, ground water table in the irrigated command area rose to within one to one and half meter of surface and created salinity problems. Collosal money had to be spent to lay out drainage net and drainage collectors to keep the land in sustained profitable production. Technology is now available to predict the ground water rise in any area after irrigation if hydrological soil characters are known and have been mapped. Measures to

check this rise and subsequent damage can then be taken up early at the time of planning the reclamation project.

Water resource survey in dry areas is important to plan drinking water for human being and for livestock. Information on surface hydrology of tract will give points and locations, where water reservoir can be successful. Groundwater exploration surveys are also important, if rational utilization of water is to be planned. Any area may apparently look good ground water potential area, but one has to know, how far this can be exploited. You have all heard of Khaira district in Gujarat, the district of milk and butter. In this district ground water exploitation has reached such a level that discharge potential of number of well adjoining to each other has gone down considerably.

Another aspect of ground water surveys is water quality and its suitability for irrigation and the hazard this will cause on the land. If sustained production with this sub-standard quality water is to be assured, the water properties, soil properties and cropping pattern and management practices have to be matched for each set of location. This can be done only if detailed information on water quality, water potential, hydrological and chemical properties of soils are available.

Apart from hydrological properties, it is also essential to have information on engineering properties of soils, particularly the load bearing characters. Any large reclamation or development project, needs a net work of roads and other infra structure and all engineering data relevant to this has to be obtained and catalogued. Considerable headaches at later stage will be saved if this is done before project planning.

You have heard of Zwider Zee project in Holland. Large dam in the sea was constructed to drain out the sea water and reclaim land for cultivation. Survey, hydrological and engineering character of soil of this area under sea were studied well in advance to enable them to lay out roads in standing water, by sinking road metal at particular location. The road metal was carried in barges. With the result that as soon as the area drained, roads were already there for heavy vehicular traffic.

Vegetation

In any project planning for reclamation, it is also necessary to collect data on vegetation characters of the region. This will include all the vegetation, e.g. trees, shrubs and grassland vegetation. Area to be put under reclamation for cultivation may be already supporting a large livestock population being maintaining on natural and sown pasture. Before the land use pattern is drastically changed, it is necessary to survey and map the areas of potential high production, and area

which according to land use capability classification should be left over to natural vegetation. The people living in the area will need fuel for energy consumption, timber for implement and buildings, therefore, some natural area of high production will have to be left undistributed. Some well vegetated areas may have to be preserved from point of view of scenic beauty, tourist attractions and wild life preservation. If this area is to be conserved and developed for live-stock industry, more intensive and detailed vegetation survey in relation to site character and water availability may be necessary. Some tree species are useful both as fuel and as top feed and may have other uses also.

Nomadic grazing may be another aspect which a plant ecologist has to take into consideration while surveying the area from point of view of pasture potential. Survey will give useful information in relation of plant species with site character and this can be later utilized for successful establishment of particular or alike plant species.

Domestic animals

Arid zone and semi-arid zone of India particularly in north and north west of the country is a potential livestock area when milch cattle thrive and good breed of sheep are available. Most of these traditional animals graze on pastures, on fallow lands and on crop residue. Cultivated areas are protected as far as possible. There is a good deal of livestock movement in these areas putting stress on meagre forage resources, resulting in overgrazing and immense biotic activity, denuding the land of vegetation and making it prone to wind and water erosion.

Along with explosion of population in human beings there is also explosion of population in animals. Some of these animals are low producers and could well be eliminated and replaced by high producer. In project planning in any area therefore survey of livestock and its grazing behaviour and grazing sites is essential to gauge the magnitude of problem and meet with the situation in new management practices to be introduced later.

Migratory habit of livestock and sheep have to be studied and migratory routes defined so that in time of dire distress, agencies can come forward to help this livestock along these migratory routes by making prior arrangements. This will remove much of the handicap at present being felt by migratory cattle breeders in finding forage for their animals.

Wild life and pest control

Some of the wild life e.g. animals and birds are useful and some are our national heritage and have to be preserved, others are pests

and have to be controlled. Survey of living habit of these will help in achieving some objectives of preservation/control. Example may be taken of desert rat, which destroys vegetation and depletes the pasture vegetation which would otherwise be available for livestock. These desert gerbil feed on plant seeds. With the result that seed depletion brings about regeneration problems. Survey of these feeding habits, breeding habits, and territorial possessionship of each species of these desert gerbils have helped to develop cheap control methods, where one shot baiting is adequate to have large kill and give good control.

Human population—Social and economic conditions

Lastly it is essential to have information on the social and economic conditions of human beings of the project area and their relationship with surrounding areas. Information should be available on average size of land holding, population stress on land and vegetation resource, food needs of the area, forage and feed needs of livestock, ownership pattern, indebtedness, income levels and from different source and social relationship of sedentary and nomadic population and their relationship and interdependence on each other. These figures will greatly help in the extension enterprises to be conducted in the project area to demonstrate new innovations.

Assessment and Coordination for Project implementation

Thus it is seen that the integrated survey approach give an overall picture of all the elements of landscape which determine the existence of life in any areas. Project development is bound to result in changes in present existence pattern of human, livestock and plant life. Unless their present status is surveyed and mapped and their problem, location and extent are brought forth, impact of development project on improving conditions cannot be fully gauged. Although the surveys lead to development action, simultaneous studies may be necessary or information on process studies of management may be already available and can be utilised for planning. Many times it happens that administrators expect too much from surveys. Inventories are necessary to know their location and extent so that problem can be pinpointed, but surveys should not be taken as end in itself for all development purposes. Assessment of resources is essential before development programmes are undertaken.

Surveys will give the technical feasibilities of resources use. Project economic implications will however to be studied before investment on reclamation are concomitted. Knowing the different resources,

their quantum, extent and location, it should be comparatively easy to determine which of the factors could be modified to make the project economically feasible and socially acceptable. Economic assessment of project will also depend on validity of data used and reliable data in all respect can be only obtained if integrated surveys are well planned and conducted.

It is necessary to understand that for any project planning in land reclamation, preparation of initial resource data and later stages of resource assessment upto planning stage are a part of one programme. If separated at any point, it may lead to difficulties as persons connected with planning stage will not have any direct dialogue with persons associated with surveys. The information from integrated surveys will indicate the kind of technical resources that are needed to assist in project planning. It is essential therefore that different organisations in the State that have these technical resources are associated with survey personnel at one stage or other so that a continuance and unified approach to resource assessment is maintained. In some cases it may be necessary to have a new organisation machinery to assess the resource and conduct project planning. In any project planning, for reclamation therefore integrated approach to resource survey, prior to resource assessment and project planning is necessary to assure the success of the reclamation project.

LAND USE CAPABILITY CLASSIFICATION

R. P. Dhir and S. N. Bhola

Land use capability classification is an interpretative grouping of soils meant to show the use to which the land should be put for maximum sustained production. The term land use as adopted here is a comprehensive form that includes not only major land uses like arable farming, pasture and forestry but also the magnitude of the risk involved if mismanaged or in other words management needs like choice of crops and soil water conservation measures that go with the particular land use for continued productive use of the land resources. The factors used in this classification are soil properties like texture, depth, internal drainage and associated features like slope, degree of erosion, stoniness or rockiness. Since choice of land use is governed also by climate, this factor is given due emphasis in land use capability classification.

Land use capability classification consists of eight classes with Class I comprising of lands which have hardly any soil or climate limitation and are therefore capable of giving return from a wide range of plants with simple management without any risk of deterioration. From Class I onwards, the degree of the limitations increases progressively upto the last class i.e. Class VIII which comprises of lands that have so severe soil or climate limitations that no significant commercial usefulness is obtained even from pastures or forestry land uses with best management. In between upto Class IV, lands are considered fit for arable farming though under increasingly careful management from Class I to IV. Class V lands have even severe limitations so that these are not suited to cultivation even with feasible intensive soil conservation measures and therefore their usefulness is limited to only pasture or permanent tree vegetation. From Class V upwards increasing care by way of deferred grazing, is required for sustained production even under these land uses. Land capability classes are sub-divided into sub-classes based on kind of major limitation i.e. erosion, root zone limitation or climate etc. and further into units taking into account specific management requirements and responses to the same.

Concept of land use capability classification and the criteria for classification were first evolved and developed by United States Department of Agriculture. An adopted form of the same is being followed in our country by All India Soil and Land Use Survey Organisation,

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Central Soil Conservation Research and Training Institute and other agencies. All these classifications are on the sub-continental scale and therefore when applied to a local environment considerable elaboration or modification is required. For example in USDA classification (1954) arid climate is considered already too adverse to permit arable farming even with best available soil conservation practices. Whereas in the Indian arid zone, it is well known that cropping is not only feasible but also practised. This is partly because of socio-economic factor but mainly due to the peculiarities of climatic conditions which do permit successful cropping. Unlike other arid zones, the limited rainfall in our arid zone is received within a short span of 70-90 days when humidity conditions are also high. Further, there are highly adopted crops like Bajra and pulses which very well fit into rainfall pattern. It is because of this that in more favourably placed areas like Churu, Sikar, Nagaur, Jodhpur and Pali more than 60% area is under cultivation. Likewise in these classifications sandy texture of soil is considered a highly adverse factor because of its low available moisture storage capacity of the soils and increased droughtiness of soils. Experience in arid zone shows that with the prevailing crops, sandy texture of soils does not pose such limitations because the root system of the crops are sufficiently ramified and deep. It will be seen from this that the present national classification is too condensed to permit a fair representation of the limitations and potentialities of soil and environments of arid zone and the variability within the same.

In the use of this concept, it is emphasised that land use capability classification be developed for each environment zone with due regards to the local socio-economic factor. In view of this a land use capability classification is proposed with the knowledge available at present. It is not intended to be the final since, it is a dynamic concept based on increasing knowledge and research experience on management of resources on one hand and social norms on the other.

Capability units of arid lands

In developing this classification for arid lands, Bajra has been taken as an index crop in assessing suitability for arable farming. Arable farming is considered successful if satisfactory to good yields are obtained in three or more years out of five. Below this average, farming is considered unsuccessful. This division for western Rajasthan is roughly around 275 mm rainfall isohyete. On basis of climate alone rainfed lands receiving more than 275 mm are placed in Class IV and those with less rainfall in Class V. Presence of depths shallower than the ideal for Bajra, greater erosive nature of some soils necessitating more vigorous wind erosion measures on such lands brings in variability

in suitability of lands for farming but unlike other environments there is no scope of showing their differentiation at the class level since climate alone places even the best land in the last class suited to farming. In the present classification, this variability has been shown by increase in number of limitation which is to be taken as decreased suitability.

Further, in the present classification texture, for reasons outlined earlier, has not been considered an adverse limitation unless greater degree of erosion reduces its capability. Depth less than the ideal for bajra is considered an additional limitation. In calculating depth, calcium carbonate concretionary strata is not considered a total limitation and it has been assumed equivalent to 10 cm of effective soil. Conversely, where the concretionary zone is compact and indurated, 10 cm soil depth is added in order to match a soil with a non-indurated zone. Soil depth for different texture is not constant since medium textured soils even with a lesser depth can store equivalent amount of available water.

After climate, wind erosion is the most dominant factor in arid zone. Its magnitude is assessed from volume of active wind sorted sand piled along obstructions exposure of sub-soil or sub-strata. Further it is not only the effect of past erosion but also hazard if not properly managed that has been considered in land use capability classification. In the above 275 mm zone, high hummocky lands are considered as belonging to Class V and dunes to Class VI. Both of these are considered unfit for arable farming and suited to pastures, the latter dunes under greater care like deferred grazing and perhaps frequent reseed-ing. Slope of land is not considered a serious factor as conducive to erosion, since water erosion is a negligible problem. However, from view point of ease of management, dune physiography is considered an adverse factor.

Salinity in soil imposes an additional stress on vegetation over that due to climate. On account of this, lands with high salinity are devoid of any significant vegetation. Therefore lands with salinity above 8 mmhos E.Ce are considered as belonging to Class VIII and those with 4 to 8 mmhos as belonging to Class VII. Salinity due to irrigation water as has been shown by work at this Institute is manageable. Waters below 2.25 mmhos hardly cause any significant problem, and so lands irrigated with such waters are put under Class II because of climate alone. With waters between 2.25 to 5.0 mmhos lands are put in Class III since only one good crop per year can be taken with certainty. Those with higher salinity are put in Class IV. Rocky areas yield a small fraction in terms of forage and instead these require an extreme care of management and hence placed in Class VIII. Eroded gravelly plains are in Class VII.

Extent of area under different land use capability classes and sub-classes

As an illustration data with regard to Jodhpur district shows that Class IV lands i.e. lands suitable for cultivation form nearly 36% of the area of the district. A break of these shows that sub-class IVc, that is lands with no limitation other than climate form 12%, sub-class IVec i.e. lands having severe wind erosion hazard in addition to climate form nearly 20%. Therefore soil conservation measures like wind strip cropping (Misra, 1967) or stubble mulching are necessary for sustained production under cultivation. Sub-class IVes that is lands with depth limitation which makes them less than ideal for crop production form the rest 4%. Class V lands cover roughly 38% of the area of the district. Strictly from soil conservation point of view these lands should be put under permanent pastures wherein sustained production with simple management is assured. However, from immediate socio-economic points of view part of the area comprising of hummocky undulating lands can be cultivated though with a risk of enhancing erosion. Class VI lands are made up of dunes and these form nearly 15% of the area. Such lands should not be cultivated at all because of very severe erosion hazard. These are well suited for permanent pastures which can be established through reseedling and fencing. Even after establishment care by way of exclusion of cattle during critical period is required for their maintenance. Class VII comprise of very shallow, gravelly lands. These cover more than 10%. Class VIII comprising of exposed rocks also occupy an appreciable area. Saline depressions of Class VIII form 0.8% of the area.

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SOILS

R. P. Dhir*

ABSTRACT

It has taken tens of thousand to millions of years for development and evolution of soil and it is therefore too precious a source to be allowed to be blown or washed away. Many of arid zone soils are also highly evolved and diverse because of pedogenic processes and past history. Amongst these, light textured soils are dominant. These soils though more prone to erosion, are good habitat at because of their high intake rate and very low unsaturated hydraulic conductivity which endows them with moisture conservation property in face of an acute moisture deficit. Low moisture retention capacity permits deeper recharge enabling a regular stand of useful phraetophytes. Data on *fertility status reported in paper shows that soils including those of dunes* have reserves of potassium and phosphorous. Even the fresh blown sands are fertile enough as to permit their quick rehabilitation provided adequate protection against biotic interference. Depth of soil as limited by indurated or rocky layer is a frequent occurrence and such lands together with those of dunes are best left under perennial grass.

INTRODUCTION

Soil is that material of the surface crust that serves as a medium for plant growth or that can be made to do so with reasonable effort. In order to fulfill its function, soil has depth to provide a foot-hold for plant roots, porosity to permit intake and retention of water, organic and inorganic colloids to hold most of the nutrient elements in forms available to plants. To obtain these properties in soil from hard compact parent rock, it has taken tens of thousands to millions of year. Obviously soil is too precious a component of the eco-system to be allowed to be blown or washed away. It has instead to be preserved, and if possible, improved, for existence of human and other terrestrial life. Since soil is a product of environment and parent rock and both of these are not constant in time and space, we have a large variety of soil on the earth and thus are habituated to talk in plural form as soils or soil bodies.

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SOILS OF HOT ARID ZONE

Because of characteristic climatic regime of arid zone, the soils of arid zone have some features in common on account of which they differ from soils of higher rainfall regions. These are low organic matter content, incomplete leaching resulting in alkaline reaction, accumulation at some depth of sparingly soluble salts like carbonates or sulphates of calcium, lower degree of chemical weathering thus greater amount of primary, weatherable minerals and lesser accumulation of secondary minerals or weathering products. However, within the framework of these dominating features, there are variations in soils depending on parent rock, history of evolution of landscape, physiographic position. Thus one can come across in arid zone from completely sandy soils of dunes to very heavy textured clayey soils from limestones. There is variation also on account of salinity, depth of soil as limited by presence of lime indurated zone.

Dominant land-forms in arid zone are the sandy plains with varying degree of hummockiness and the dunes (Ghose et. al 1968, and Roy, B. B. et. al, 1968). The sandy plains have a soil profile characterised by a 10—30 cm thick, wind sorted, structureless sandy surface and a loamy sand (6—10% clay, 4—8% silt), very weakly blocky, generally calcareous sub-soil followed often at depths of 60 to 100 cm by a moderately to strongly indurated lime concretionary zone. The soils are non-saline with a pH around 8.0. In Jodhpur district these soils have 0.08 to 0.20% organic carbon, 12 to 20 kg and 110 to 220 kg per hectare of each of available phosphorous and potassium respectively. Such soils in more arid parts have been found to contain less of organic matter but more of potassium. The soils can retain 50 to 90 mm of water in profile unless limited by depth. The dune soils are deep, structureless sandy (3—5% clay, 0.5 to 3% silt), with occasional nests or lenses of free carbonates. The dunes are dominantly of coalesced parabolic type and these have 3 to 7% slope on the windward side and over 15% on the leeward. The dune soils have even lower amount of organic carbon (0.05 to 0.12%), available phosphorus (10—15 kg P_2O_5 /ha and potassium (175 to 280 kg/ha). Water storage ranges between 50 to 65 mm. In the inter-dune as well as in sandy plains, there are small natural depression which are medium textured highly calcareous and sometimes saline.

Besides the above soils, there is an appreciable area of medium and heavy textured soils particularly in central and eastern part of arid zone. For example in Jodhpur district such soils cover 10% of the area. In Nagour and Pali the extent is even larger. These are often 40 to 90 cm deep and have water retention capacity of 150 to 280 mm in clay loam to 100 to 140 mm in other loams. Their organic matter

and available potassium contents are higher than those of soils described above. These soils are less erosive and therefore safer to cultivate.

BEHAVIOUR OF SOILS IN THE ECOSYSTEM

Characteristic soils of the arid zone are light textured. These soils have high infiltration rate but low unsaturated hydraulic conductivity. Childs (1969) reports that in medium sands hydraulic conductivity X_{10}^2 values fall from 14 cm/sec at saturation to 1 cm/sec just below saturation. Since sandy soils are all the time in unsaturated stage except for very brief periods of torrential rainfall, low moisture conductivity in the soil environment is a rule rather than an exception. Whatever movement does take place is in vapour phase. This reflects in the behaviour of soil in two ways. Firstly, that utilisation of stored moisture will depend largely on the extent of root ramification. More fibrous the root system more effective will be the plants' ability to make use of the moisture. Secondly, the vapour phase movement is slow and depletes only top 30 cm of soil (Abichandani et al. 1967). The rest of soil profile remains at field capacity. This property makes the soils highly suitable for moisture conservation and this also explains significant moisture reserves in unstabilised sand dunes.

Moisture retention capacity of the soils as has been shown in previous section is low. In the seasonal character of rainfall and that too confined to few showers, there are situation when natural precipitation exceeds the available storage capacity of soil and the excess goes as recharge. This percolation should be sufficient to permit a regular stand of deep rooted, perennial tree or shrub vegetation without any fear of loss in grass or crop production.

Wind erosion is an intense phenomenon in arid zone. In Bikaner district 46 and 20% of the area has very severe and severe wind erosion hazard. In Jodhpur district the area affected is 15% and 25% respectively. Further east i.e. in Central Luni Basin (Ghose, et al. 1968) the hazard decreases fast. Wind erosion hazard is serious particularly on dune land forms. Information shows that crop stand on dune flanks is 50% or even less of what is in the interdunes. However, the fresh blown sand is not all sterile, quartz sand but contains appreciable reserves of potash. Samples of such sand in Jodhpur contained 75 to 120 kg/ha of potassium and 7.2 to 11.2 kg of phosphorus as compared to 75 to 150 kg of potassium and 10-15 kg of phosphorus on dune flanks. Thus given required anchorage and protection, these deposits are capable of being rehabilitated quickly.

Further the unstabilised dunes have also been found (Agarwal, loccit.) to contain significant quantity of nitrates.

Natural fertility of the soil particularly with regard to nitrogen and phosphorus is low. This is partly because of high temperature which causes rapid oxidation of organic matter. But it is also due to the fact that recycling of organic residues into soil is highly inadequate. In cultivated as well as grazing lands all usable organic residue is cut or grazed allowing little return to land. In natural grazing lands the density of vegetation is already too low to make any effective contribution. However, under well managed conditions it has been seen (Dhir et al., 1973) that perennial grasses are able to build a better environment around themselves. Soil below grass clumps contained 33% more organic carbon and 50% more phosphorus than what was present in soil away from influence of grass clump.

Arid zone soils save for dunes proper, often contain large accumulation of free carbonates in form of concretion or as coatings on gravels and rock fragment below the sub-soil. In some landforms this zone of accumulation is indurated and also closer to surface and thereby limits effective soil depth particularly for useful perennial vegetation. For example in Jodhpur district, 16% of the area is formed of such shallow soils. Growth of *Prosopis cineraria* is poor on such lands and yields even of annual crops are 25 to 50% less. The limitation is imposed by low moisture retention capacity and therefore such lands are better suited as grasslands.

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SOCIO-ECONOMIC STRUCTURE AND LIFE STYLE OF SETTLED POPULATION

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The portents rather than the promises weigh heavily in any programme of the development for the desert areas. The dual increase of population and its needs set up an alarming situation specifically when viewed in the context of extremely limited potentialities for agricultural and industrial developments in the arid areas. Economic, social and political considerations condition the multifarious problems involved in developing the arid areas. The problems of economic development are conditioned by the physical characteristics, the hot Indian arid zone being characterized by low and erratic precipitation, frequent occurrence of drought, high temperature with high wind velocity resulting in severe kind of wind erosion hazards. The land forms comprise barren rocky stretches, vast sand dune areas and undulating topography. Drinking water is scarce. The sub-soil water level is often too low and has high salt contents. The economic problems have also a human dimension and most of them are embedded in the social structure of the population inhabiting the desert areas. The rate of growth of population has been observed to be comparatively higher due mainly to the early and universal practice of marriage and to the non-adoption of family planning methods. The percentage literacy and its level is much low, people by and large are traditionalists, feelings of factionalism are heavy and consequently the adoption of innovations receive only a luke-warm response. The major forms of the human occupation are marked by instability that carry the hazards of sudden failure and rapid degradation.

The crucial problem of the Indian arid zone is thus of human ecology and it is often said that the Indian desert is man maintained if not man made. Recognizing this the Division of Human Factor Studies (now designated as Division of Economics and Extension) of Central Arid Zone Research Institute, Jodhpur, has been conducting investigations among different nomadic groups to assess their role in the economy of the region and to suggest welfare measures. The socio-economic survey of the sedentary population inhabiting the arid zone of Rajasthan has also been taken up to make available the socio-economic data which could form the base for drawing up developmental plans for raising the standard of living of people.

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In this lecture I will be covering the Socio-economic aspects related to the settled population in the desert. The details of nomads and nomadic way of life will be dealt with in a separate lecture.

Settlement Pattern

The natural form of settlement in India is the compact village type which seems to establish itself in different regions as a part of cultural heritage. The pattern of settlement both influences and is influenced by the physical, social and economic factors. As an interplay of these factors the form of settlement in desert areas is of distinct nature. The villages in the arid areas are scattered over long distances, human habitations springing up only where the conditions permit sedentarization. There were only four village per every 100 sq. km of total area in the arid areas of Rajasthan as against 10 villages for every 100 sq. km area in the whole State of Rajasthan. The settlement pattern of the sedentary population falls in three categories viz. entirely compact, entirely scattered and villages having both compact settlement and scattered homesteads. Majority of the villages fall in the last category. The factors conditioning this form of settlement are larger population of villages, dunish character of the land surface resulting in poor accessibility, scattered location of water sources, socio-cultural heritage of certain castes, jagirdari system and custom of bringing in tenants for use of land and the practise of subsistence farming. It has been observed that there is a tendency among households belonging to the same caste to live together whether in the *dhanis* or in village core. Tracing the history of settlement pattern in arid zone villages it has been observed that the sequence of settlement in the village has been first for the compact settlement to grow around the houses of the first few families who settled here. Later people moving seasonally to their fields and then the households started settling in the fields. People living in scattered homesteads (*dhanis*) have greater economic advantages through close and continuous contact with the land while the people living in compact settlement at the core enjoy a richer social life. The nature of activities and the type of social relationships have been conditioned by the form of settlement. The web of social relationships is confined within the cluster of *dhanis*. Households living at the core make greater use of the community facilities while households living in *dhanis* are inadequately covered. The tendency towards isolation is more marked in the case of houses living in *dhanis*.

Housing

The type of housing is also influenced by the indigenous flora and the materials available in the arid regions. The nature and type

of housing at the core differs from that in the *dhanis* in several ways. At the core the different families live close to each other while the cultivated fields are at a distance. In the *dhanis*, however, the family builds a *jhupa* (hut) in one of its fields so that the families live scattered. Secondly, at the core a few houses belonging to Mahajans, ex-Jagirdar and some other are built of sandstone brought from towns. Most of the families in *dhanis* live in *Jhupas*. Bardi fencing about six feet high is put round the compound toward off animals, thieves, and also as a protection against strong winds. Inside the compound two to three *jhupas* are built depending upon the nature and size of the household. The cattle are tied at a corner of the compound. Fodder and grains are also stored here. The *jhupa* has a cylindrical base and a conical top. In the construction of *jhupas* trees and shrubs available locally are used. The frame is usually made of the timber of khejri (*Prosopis spicigera*) branches of aakra (*Calatropis procera*) and kair (*Capparis aphylla*) are used at the conical top. On the outer side bajra stalks are put while on the inner side senia (*Crotalaria burhia*) stalks are used. The floor is katcha and is coated with a paste of cow-dung, water and earth. A part of the sides of cylindrical base has a similar coating. There are usually no windows. The entrance to the *jhupa* is low so that one has to bend before entering. There is no door. There is no provision for a separate kitchen. Defecating is done in the open. Water is stored in earthen pitchers. Some families have dug *tankas* or pits where they store water. Unlike the families living at the village core, the families in *dhanis*, tie the bullocks and camels in the compound and the rest of the livestock in separate enclosures. The sites are shifted at regular intervals so that proper manuring of the fields is done. Thirdly, in the village core the structure and *jhupas* have mixed uses—most of them are residential while the rest are put to commercial use and for housing community facilities and government functionaries. In the *dhanis* the *jhupas* are put only to residential use. Fourthly, in the village core the members of the extended family live adjacent to each other. When the joint family breaks up the partition is made in the compound of the dwelling. In the *dhanis* when the joint families break up, they establish themselves in separate fields.

Population Characteristics

India is today faced with the problem of rapidly growing population and this problem is more pressing in the desert tract which is confronted with the dilemma of providing for a population which tends to out-strip the meagre available resources. The total population of the hot Indian arid zone comes to over 19 millions according to

1971 census. The population of this zone is thus almost double than that of the total population of Australia and is almost equal to that of the country like Canada. Within the Indian arid zone the percentage of population in Rajasthan, Punjab, Haryana, Andhra Pradesh, Mysore and Mahārashtra accounts for 44, 15, 14, 10, 11, 5 and 1 per cent respectively.

Density of population

The striking discrepancy between the area of the arid zone (36% of the world's land surface) and the number of people living therein (13% of the world's population) stresses the slight use made of arid lands. In India the total area under arid conditions is about 12% of the country while only 4 per cent population of the country inhabit these areas. Thus as compared to the entire areas of the world still slighter use is made of the Indian arid lands.

Though the variation in the densities of population do occur on account of topography, soil, lands, occurrence of economic minerals, accessibility and other socio-economic factors, water being the most important factor in the arid areas, the density of population can be expressed in terms of the availability and suitability of surface and ground waters. The coefficient of correlation between the rainfall and the density of population in the Indian Arid Zone came to be +0.6070. In arid zone of Rajasthan the density of population declines from the piedmont belt of Arravallies, to the narrow zone between the Sutlej and dry bed of Ghaggar to the thirsty sands of the desert. The density of population in Jhunjhunu is 157 persons per sq. km, in Sikar 135, in Pali 78, in Nagaur 71 and in Jalore 63. Proceeding towards the west the densities decrease fairly repaidly from 52 in Churu, 50 in Jodhpur to 27 in Barmer, 21 in Bikaner and only 4 in Jaisalmer.

Growth rate of population

The decennial growth rate of population between the decade 1961-71 for the Indian arid zone had been 26.04 as against 24.66 for the country indicating thereby that the rate of growth of population in the arid regions is comparatively higher than in the rest of the country. Details regarding the growth rate of population in the above mentioned districts of arid zone of Rajasthan have been further worked out and this has exhibited interesting findings. The data indicate that the increase of population in the arid zone of Rajasthan between 1901-1971 has been of the order of 157.35 per cent 149.89 per cent for the whole state of Rajasthan. Within the arid zone the percentage increase of population is higher in the areas receiving comparatively lesser rainfall. The percentage annual growth rate worked out by exponential curve equation for the country, Rajasthan, arid zone of Rajasthan

the country, Rajasthan, arid zone of Rajasthan and arid districts receiving 16" and above, 12" to 16" and less than 12" rainfall, came respectively to be 1.1686, 1.3012, 1.3655, 1.2845, 1.3986 and 1.4575. The percentage increase in population between the period 1931-1971 has been 143.8, 132.1 and 107.2 in the regions receiving annual rainfall of less than 12" between 12"-16" and 16" and above respectively. Thus an annual growth rate of 1.4575 per cent in population from 1901-1971 as against 1.1686 per cent only for the country and 143.8 per cent increase of population during 1931-71 in the areas receiving less than 12" rainfall as compared to only 119.0 per cent increase for the entire Rajasthan state sets up an alarming situation specifically when viewed in the context of extremely limited potentialities for agricultural and industrial development in the arid regions.

The comparatively higher population density as mentioned earlier in this paper is likely to further increase unless measures to check the growth rate of population are accelerated in this area.

The increase in population is mainly due to the increasing birth rate and declining mortality rate. If the birth rate does not fall, the gap between births and deaths will widen and the region will be faced to the rapidly increasing multitude of population explosion. It is further interesting to note that the percentage increase in female population during 1931-61 has been 97.4, 79.2 and 69.15 in the three tracts respectively as compared to the percentage increase of 96.7, 76.6 and 64.5 among the male population of those three tracts. Thus there is a greater percentage increase in female population in all the three tracts during the period 1931-1961. The present sex ratio shows a greater disproportion in the tract receiving less than 12" rainfall there being only 875 females per 1000 males as compared to 922 and 950 females per 1000 males respectively in the tracts 'B' and 'C'.

The present age sex and marital status of the population reveal equally high concentration of population in lower age groups, and high percentage of married women in reproductive period. The present demographic features of the population in the arid areas, thus, reveal equally high potentialities of future growth rate of population. It is, therefore, most essential to immediately initiate measures of population control placing greater emphasis in the districts receiving lesser rainfall.

Caste differentials

Most writers on caste system have attempted to group castes on the basis of their economic function and ritual status and discussed the role of this pivotal institution in rural social structure (Dube, 1955; Mayer, 1960). Some of the basic quantitative data for any region, on aspects like demographic features, household characteristics and sources of livelihood have, however, generally been lacking.

The villages in the arid areas have heterogenous caste composition and the village society enjoins upon each caste to perform certain functions which are inter-dependent and complementary and weave the economic system into a single integrated unit. All the castes practice cultivation, but some follow their traditional caste occupations as well, often as a household industry. Traditional occupation lies at the basis of caste distinctions and on the basis of economic system and its consequent bonds of mutual obligations. On the basis of the traditional occupation or functional specialization the castes in the villages in the arid areas may be grouped into five broad categories viz. (i) agricultural castes like Jats, Bishnois, Rajputs etc. (ii) castes practising agriculture and also serving needs of agriculturists, like Suthars, Lohars, Bambis etc. (iii) castes practising agriculture and also serving the needs of the community with regard to the socio-religious ceremonies like Brahmins, Sads, Swamies, Sewaks, Dakotas and Dadis (iv) castes practising agriculture, and also serving the other needs of the community like Nais, Darjis, Sonars, Khatris, Bhils, Jogis, Kumahars, Bhangis and Sansis and finally (v) the castes having animal husbandry as the major occupation like Raikas, Muslim cattle breeders (Goberas, Kharls, Billoch etc).

The interdependence of the different castes in the economic organisation of the village becomes more emphasised during occasions of marriage, festivals, etc. when each caste has a specific contribution to make. The services rendered by Suthar, Lohar, Nai, Bambi and Darji castes are governed by what is known as the *aat system* under which every family, caters to the needs of a group of families for a particular type of services, payment for which is fixed by tradition and made on an annual basis either in cash or kind at the time of harvesting of grains. The amount to be paid depends upon the quantum of work, families with large agricultural holdings or large number of members generally paying more. Sometimes a part of the services are governed by *aat* and a part by other transactions.

The studies on agricultural castes in the desert regions have shown them to be numerically strong and high in ritual status with larger economic assets (larger land holding and livestock) than the other groups. This makes them the dominant group in village and even in political affairs, particularly in matters connected with land and agriculture. Most of the Sarpanches in Gram Panchayats come from these castes. Commonness of interest and kinship ties among more families of these castes in the village adds to their solidarity and effective functioning as a group. The recent land reforms devastating the Jagirdar of his powers over land have improved the political strength and prospects of the non Rajput agricultural castes and made them a more vital force.

Demographically, these castes indicate trends similar to others since the broad factors affecting birth rates, death rates and migration operate for all these castes with some minor reservations, as for instance, those relating to widow remarriage. The absence of alternative means of livelihood within the village open to those castes limits the diversion of any population from land and results in over-crowding and uneconomic holdings. The percentage of joint households among agricultural castes (58.1 per cent) is higher than among the non-agricultural castes and is possibly influenced by the needs of a larger labour force for larger land holdings.

Occupational castes are usually found in bigger villages. The average number of households of these castes per village is Suthar 3.1, Kumbhar 5.9, Lohar 1.4 and Bhambi 15.3. Four-fifths of the households of these castes reside in compact village settlements. Cultivation is followed as a main occupation by nine-tenths of the earners among Suthars, Kumbhars and Bhambis and seven-tenths of the earners among Lohars.

Livelihood Sources

Cultivation and not animal husbandry forms the main occupation of the majority inhabiting the arid zone of Rajasthan. According to 1971 Census about two-thirds of the total earners in the arid areas of Rajasthan have been enumerated as engaged in the main occupation of cultivation. Over this about 9 per cent of the total earners have been enumerated as engaged in the main occupation of agricultural labour. Thus approximately three-fourths of the total workers in arid zone of Rajasthan are engaged in the main occupation of cultivation and agricultural labour. Animal husbandry is quite often followed as a subsidiary occupation in the arid areas but it will be wrong to generalise that in Rajasthan desert or for that matter in the desert of Gujarat, Haryana and Punjab the main occupation is Animal husbandry.

Agriculture

Prior to independence and the subsequent land reforms, one seventh of the villages in Marwar were under the direct management of the Darbar and were called Khalsa villages (Erskine, 1909). Most of the remaining land was under the system of tenure known as *Jagiri* whereby the Jagirdar paid annually to the Darbar certain dues besides having some other obligations regarding military service, etc. The cultivators in the Khalsa and Jagiri villages were of two types—viz. *Bapidars* and *Gair—Bapidars*. The latter were merely tenants—at will while the former possessed occupancy rights and had certain other privileges regarding mortgage, etc. now, almost all the land is held directly from

the government on payment of land revenue, the rates of which vary according to the type of land.

The distribution of the size of cultivated land reveals uneven distribution of cultivated lands among the farming households in all the three tracts within the arid zone of Rajasthan namely 'A' receiving average annual rainfall of less than 12", having the mean aridity index 84 and consisting of the districts of Jaisalmer, Barmer and Bikaner, 'B' (Jodhpur, Nagaur, Churu and Jalore) receiving an average annual rainfall of 12" to 16" and have the mean aridity index 75; and 'C' (Jhunjhunu, Pali, Sikar and Sirohi) receiving an average annual rainfall of 16" or more and having the mean aridity index 58. In the eleven districts of arid zone the percentages of less than 5 acres, 5-15 acres, 15-30 acres and 30 or more comes to 14.52, 29.18, 24.22 and 30.94 respectively. The distribution of the size of land cultivated in the three tracts revealed that the percentage of households who cultivated 30 or more than 30 acres of land comes respectively 60.92, 38.9 and 8.9, in the tracts, A, B, and C on the other hand the percentage of households who cultivated less than 5 acres of land comes respectively to 2.37, 7.17 and 28.97 in the three tracts. The data thus clearly reveal that comparatively larger holding size are more prevalent in tract A as compared to the holding size with a household in tract B and C. There is hardly any problem of landless labour as such. However, people who have small agricultural holdings do agricultural labour for which there is a demand during the ploughing and harvesting seasons. Subsistence farming is still largely in vogue. Bajra is the most important kharif crop in the region followed by Guar. The crop yield is, however, poor due to the natural hazards and also due to the traditional agricultural practices being still largely followed in the region. Additionally as a consequence of high population growth more & more marginal lands have been put to plough. The percentage net area sown in arid zone of Rajasthan had been 26.1 in 1951, 39.0 in 1961 and 42.2 in 1971 while the percentage double cropped area during the period 1951-71 ranged only between 0.3 to 1.3 per cent.

Despite, though not substantially, the arid zone of Rajasthan does contribute to the total cereals and pulses produced in Rajasthan as well as in the country. Taking into account the production figures for the year 1969-70 it has been found that the arid zone of Rajasthan produced 68.95% of total (other) pulses produced in whole of Rajasthan and this worked out to be 4.84% of the total pulses produced in the country. Similarly over 50 per cent of the total Bajra produced in Rajasthan was harvested from its arid districts which inhabit only a little over one-third of the total population of Rajasthan. The arid area of Rajasthan contributed about one-tenth of the total wheat produced in whole of Rajasthan and has also contributed in the production of other major crops

though not to a great extent as in case of Bajra and other pulses. It may be interesting to mention that per hectare yield of wheat (Malhotra *et al.*, 1972) is higher in the Indian arid zone than that of the average of the country. With the increasing amount of availability of irrigation, research results and successive changes being brought about by the developmental plans there appears to be quite a good scope of registering significant improvement in agriculture in arid areas on which occupation the majority depends even today. Further in certain districts like Jhunjhunu, Sikar, Pali, Jalore of the arid Rajasthan good double cropped areas are available and improved intensive cultivation has a lot of scope.

The major drawback, however, is that the farmers in the arid areas have so far largely endeavoured to conserve the hold of tradition and the adoption of improved practices has made only a small leeway. The differential adoption of the recommended agricultural practices is a crucial problem facing the extension workers. Some of the Socio-economic factors like age of the farmer, size of land holding, social participation, caste status, educational status, technical know-how, value orientation etc. have been widely reported to have some relationship with the adoption of innovations.

A study on the relative importance of some socio-economic factors in the adoption of agricultural innovations in the arid region revealed that the most important factors for predicting innovativeness were the membership participation score and the knowledge test score followed by the material possession with the household & land holding and irrigated land held with a household. The value orientation, age of the head and the livestock owned which accounted for the socio-economic status of the household explained variation in adoption score only to the extent of 3.19% negligible and 0.06 per cent respectively. Caste and education did not appear to be relevant in this case as the population belonged to the same caste and educational stratum.

The findings suggest that it will be useful to encourage as much participation and involvement in various activities as possible and to fully explore the ways and means to provide full knowledge of the improved package of practices and the qualities of the innovations as there two factors predispose the farmers to quicker adoption of innovations. It may also be useful to start extension activities with the people having comparatively greater participation in various activities and possessing more knowledge about the innovations rather than giving greater weightage to those possessing larger farms having greater material possessions better value orientations and to those belonging to certain particular age group. The practicability of extending improved practices needs to be thoroughly scrutinised. The operations recommended should be simple and within the technical competence and

level of understanding of the farmers. Emphasis should be placed on demonstration in introducing new and improved methods as tendering of advice only shall not make such headway because the farmer is extremely cautious and would like to see for himself the effect of a change of technique before he adopts them. Adoption regarding improved seeds must be backed by its timely availability. Advice regarding adoption of improved implements should also be backed by its availability and facilities for the purchase of spare parts, repairs, etc. All measures to increase production should be widely distributed geographically and embrace all the groups widely distributed. At present the *Dhanis* receive comparatively lesser attention, primarily on account of the difficulties in communication. It has further been found that in the propagation or diffusion of innovations inter-personal communication along informal channels play far more important role than through the media of mass communication.

Animal husbandry

Despite the limiting factors the region has certain important potentials of growth in the sector of Animal husbandry. Among the primary sectors within Rajasthan State, Animal Husbandry is the next important sector to agriculture and contributes about 13 per cent of the State's income amounting to about Rs. 90 crores and above annually to the State exchequer. Animal husbandry in arid regions has traditionally a firm base as large areas of pastures are available for grazing though their carrying capacity at the present is very low. It has been observed that while in drought years the agricultural production from crops falls to 10 percent of the normal, average livestock production falls only by approximately 33%. Marginal improvements in fodder production and water availability is therefore likely to add considerably to the yield and stability in livestock farming in these desertic regions.

Livestock population exceeds human population both in the State of Rajasthan as well as in its arid areas. During 1972, the total livestock population in the state was 388.78 lakhs of which the population of cattle was 124.70 lakhs, buffaloes 45.93 lakhs, sheep 85.56 lakhs, goats 121.62 lakhs, camels 7.45 lakhs and pigs 1.17 lakhs. The livestock population increased @ 2.5% during the period 1901-1961. Thereafter the rate of increase came down to 1.5% during 1961-66 and it registered a decline by 5% during 1966-71. The livestock population of the arid zone of Rajasthan (as compiled for the year 1965-66) worked out to about 158 lakhs of which cattle constituted about 45.7 lakhs (28.95%), buffaloes 10.2 lakhs (6.45%), sheep 53.7 lakhs (34.07%), goats 42.6 lakhs (26.97%), camels 4.6 lakhs (2.93%) and other livestock 1.1 lakhs (0.68%).

Converting the livestock into adult livestock units it was found that during 1956 and 1966 the arid region of Rajasthan possessed respectively 53.0 lakhs and 69 lakhs adult cattle units, of the total of 166 lakhs and 179 lakhs adult cattle units respectively during these years for the whole state of Rajasthan. The relative growth rate is higher in arid regions. The livestock population in arid zone of Rajasthan increased from 9.4 millions in 1951 to 14.4 million in 1961 (53% increase) and 15.52 million in 1971 (8% increase). The density of livestock per 100 ha of grazing lands increased from 72 in 1951 to 175 in 1971 (293% increase). The increase rate in bovines (cattle and buffaloes) and camels has been spectacular in arid regions, however that in sheep and goats was of the practically same magnitude in arid regions as well in the state as a whole.

The desertic areas possess some of the best breeds of livestock viz. Cattle, sheep, goats, camels etc. This region is the home of famous breeds of cattle viz. Konkrej, Tharparker, Rath, Haryana and Nagauri Cows of Tharparkar, Konkrej, Rath breeds have the potentials to produce high milk yield (2,000 to 2,500 litres per lactation) under desertic conditions if fed and managed properly. Bullsellers of Nagauri, Haryana, Konkrej breed are in repute for their draught characters under hard condition. These animals are in demand in other parts of the country for upgrading the local stocks. Sheep are reputed for medium to fine wool, good quality mutton and drought hardiness.

Although sheep population in Rajasthan is about 16 percent in the country, yet it produces about 10.85 million kg. wool which is about 45 percent of the total wool of the country, and 25 percent of which is fit for apparel wear production.

About one million sheep, mostly male are slaughtered annually for meat purpose and more than half a million sheep are exported to other states. Goat breeds of arid region are reputed for high milk production potentials, and are very prolific breeders under adverse condition.

The general practice is to raise the sheep and goats in a mixed flock. The goat has been branded as the most harmful animal towards soil conservation measures since it nibbles away the grasses and it has often been recommended that goats should be eradicated. The importance of goats, however lies not merely in the returns this hardy animal gives to the owner but also in its role as an aid to the raising of sheep. Goats often act as foster mothers to lambs as well as assist the shepherd in grazing and herding the sheep. Also, in case of any attack by wild beasts it is only the goats who cry and give an instant indication to the owner about the attack, comparative mortality

among sheep is much higher than in goats during scarcity conditions. It is a common saying that "Oont chodde Akkra aur Bakri chodde Kankra" i.e. the camels will not eat *Calotropis* only during scarcity conditions but the goats will survive on most scanty vegetation and will only leave pebbles. The goat also acts as a poor man's cow. If, therefore, the goat is to be displaced because of its alleged association with rapid deforestation and soil erosion, a suitable substitute has to be found out in order that there may not be a functional vacuum with consequent difficulties in sheep rearing which is an important arid zone industry.

Animal husbandry practices are still largely traditional. The produce is meagre and the sale of livestock and livestock produce is extremely limited. The decidedly greater advantage of keeping a smaller number of animals of superior breed are understood by the farmer. It is, therefore, suggested that facilities for exchange of poor quality livestock with better ones be provided. This should include giving of bullocks in exchange of bulls as due to prejudice against castration, the exchange of bulls for bullocks done by the villagers at present are to his disadvantage. The Panchayat Samitis should take upon themselves the responsibility of maintaining bulls of better breeds. The useless livestock should be sent to Goshalas. Vigorous efforts need to be made to control disease dissemination, to demonstrate improved techniques of animal husbandry and to extend supply, marketing and other facilities.

Farm Forestry

To meet the requisite needs of wood, the farmer's resources are becoming inadequate day by day. Villagers are facing great difficulty in procuring their requirements of fuel, wood for implements and housing, shade for the family and animals, fodder trees for animals, trees to beautify the environment and fruits to enrich diet. The farm yard manure which should have been used for increasing the productivity of land, is being used as fuel. Therefore, the emphasis has to be given on farm forestry in the region. A survey conducted in the Central & lower luni basin in arid zone of Rajasthan revealed that 89.7 per cent households meet fuel requirements from their own fields; however, for agricultural implements 59.7 per cent households had to make purchase from the market. Shortage of fuel wood is experienced by seventenths of the households. Only 14.4 per cent households had planted trees during the three preceeding years of the survey. Villagers were interested in planting trees primarily for shade and for obtaining timber for agricultural implements.

The cultivators, in the arid areas should be encouraged to plant a few recommended tree species around their habitations, sand dunes, pasture lands, road sides and near the water sources. Religious feelings of women folk should be exploited by having a small grove of peepul (*ficus religiosa*). Again in the orans (land attached to the religious places) cutting of vegetation is prohibited and important trees, bush and grass materials should be planted and propagated at such sites.

Other sources of livelihood

The chief sources of livelihood other than agriculture and animal husbandry are agricultural and casual labour and the traditional caste occupations like carpentry, blacksmithy, oil pressing, drumming, dyeing, money lending and shop-keeping, pottery making, basket making, leather work etc. These are generally followed as subsidiary occupations and generally cater to the needs of the village. Since there is at present overcrowding in agriculture it would be necessary to develop cottage industries to provide the much needed supplementary income. The present cottage industries of shoe making, basket making and weaving need to be reorganised. Credit facilities should be set up which will buy all the products and acquaint the industry with the types of product required. Quality control needs to be enforced and training facilities provided. To provide the additional opportunities of employment to the villagers the practicability of setting up of rural estates of small industries for clusters of say five villages should be explored.

Indebtedness

In the desert regions more often than not the crops fail and the savings accumulated over a number of years are a rare feature for meeting the future capital needs of investment in different occupations and for meeting the heavy expenses to be incurred in Socio-religious ceremonies. The survey conducted in the Central Lower Luni basin revealed that six-tenths of the rural settled households were indebted. The average indebtedness per household comes to Rs. 533/-. Most of the loans have been procured for socio-religious ceremonies where obligations to community over-ride prudence and force the cultivators into the clutches of the Mahajan—the traditional money lender who still remains to be the Chief source of credit and quite a substantial part of the debt is the high rate of compound interest on the loans charged by him. Co-operative societies have been functioning in some

villages but these have been unable to replace the money-lender. One of the chief reasons is that these societies give loans only for productive purposes and not for other purposes including the socio-religious needs of the community for which people more often than not run to the counting house of the Mahajan. Also the foresight of the people for advantages of controlled credit and its punctual repayment is lacking. The propaganda and persuasion to induce such a foresight among the inhabitants of the region should be taken up by the extension workers without delay.

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NOMADS AND NOMADISM

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INTRODUCTION

Nomadism is an extreme case of a human society's adaptation to an unfriendly natural climate and is spread over large parts of the desertic tracts of the world (Berque, 1959). The nomads of the Old World have been studied by different social scientists. Tursunbayev and Potapov (1959) described some aspects of the socio-economic and cultural development of about 10 million nomadic population in the U.S.S.R. They stated that these people are leading a nomadic or semi-nomadic life with extensive livestock-breeding as their main economic activity. Planhol (1959) described geography, politics and nomadism in Anatolia. He stated that in the age of classical antiquity and in the Byzantine era, there was no true nomadism in Anatolia and wandering shepherds of the hillside grazings or the steppe sheep walks of the table land were almost entirely peasants from the valley settlements or paid hands employed by the city dwellers. Nomadism was a result of the mass influx of Turkish pastoralists from the end of the eleventh century onwards. Abou-Zeid (1959) studied the nomads of the western desert of Egypt and discussed ways and means of sedentarization. The somali nomad studied by Silberman (1959), the *Bedouins* of Saudi Arabia by Helaissi (1959), Muhsam (1951, 1955, 1959) and Elath (1945), the nomads of the Sahara by Monteil (1952, 1959) and the nomads in the Arab Lands of the Middle East by Awad (1962), Krader (1959) stated that the nomadic pastoralism in the arid parts of the Old World was the resultant of the coalescence of its components, nomadism and pastoralism. They appeared long after the neolithic period with domestication of plants and animals.

NOMADS IN THE DESERT.

In India nomads are largely concentrated in the arid and semi-arid zone of Rajasthan where the source of livelihood and the way of life of the people have been conditioned by disturbance in ecological balance due to severity of arid climate, continuous deterioration of soil, dwindling natural resources, occasional droughts, invasions, poor means of communication and consequential social and economic uncertainties.

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The salient findings on the studies conducted among the nomads of arid zone of Rajasthan in the Human Factor Studies Division are reported below.

The nomads of the arid zone are not a separate ethnic group and do not have a separate territory with exclusive rights and economic framework. They have in general symbiotic relationship with the settled population and function as an ancillary to their economic pursuits. Based on the studies at this Institute the nomadic groups of arid zone may be broadly grouped in four categories viz. (a) the pastoral nomads (Raikas, Sindhis, Parihars, Billochs etc.), (b) the trading nomads (*Banjaras*, *Ghatti-wala Jogis* and *Gowarias*), (c) artisan nomads (the *Godliya Lohars*, *Sansis* and *Sattias*) and (d) miscellaneous type of nomads (*Nats*, *Kalbeliya Jogis*).

The nomads performed an important complementary function in the economy of the region but in recent years, however, due to changes in the political, social and economic set up the source of livelihood of nomads has received a set back.

Each type of nomad is associated with some kind of livestock which make indiscriminate use of the meagre available water and grazing resources and destroy the local soil conservation measures. The nomads in the present day thus prove a menace for the whole society and their sedentarization is inescapable. The opening up of means of communication has reduced the importance of distribution activities by the trading nomads. Shrinkage of grazing lands in same area due to extension of cultivation has created difficulties for the cattle breeder nomads. Villagers are no longer dependent upon those nomads who rendered specialised services. Our studies have shown that the sedentary population, in general, do not welcome the nomads for various reasons.

Table : 1 The response of settled population to the visit of the different nomadic groups.

Nomadic Groups	Want %	Do not want %	Indifferent %	Total %
Raikas	4.7	92.0	3.3	100.00
Sindhi cattle breeders	12.5	83.0	4.5	100.00
Banjaras	32.1	64.5	3.4	100.00
Gawariyas	62.2	33.5	4.3	100.00
Ghattiwala Jogis	60.9	34.8	4.3	100.00
Gadolya Lohars	61.2	34.9	3.9	100.00
Sansis	1.7	95.7	2.6	100.00
Sattias	18.3	78.6	3.1	100.00
Nats	6.3	90.3	3.4	100.00

The data in Table 1 show that feelings run strongest against the visit of Raikas, Sindhi cattle breeder, Banjaras, Sansis, Sattias and Nats. Gawariyas, Ghattiwala Jogis and Gadolya Lohars are more welcome.

The disadvantages to the settled population from the visit of nomads are indicated in Table 2 which gives the responses of sample household heads.

Table : 2 Disadvantages to the settled population from the visit of nomads.

Type of response	Raikas	Sindhi cattle breeders	Ban-jaras	Gawari-yas	Ghatti-wala Jogis	Gadolya Lohars	Sansis	Sattias	Nats
Their livestock destroy standing crops	82.9	69.5	80.2	4.1	8.0	2.8	0.6	0.7	3.3
Their livestock exhaust local grazing resources	84.3	68.3	79.3	3.6	6.7	2.1	0.6	0.7	2.5
Their livestock exhaust local water resources	28.9	25.6	36.1	1.4	0.9	0.1	0.1	0.1	0.9
Their livestock bring diseases and infect village livestock	11.6	5.8	9.8	0.6	0.1	0.5	0.1	0.1	0.1
They commit theft of livestock	1.5	2.3	2.2	0.1	2.3	0.5	63.3	12.7	31.2
They commit theft of crops and other articles	0.1	0.9	0.1	0.1	4.6	0.8	81.2	20.1	41.7
They commit other types of crime	0.3	0.6	—	0.6	2.8	0.1	14.2	10.7	6.9
They are immoral	—	0.5	—	0.1	1.5	0.1	2.7	17.6	1.6
They cheat the village folk in transactions	—	—	0.1	12.4	8.8	0.4	4.5	2.5	5.3
They beg and are a nuisance	—	—	0.1	1.2	4.4	0.1	0.3	1.9	9.6
Other	1.2	0.2	0.4	0.1	0.8	1.0	0.6	2.9	1.1
No harms	10.3	20.9	21.1	79.8	79.9	85.7	7.1	57.9	37.8

Most of the respondents felt that the visit of pastoral nomads and trading nomads with large herds of cattle results in the destruction of standing crops and exhaustion of local water and grazing resources thus imposing hardships on the livestock of the settled population. The problem has been aggravated on account of shrinkage of grazing lands and the extension area under cultivation. A significantly greater percentage of respondents consider that the visit of Gadolya Lohars, Gawariyas and Ghattiwala Jogis is not disadvantageous to the settled population; some, however, feel that the livestock kept by them as pack animals cause damage to crops and exhaust water and grazing resources. It is also alleged that they charge higher prices for low quality goods. Sansis and Nats are commonly believed to be asso-

ciated with thefts and other criminal activities. A significantly greater percentage of respondents felt that the visit of Sattias does not result in any harm to the settled population. An appreciable number, however, feel that they are associated with thefts, crimes and immoral activities.

Table : 3. Benefits to settled population when Nomads visit their village.

Type of response	Raikas	Sindhi cattle breeders	Ban-jaras	Gwariyas	Ghatti-wala Jogis	Gadolya Lohars	Sansis	Sattias	Nats
Articles can be purchased sold, exchanged or repaired	1.2	12.0	32.1	73.2	69.9	68.1	0.4	0.8	—
Animals can be purchased, sold or exchanged	0.6	6.2	2.1	0.4	0.3	0.3	0.1	0.8	0.1
Animal produced can be purchased or sold	—	0.3	0.1	0.1	—	—	—	—	0.1
Services like treatment of animals, castration, etc. can be available	—	0.4	—	—	—	0.4	1.7	16.8	—
Fields can be man manured	1.6	0.1	0.1	—	—	—	—	—	—
Entertainment	0.1	—	—	—	—	—	—	0.3	8.3
Others	0.1	0.3	0.5	—	0.1	—	—	—	0.6
No benefit	97.1	80.9	68.7	27.9	31.3	31.3	97.8	81.3	90.9

The data show that most of the respondents feel that the settled population does not get any benefit from pastoral nomads, Sansis, Sattias and Nats. About the visit of Banjaras two-thirds of the respondents felt that there was no benefit, while one-third felt that the settled population could purchase salt and other commodities from them. About the other trading nomads a significantly greater percentage felt that articles could be purchased, sold, exchanged or repaired.

The nomadism and the rehabilitation measures suggested for different categories of nomads are discussed below.

Pastoral Nomads

The pastoral people inhabiting the Rajasthan desert have been carrying on livestock breeding for generations and have contributed to the economy of the region by way of providing milch cattle, ghee, wool, mutton, etc. Detailed survey conducted among the livestock breeders of Anupgarh-Pugal region revealed that these nomads have been facing difficulties in grazing their livestock as there has been shrinkage in the extent of grazing lands due to the extension of cultivation and

also with the coming in of Rajasthan Canal in this area the economy of these livestock breeders is being much disturbed. The inhabitants of the region are not completely nomadic but have a permanent home and generally a parcel of land. Their nomadism is directly dependent on the necessities of their herds. The economy of these breeders is largely dependent on the harvesting of available water and the efficient use of extensive grazing lands available in the area, as the cultivated area is only 4 per cent of the total land surface.

Among the breeders water harvesting for livestock is in vogue since generations. Having regional ecological association the traditional livestock breeders of the region have evolved it and is being implemented more profitably and effectively for raising livestock in the region. This old method, presently known as *toba* constructed amidst the sand dunes which provide water and pasturage to the livestock. It is a very fascinating place to live. A hard plot of and with very low porosity is searched for construction of *toba* and again this place should form a good catchment area so that water of all the four sides runs down and collects at this place. Each village of the cattle breeders have 5-6 'tobas dug' depending upon the caste and community composition.

With the onset of the monsoon there is dispersal of herds far and wide within the boundaries of the village where-ever surface water is available in the dug out ponds locally known as *tobas* which are constructed and kept in repair for the efficient use of meagre available water and the grasses. The use of *tobas* is regulated by conventions and it is customary to make use of other *tobas* when the water in one's own *toba* exhausts. No body was thus prepared to deepen their *tobas* lest the water and the grazing resources are utilised by others. Thus the people stressed that the *tobas* have to be dug deep on large scale rather than making any piecemeal efforts. In case the rains fail the breeders migrate with their livestock to irrigated areas of Ganganagar and Ferozpur district. Prior to the formation of Pakistan they used to go to Bahawalpur region which is now a closed boundary.

The livestock breeders have recently been facing great difficulties for feed and water for their livestock. Due to improved means of transport the local sedentary population does not depend upon the livestock breeders for livestock and livestock produce. Their visits are generally not liked by the villagers since their animals exhaust water and grazing land of the village. The construction of the proposed Rajasthan canal may also turn the grazing lands into crop land.

Based on detailed surveys it has been recommended that each household in the Canal command area may be allotted one sq. (6.3 ha) of land and partial mechanisation of cultivation may be resorted to.

Dairying industry may be introduced on scientific lines. Sheep raising is the chief subsidiary occupation in the region. At present the sheep owners have to travel long distances and their nomadism can be arrested by upgrading the short grass rangelands by reseeding these pastures by *Anjan* and *Dhaman* grasses. Introduction of mutton industry setting up of wool grading and shearing centres shall further save a lot of their energy and fetch the breeders much higher income than they earn at present.

Artisan Nomads

The nomadic blacksmiths are locally called *Gadoliya Lohars*. They are one of the artisan nomads in the States of Rajasthan, Punjab and Madhya Pradesh. Their territorial extension is even in semi-arid and humid environments. Their nomadism is traced back to the conquest of the fort of Chittor by the *Mughals*. History has it that consequent upon this conquest the *Gadoliya Lohars* took a vow that they would not have a settled home, would not eat in a plate and would not sleep on cot till the fort is reconquered (Malhotra *et al.*, 1966). The defeated ruler of Chittor fort needed blacksmiths to make weapons for war. The ruler had gone in the forest for seclusion and preparation and was moving from place to place so that the enemies would not trace them. This also rendered the settled blacksmiths to live a nomadic life and since then they became nomads.

The traditional occupation of the *Gadoliya Lohars* is blacksmithy and trade in cattle. Their movement to different places are dependent upon the availability of blacksmithy work and prospects of trade in cattle. They have developed a symbiotic relationship with the sedentary farmers for supplying them with agricultural tools and implements which they require. They also sell utensils for farmers' household affairs. These materials are supplied to the rural population on cash or exchange basis. The technology of manufacturing the tools, implements and utensils of iron is indigenous that involves hard work and large amount of labour. Almost all the members of each family remain engaged in this occupation. On the average a household earns about one thousand rupees annually from this occupation. Uncertainty of availability of work and risk in earnings has created feelings of fraternity and mutual give and take in the society. Unlike other nomadic groups generally, they do not take loan from the money lenders. They are economically and culturally very backward. Their children are not sent to schools, and as such illiteracy is very common.

They move about in small kinship bands in their bullock-carts with their full family. The nature of movement of different bands of these

artisan nomads follow a regular cycle on regular monthly intervals. They owe their allegiance to a definite demarcated area. In one hand the number varies from one to twelve families. During movements they split themselves into smaller constituents which group and re-group at different places depending upon their social and economic needs. Their movements are limited only to those places which are connected by roads or track in which their bullock carts can go. Due to the recent changes in economic and political set up and the increasing means of communication the *Gadoliya Lohars* are not as welcome in the villages now as about 15 years ago. About one-fourth of the *Gadoliya Lohars* stated that there has been a definite decrease in their getting work of blacksmithy or cattle trade in recent years. Ninety five per cent of the households surveyed, therefore, desired to divorce nomadic life and lead a sedentary or semi-sedentary life leading finally to sedentarization.

Efforts have been made by the State Government of Rajasthan to sedentarize *Gadoliya Lohars* in colonies consisting of many households at one place but such sedentarization has achieved only a partial success.

The present investigations revealed that most of the *Gadoliya Lohars* desired to sedentarize in small kinship groups consisting of mostly agnatic (blood relations) and affinal (relations through marriage) relations. The nomadic *Gadoliya Lohars* desired sedentarization in scattered fashion at a central place within the present area of their movement locally known by them as *Chokla*. (Malhotra *et al.*, 1966)

Trading Nomads

From the remote past to the eighteenth century trades were dependent on the nomad caravans. There were very few lines of communication which could connect big cities. The villages were in isolation and very poorly connected by cart tracks and footpaths. Even at the present time there are villages in the Great Desert which are approachable only by walking and goods are carried by packed animals.

In the arid and semi-arid parts of Rajasthan the *Banjaras* are one of the most publicised trading group of nomads. They are camp dwellers. Their entire drama of life is enacted under the open sky. Historically these are very old nomads and were associated with the desertic landscape. Their role in carrying grains from one place to another is referred to by Elphinstone (1916) and Hague (1928). Hutton (1961) has described them as a caste of "Carriers, traders, and cattle-herders more or less nomadic". The 1911 Census Report of Marwar lists the *Banjaras* as carriers by pack animals. Aggarwal (1956) has mentioned their role

in the distribution of salt in the desert villages and their high sense of honesty. Todd (1957) has also referred to their function in purchasing and distributing salt on caravans of bullocks.

The *Banjaras* are organised into distinct clans in different territories (Malhotra and Bose, 1967). Each clan is divided into smaller groups called *tandas*. In each *tanda* there are six to twenty families. The doctrine of collective responsibility operates among the members of the *tanda* (Malhotra and Bose, 1967). The families within the *tanda* are bound by kinship ties which give security to the members. The rights, obligations and expectancies towards one another are well established. The structure of the family is patriarchal. Early marriage is very common among them. Every *tanda* has a headman who commands respect from other members.

The main occupation of the *Banjaras* is trading in salt. They roam from village to village with bullocks which carry goods and other material possessions that are few and limited to the bare necessities of life. Even though now-a-days, the salt trade is carried by big wholesale traders with modern transport facilities, it remains the main source of sustenance of most of the families of the *Banjaras*. The trade is carried on with the family labour force. The women render only minor assistance in economic pursuits.

With the onset of rains, the *Banjaras* move towards saline basins where salt is manufactured. After rains, grass and water are available enroute for their animals. In addition to salt trade, they sell fuller's earth and onions in the remote villages of the desertic tracts. These *Banjaras* move towards Gujarat state during post monsoon period where they get ready employments in the form of haulage of commodities, like building materials, grains, etc., on the back of their bullocks.

The nomadic *Banjaras* do not avail of any community facility and have no social as well as cultural relationships with the settled population whom they meet only for trade purposes. There is some communication between the money lenders and the *Banjaras*, as the latter generally take loans from them for their trade etc.

The *Banjaras* are economically backward and their standard of living is very poor. As a result of improved means of communication and the opening up of hitherto inaccessible areas to road transport their traditional relationship of mutual dependence with the sedentary population has broken down. The *Banjaras* find it difficult to sell their commodities with good margin of profit as in the past. Shortage of grazing land is another problem for them. Their earnings have sufficiently declined and several of them are in perpetual debt.

Rehabilitation Measures

The technological, economic and political changes of the recent times are influencing their nomadic population in this region with such a rapidity that they are facing a social decay. This influence is chaotic in so far as it is not based on balanced and well conceived plans, and is not adaptable to the traditional nomadic way of life and their aptitude. The sedentarisation of nomadic way of life is a gradual and slow process. Though all round development of the region may result in spontaneous sedentarization of the nomads, there is a possibility of social as well as cultural annihilation of the nomads. As such the initiated sedentarization schemes taken up by the government agencies for raising the living, social and economic standards are applicable. Some of the recommendations based on our studies are detailed below :

1. For the area coming under canal irrigation it is recommended that each household of livestock breeders may be allotted about one square (6.3 ha.) of land and partial mechanisation of cultivation may be resorted to. However, about 800 households in this region who have large number of cows of Rathi breed should preferably be sedentarised in colonies and dairy industry be introduced among them on scientific lines.
2. The system of rotational grazing and management of pasture lands and reseedling of vast fallow lands with good strains of grasses should be introduced.
3. Cooperative Forage collection centres and Fodder Banks should be opened.
4. Improved animal husbandry practices should be introduced on a large scale in the region.
5. Introduction and development of cottage industries of spinning and weaving, and mutton production should be taken up.
6. Efforts made by the State Government to sedentarise the artisan nomads (Gadoliya Lohars) have not achieved the success since the number of families was large for the place and their kinship structure, cultural values and economic organisations were not kept in view of which these nomads are very particular. It may be essential to sedentarize these nomads in bands of small kinship groups within their own *Chokla* or present area of movement as is desired by them. Such a settlement shall ensure the continuation of their symbiotic relationship with the sedentary population, provision of marketing facilities for the articles fabricated by them and shall also provide better prospects for allotting them suitable agricultural lands of which the

Gadoliya Lohars are most desirous to get. Over and above this shall also rule out occurrence of any serious feuds which are likely to occur when too many households of different clans are settled at one place.

7. For sedentarising the trading nomads (Banjaras) the *tanda* should be taken as one unit for settlement purposes in different villages. It shall be highly desirable to make use of the existing administrative machinery among the nomads rather than supersede them.

8. Suitable arrangements for storage of drinking water, school-cum-community centres and marketing of surplus produce should be made for all the nomads.

9. The cooperative societies should be formed for giving loan on nominal interest for their efficient running of their traditional occupations of blacksmithy and cattle trade as well as for the proper initiation and accelerated adoption of cultivation.

10. The demographic features reveal that there are potentialities of high future growth rate of population and it shall be highly desirable to initiate steps for introduction of family planning and planned parenthood among them.

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VEGETATION OF INDIAN DESERT BIOME

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INTRODUCTION

Rajasthan desert, which lies in the desert belt of the world, is land locked, hot and inland type of desert. It occupies an area of about 0.32 million km². It is located in the north western part of India between 23°3' and 30°12'N, and 69°30' and 78°17'E. The Aravallis intersect the desert country, almost from end to end by a line running nearly north-east and south-west. In western Rajasthan, Luni is the main river which has about half a dozen tributaries. It starts near Pushkar (Ajmer), runs about 320 km and then is lost in the Rann of Kutch.

The vegetation of this tract is quite sparse with limited number of species. The forest form almost negligible proportion (0.69%). While fallow lands, other uncultivated areas and areas not available for cultivation, together constitute 63.69%. The remaining 36.3% comes under cropped area, 0.69% as classified forest is from the forestry standard point of view. This does not mean that the vast areas are devoid of tree vegetation. Areas covered under uncultivated areas include the waste lands, Beers, Jhors and Orans located near the villages. These areas are generally controlled by Grampanchayat. They all are very badly managed but distinctly depict the relict vegetation of the tract. The exploitation of vegetation by man and animals is so severe that vast stretches of land are almost devoid of tree vegetation.

The topographic changes are well known to produce the characteristic changes which are ultimately reflected in supporting a definite composition of plant population. Thus making different plant communities on various landforms (habitat). For the last twelve years the section of Plant Ecology has been conducting vegetation resource surveys, which is a part of integrated survey project, in western Rajasthan and have published several reports on this aspect (Anonymous 1963, 65, 66, 67, 69, 70). Based on the survey experience, the vegetation of the Desert Biome can conveniently be described into the following nine broad ecosystems.

(1) Hills and rock outcrops. (2) Piedmont plain. (3) Pediment plain. (4) Gravelly plains. (5) Alluvial plains. (6) Sand dunes. (7)

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Graded river beds. (8) Saline flats and depressions and (9) Aquatic areas.

Review

In the last two to three decades small regions vegetation and floristic surveys in western Rajasthan have been made by various workers, i.e. Sarup (1951, 52, 53, 55, 57 and 58); Vyas (1955, 56); Sarup and Vyas (1958); Das and Sarup (1951); Puri and Jain (1961); Biswas and Rao (1953); Nair (1956, 57, 61); Nair and Nathawat (1956, 57); Nair and Joshi (1956); Nair and Kanodia (1959); Nair *et. al.* (1961); Tandon (1958); Ratnam and Ramdeo (1958); Sharma (1961, 62, 65 a and b, 72); Satyanarayan and Saxena (1966); Saxena and Gupta (1973), Kanodia and Gupta (1966); Gupta and Saxena (1966, 68, 70, 71); Satyanarayan *et. al.* (1966); Saxena *et. al.* (1972). All these above workers have either surveyed small areas or described upto district level. Taking all the above publications into consideration an overall picture of desert does not come out.

First comprehensive work on the plants of Rajasthan desert was carried out by Blatter & Hallberg (1918—21) in which they classified the vegetation types of western Rajasthan into formations i.e. Aquatic, Sand, Gravel, Rock and Ruderal. Champion (1936) recognised four principal types of vegetation in Rajputana i.e. (1) Northern Desert Thorn forest, (2) Northern Acacia scrub forest (20-40" rainfall), (3) Northern Euphorbia scrub and (4) Inland dune scrub. Santisarup and Vyas (1957) recognised six plant associations according to different "situations". Chaudhry (1957) followed a geobotanical approach in classifying the vegetation of western Pakistan. The habitat recognised by him are : (1) Detached low hills, (2) Water logged areas, (3) Flat saline soils, (4) Riverine tracts and (5) Areas of shifting sand dunes. Biswas and Rao (1953) dealt with Rajputana vegetation and divided Rajasthan into three zones on the basis of rainfall. They treated the vegetation with reference to edaphic and environmental factors and grouped into sand, gravel and rock communities. Mathur (1960) elaborated champion classification and listed seven forest types in western Rajasthan. Bharadwaj (1961) distinguished three primary and three secondary land forms in western Rajasthan. Bharucha (1952, 55) described the plant ecological research in Indian desert and other adjoining regions like Pakistan and Afganistan etc. Satyanarayan (1963) distinguished two major landform groups i.e. (1) Erosional forms and (2) Depositional form and classified the vegetation of Central Luni basin into five formations. Mulay and Joshi (1964) recognised four Eco-systems while recently Saxena (1972) distinguished seven eco-systems which are now extended to nine eco-systems.

Environment

Climate: The climate of Rajasthan desert is of extreme type and is characterised by high solar radiation, extreme variations of diurnal and seasonal temperature and erratic rainfall with marked variation from year to year. The low humidity of the atmosphere for greater part of the year, except rainy season, powerful winds and dust storm during summer, high evaporation rates are also common feature of this desert. These climatic conditions and the edaphic features when combined together, play a greater role and present the vegetation of Rajasthan desert into its present status. Here some of the perennial plants are capable to adjust themselves according to seasonal changes while others try to evade inhospitable period by shedding of leaves or becoming dormant. The annuals evade the harsh period by keeping themselves into seeds.

Soils

The soils of the Indian desert are immature like other desert soils and are mostly sterile with a poor fertility status, poor water holding capacity, very low in organic matter, weaker in exchangeable bases, high in pH values and low in nitrogen and phosphates. Raychaudhury (1952) described that N.E. of the desert support light loam and heavy loam type of soils and the clay percentage is less at the surface than in the sub-soils which is due to wind erosion and runoff. Thamane (1952) grouped desert soils into two divisions : (1) The part lying in the north west of Aravallis is almost sandy, ill-watered and unproductive but comparatively more fertile in the east as the soil changes from sandy to clayey in character and (2) The part lying to the south-east of Aravalli range is fertile containing variety of soils. The sandy soils of western Rajasthan contain as much as 90-95% of coarse and fine sand and 5-7% of clay and silt. Misra (1967) based on soil survey map of India (1962), classified the soils of Rajasthan into seven categories. Ray Chaudhury (1964) gave the classification and fertility of soil of desert and semi-desert regions of India. Abhichandani and Ghose (1964) described the origin of land forms and the parent material in the tract has variously been described as of fluvial and aeolian in origin. Recently Roy and Sen (1968) classified the soils of Rajasthan into following seven categories. (1) Desert soils confined to interdunal areas; (2) Dune sands, extensively distributed into entire western Rajasthan; (3) Red desertic soils, pale brown to dark brown, loose sandy loam to sandy clay loam; (4) Sierozems are like red desertic soils but are sandy clay loam; (5) Saline soils, dark grey to pale brown heavy

soils with water table very close to the surface; distributed in Ranns and saline depressions; (6) Lithosols and regosols shallow, light textured soil of sloping hill side; (7) Red and yellow soil along the foot hills.

Biota

Unlike other deserts of the world, Indian desert is heavily populated both by men and animals. The sparse and limited vegetation of the desert is variously exploited by men through cutting, lopping, felling, killing and amputing the branches as such, stripping and scrapping the ground vegetation for its immediate need. Excavation earth quarries, tunnelling and many other such destructive activities on vegetation result in various degree of plant shape modification. Stunted dwarf, badly mutilated, crooked or prostrate form of trees itself speak the conditions to which they are placed.

Enormous livestock population of cattle, sheep, and goats leave the natural grasslands or grazing areas as over-grazed whose production goes to the lowest level. Due to this over-grazing unpalatable and less nutritive species like *Tephrosia purpurea*, *Crotalaria burhia* and *Aristida funiculata* flourish on such sites. Large amount of top feed from plants like *Zizyphus nummularia*, *Prosopis cineraria*, *Calligonum polygonoides*, *Capparis decidua* and *Salvadora oleoides* are exploited by domesticated animals.

Besides grazing, browsing, tremping, treading and truding are other ways of damaging the natural vegetation at its various levels of development. Other elements which either utilize and destroy the vegetation in the desert eco-system are various birds, rodents and mammals. The natural fauna of Indian desert is sufficiently rich which also exert a substantial pressure on the vegetation as secondary consumer. The common herbivore birds of the desert as indicated by Prakash (1974) are painted partridge (*Francolinus pictus pallidus*), Grey partridge (*F. pondicerianus*), Sand grouse (*Pterocles exustus erlangeri*), Imperial sand grouse (*P. orientalis*), Common quail (*Cotrunix cotrunix*), Great Indian Bustard (*Choriotes nigriceps*), Babbler (*Turdioides striatus*, *T. caudatus*), Dove (*Streptopelia decaocto*), Bulbul (*Pycnonotus cafer*) and Parakeet (*Psittacula krameri*). All these birds are found to depend largely on the fruits of trees, shrub, herbs and crops (Rana, 1973). During summer months, when the vegetation is scarce, they are found to be partially carnivorous as well.

Rodents are the major consumer of the ground herbage. Prakash (1974) have shown their distribution on various habitats in Indian desert. They include Desert Gerbil (*Meriones hurrianae*), Indian gerbil

(*Tatera indica indica*), House rat (*Rattus rattus*), Cutch Rock rat (*Rattus cutchicus*), Soft-furred field rat (*R. meltada pallidior*), Hairy footed Gerbil (*Gerbillus gleadowi*), House mouse (*Mus musculus*), Field mouse (*Mus booduga*) and Bush rat (*Golunda ellioti*).

Amongst large animals who are the bulk consumers in the major grasslands, crop lands or woodland are Blue bull (*Boselaphus trago camelus*), Black buck (*Antelope cervicapra rajputanae*), Wild boar (*Sus scrofa*), Gazelle (*Gazella gazella benetta*), Chinkara (*Axis axis*), Fox (*Vulpes V. pusella* and *V. bengalensis*), Hare (*Lepus nigricollis*), Langur (*Presbytis entellus*) and Squirrels (*Funambulus pennanti*) are few other herbivore mammals.

Amongst arthropods, desert locust (*Shistocerca gregaria*) is the quickest destroyer of vegetation. Grasshoppers and other insects also play comparatively minor role as consumer especially in the grasslands and cropland eco-system.

Principal Ecosystems and the Vegetation Type.

1. Hill and rock outcrops

Majority of the hill ranges in western Rajasthan are of granite, rhyolite, sandstone and limestone while few are quartzite, adamellite, slate and schists. In general the hills are steep with 40-60 per cent slope. Granite hills are rugged and their lower slopes are covered with rock fragments and rounded boulders. Here the vertical joints are well developed and their exfoliation is also along these joints the streams follow the path of these major joints. Skeletal soil accumulation takes place between the boulders where roots of the plants can have better foothold. Granite rocks show comparatively more vegetation cover than other rock types. The rhyolite hills are comparatively hard and compact smooth surface which do not allow any soil accumulation and thus such rocks are almost bare. The sand stone rocks are highest in percentage. Most of them have flat tops and sharp slopes. They have horizontal bedding with vertical joints and numerous channels flow along these joints. These rocks are also almost bare as no soil accumulation takes place on them. Junction of horizontal and vertical joints allow some plants like *Capparis decidua* and *Maytenus emarginatus* to come up. The growth of these are very much stunted. The limestone rocks are generally low in height and these too do not have desirable soil cover and hence these are also very poorly vegetated. But this formation is good host for ground water.

The plant communities growing on these hills have been grouped under "Mixed Xeromorphic Thorn Forest" (Satyanarayan, 1963) but

vary from a low statured thorn forest to a sparsely distributed scrub. The principal plant communities of this ecosystem are:

- 1) *Anogeissus pendula*—*Acacia senegal*, 2) *Acacia senegal*—*A. pendula*, 3) *Anogeissus pendula* 4) *Acacia senegal*.

A. pendula—*A. senegal* is supposed to be the climax community of the hills (Satyanarayan 1963, 64). But due to the severity of biotic influence majority of hills are found to occupy the "Seral" communities. Both these valuable trees are good fuel and top feed plants and hence destroyed by cutting, lopping and felling. The power of recovery and regeneration of these species is very slow but with protection they seem to recover back to their original status. Following degraded communities which are met on several types of rocks are (1) *Euphorbia caducifolia*—*Acacia senegal*, (2) *E. caducifolia*—*Grewia tenax*, (3) *Euphorbia caducifolia* (4) *E. caducifolia*—*Capparis decidua* (5) *Capparis decidua*, (6) *Cassia auriculata* and (7) *Maytenus emarginatus*—*E. caducifolia*.

The associated trees and shrubs of the above climax and seral communities (under protection) are *Anogeissus rotundifolia*, *Cordia gharaf*, *Moringa coccinensis*, *A. senegal*, *A. pendula*, *Salvadora oleoides*, *Wrightia tinctoria*, *Azadirachta indica*, *Maytenus emarginatus*, *Solanum albucaule*, *Grewia tenax*, *Capparis decidua*, *Euphorbia caducifolia* and *Cassia auriculata*. Some of the lianas (climbers) i.e. *Cocculus pendulus*, *Asparagus racemosus*, *Tinospora cordifolia*, *Sericostemma brevistigma* and *Ephedra foliata* are usually grown in association with *A. senegal*, *M. emarginatus*, *Euphorbia caducifolia* and *Capparis decidua*.

The plants of the ground floor, their number and density vary according to rock types and also due to biotic influences. The common one with protections are *Aristida funiculata*, *Oropetium thomeaum*, *Melanocenchrus jacquemontii*, *Tragus biflorus*, *Cenchrus biflorus*, *Eragrostis* sp. *Indigofera cordifolia*, *Tephrosia petrosa*, *Tephrosia purpurea*, *Enneapogon brachystachys*, *Blepharis sindica*, *Achyranthus aspera*, *Puppalia lappacea*, *Boerhavia diffusa*, *Digera muricata*, *Sida cordifolia*, *Lepidagathis trinervis*, *Cleome viscosa*, *Eleusine compressa*, *Tribulus terrestris*, *Peristrophe bicalyculata*, *Barleria acanthoides*. Protected rocky ranges under slightly higher rainfall conditions (Jalore, Sanchor, Sumerpur, Pali) and good soil cover are recorded with good grass like *Sehima nervosum*, *Hackelochloa granularis*, *Bothriochloa ramosa*, *Apluda mutica* and *Cymbopogon jwarancusa*.

2. Piedmont plains

During monsoon season short streams bring down the wash off material from the hills along with various sizes of boulders and rock

fragments and deposit them at foothills. This can further be divided into the upper and the lower piedmont zone.

a) *Upper piedmont*:

Here the slopes are 5-10 per cent and the area is completely covered with boulders, cobbles, rock fragments mixed with loamy sand. Here much dissection takes place which results in the formation of rills and gullies of different sizes. The water action in this system is quite severe. The gullies are mostly lined by sub-montane elements like *Acacia senegal*, *Maytenus emarginatus*, *Moringa coccanensis*, *Commiphora wightii*, *Wrightia tinctoria*, *Cordia gharaf* and *Malhania denhamii*. Sometime during summer months the blown sand is deposited against the higher slopes which gets mixed up with rock fragments. This is again brought down by the rains leaving something to stabilise. The vegetation cover mainly depends on this left over soil cover.

Plant communities in this ecosystem have been grouped as "Mixed Xeromorphic Thorn Forest". Here the trees are of 3-5 m height with a very sparse cover. The communities recorded here are 1) *Salvadora oleoides*—*Euphorbia caducifolia*, 2) *Cordia gharaf*—*E. caducifolia*, 3) *E. caducifolia*, 4) *Cassia auriculata*, 5) *Maytenus emerginatus* and 6) *Capparis decidua*.

All these above communities represent the disclimax stage. *E. caducifolia* is the predominant community in majority of cases. Other associates and main sub-montane elements like *A. senegal* and *A. pendula* are generally found in prostrate or bushy form due to cutting, browsing and lopping. Rhyolite, sandstone and limestone hills, in majority of cases do not support and tree species except the ground cover which is dominated by *Tephrosia purpurea* and *Aristida funiculata*. The common associate trees, shrubs, herbs and grasses are:—

1) *Salvadora oleoides*, *Wrightia tinctoria*, *Moringa coccanensis*, *A. senegal*, *Anogeissus pendula* and *A. leucophloea*.

2) *Maytenus emarginatus*, *Commiphora wightii*, *Barleria prionitis*, *Grewia tenax*, *E. caducifolia*, *C. decidua* and *Indigofera tinctoria*.

3) *Tephrosia purpurea*, *T. petrosa*, *Indigofera cordifolia*, *Boerhavia diffusa*, *Blepharis sindica* and *Cleome papillosa*.

4) *Aristida funiculata*, *Oropetium thomeaum*, *Tragus biflorus*, *Eragrostis* sp. and *Heteropogon contortus*.

b) *Lower piedmont*

It has 3-5 per cent slope which receive the wash off material from the hill and upper piedmont slopes and gets covered by irregular and heterogenous deposits of varying depth. The top material is coarse but

the lower strata has finer material as the sediments decreases with the increasing distance from the hill. Sometime the aeolian sand piling is very deep and this makes a very good habitat for the vegetation to develop. This ecosystem gradually merges with the alluvial plains and thus it supports a mixture of species occurring both on the hills and the plains. The vegetation on this ecosystem has been classed as "Xeromorphic Thorn Forest". Here the common plant communities are 1) *Salvadora oleoides*—*Prosopis cineraria*—*Euphorbia caducifolia*, 2) *Acacia senegal*—*Prosopis cineraria*—*C. decidua* 3) *S. oleoides*—*P. cineraria*—*A. jacquemontii*, 4) *Prosopis cineraria*—*Acacia senegal*, 5) *C. decidua*—*Z. nummularia*, 6) *Euphorbia caducifolia*, 7) *Cassia auriculata*. Under protection this ecosystem supports medium thick forest while the unprotected areas support highly degraded community like *Cassia auriculata* or *Euphorbia caducifolia*. Most of the piedmont plains under degraded form are occupied by *E. caducifolia*. The associate trees, shrub, herbs and grasses of these communities include:

1) *Acacia leucophloea*, *A. nilotica* sub sp., *indica*, *A. senegal*, *Salvadora oleoides*, *Balanites aegyptiaca*, *Azadirachta indica*, *Prosopis cineraria*.

2) *Acacia jacquemontii*, *Maytenus emarginatus*, *Zizyphus nummularia*, *C. decidua*, *Grewia tenax*, *Leptadenia pyrotechnica*.

3) *Tephrosia purpurea*, *Indigofera cordifolia*, *Aerva persica*, *Cleome viscosa*, *Boerhavia diffusa*.

4) *Aristida funiculata*, *Oropetium thomeaum*, *Cenchrus biflorus*, *Eragrostis ciliaris*, *E. tremula*, *Cenchrus prieurii*, *C. ciliaris*, *C. setigerus*, *Cymbopogon jwarancusa*, *Heteropogon contortus*, *Dichanthium annulatum*, *Eremopogon foveolatus* and several other annual grasses.

Cocculus pendulus and *Asparagus racemosus* are the two climbers which commonly grow on *Maytenus emarginatus*, *Prosopis cineraria* and *Salvadora oleoides*.

3. Pediment plains

They are almost flat rocky areas with 0-1 per cent slopes. Here the rock slopes have retreated and finally taken the shape of flat terrain due to deep weathering and subsequent erosions. The differential weathering has given rise to uplands and low lands. The uplands are covered with rock fragments and little amount of sand and these are subjected to severe water erosion. The low lands are almost flat and the depth of sediments ranges from 25-125 cm. which gets deposited from upland. Some of the rocky areas get buried under aolian and fluvial deposits. (Anonymous 1972). Thus the above plain can be divided into two categories.

a) *Flat exposed pediment plain.*

Such rocky flat areas are most common in district Jodhpur and are associated with Vindhyan sandstone and limestone. In this ecosystem the ground water potentials have been found to occur with limestone and sandstone formations as the water infiltrates through joints and accumulate below the surface in the form of aquifers. The cracks and joints accumulate the soils where vegetation is also capable to have a foothold. Hence according to the condition the vegetation type on this ecosystem varies from "Dwarf Semi-Shrub Desert" to a Mixed Xeromorphic Thorn Forest". The vegetation of this system is quite sparse and this too is badly exploited. The limestone and slate pediments are dominated by *Capparis decidua* community while the sandstone-rhyolite formations are supported by comparatively better vegetation cover. Most dominant plant community is *Euphorbia caducifolia* *Acacia senegal*. Associated common shrubs, herbs and grasses are:

1) *Maytenus emarginatus* *Zizyphus nummularia*, *Lycium barbarum* and *Cassia auriculata*.

2) *Tephrosia purpurea*, *Indigofera hoschtetteri*, *I. cordifolia*, *Tephrosia petrosa*, *Boerhavia diffusa* and *Gleome viscosa*.

3) *Oropetium thomeaum*, *Melanocenchrus jacquemontii*, *Enneapogon brachystachys*, *Tragus biflorus*, *Dactyloctenium indicum* and *Aristida funiculata*.

b) *Buried pediment plain:*

These are flat plains with 1.0 per cent slope. These are mostly covered by alluvial and colluvial deposits. Here the sediments are partly transported and partly developed in situ. Some of these plains get aeolian deposits in the form of sand sheet. The depth of the deposits vary from 80 cm. to 5 m. below which directly rock is encountered. Here the rain water infiltrates rapidly through these deposits and accumulates in the underlying rocky strata. Just like the lower piedmont plain, the vegetation of this ecosystem consists of rocky and as well as plains elements. Thus the plant community is very much effected by the depth of the deposits. Here again the vegetation type varies from "Semi-Shrub-Desert to Mixed Xeromorphic Woodland". The common plant communities are: (1) *Capparis decidua*—*Maytenus emarginatus*—*Acacia senegal* (3) *Prosopis cineraria*—*Capparis decidua* (3) *Prosopis cineraria*—*Acacia nilotica* *Ssp indica*. The structure and composition of these communities include:

1) *Acacia leucophloea*, *Salvadora oleoides*, *Acacia senegal*, *Prosopis cineraria* *Acacia nilotica* *Ssp indica*.

2) *Zizyphus nummularia*, *Capparis decidua*, *Maytenus emarginatus*, *Lycium barbarum*.

3) *Tephrosia purpurea*, *Indigofera cordifolia*, *Ferretia hamiltonii*, *Corchorus depressus*, *Boerhavia diffusa*.

4) *Cenchrus biflorus*, *C. prieurii*, *Eleusine compressa*, *Dactyloctenium indicum*, *Eragrostis* sp, *Lasiurus indicus*.

On the whole the vegetation is quite sparse. The trees are widely scattered.

4. Gravelly plain

There are extensive patches of gravelly plains in Phalodi and Pokhran tehsils of Jodhpur and Jaisalmer district respectively. Here the surface is covered with the gravel of various sizes where the sheet wash takes place. Only surface depositional material is carried away by water action. The material down below the gravel is well protected from water and wind action. This is also called as "Desert pavement". Some of the plains where upper soils mantle was completely removed by sheet wash and the underlain kankar pan is exposed (i.e. Nal to Gajner in Distt. Bikaner) also supports identical vegetation. Here the exposed kankar pan which is lime-coated layer gets mixed with blown sand (aeolian) at various points which allows the vegetation to get a foothold. Otherwise the vast stretches of these plains are devoid of tree and shrub vegetation. On the whole the vegetation is grouped here as "Semi-Shrub-Desert". The existing shrubs are widely scattered with poor growth 1) *Capparis decidua*, 2) *C. decidua*—*Zizyphus nummularia* are the two common plant communities of this ecosystem. The common associate are:

1) *Leptadenia pyrotechnica*, *Lycium barbarum* and *Haloxylon salicornicum*.

2) *Boerhavia diffusa*, *Corchorus depressus*, *Fagonia cretica*, *Cleome papillosa*, *Tribulus terrestris*, *Sericostemma pauciflorum*, *Blepharis indica*, *Heliotropium strigosum*, *H. undulatum*, *Mollugo nudicaulis*, *M. cerviana*, *Bergia odorata*, *Anticharis liniaris*, *Salvia aegyptiaca* and *Indigofera trigonelloides*.

3) *Aristida hystrix*, *A. mutabilis*, *Oropetium thomeum*, *Dactyloctenium indicum* and *Eleusine compressa*.

5. Alluvial plains

Major part of the land comes under this system. The following subdivisions depending upon the soil type and topography are as follows:

(a) Younger alluvium (b) Older alluvium (flat) and (c) Older alluvium (hummocky).

a) *Younger alluvium*:

Along the bank of the river Luni and its tributaries, the areas comes under this ecosystem. It has ground water potential. The water table is generally at 8-12 m depth. Mostly water is sweet but sometime slightly saline and hence invariably put under irrigated crops. Here the general growth of the trees is fairly good (10-15 m. high). The natural vegetation is highly modified and exist only in Orans and Beers. Some of the portion in the younger alluvium, being low gets higher fraction of silt. The silty surface is underlain by water borne sub-rounded to rounded gravels. The soils are calcareous, deep loamy sand to sandy loam. The top 30-40 cm deposits are almost water borne, coarse sand underlain by a deposit of loamy sand. Here *Acacia nilotica* Ssp *indica*, *A. nilotica* Ssp *cupressiformis*, *Prosopis cineraria* and *Salvadora oleoides* are the main trees which in combinations form the following communities and the vegetation is grouped as "Mixed Xeromorphic Woodland or Wood-ed Desert".

(1) *Prosopis cineraria* - *A. nilotica* Ssp *indica*, (2) *Prosopis cineraria* - *A. nilotica* Ssp *indica*, (3) *A. nilotica* Ssp *indica* - *P. cineraria* are mostly on the cultivated fields with sandy soils, (4) *Salvadora oleoides* - *Capparis decidua*, (5) *S. oleoides* - *Prosopis cineraria* on silted beds.

Luni and its tributaries have made some inlets in the coarse of their flow. These are generally flooded during monsoon. Such areas are dominated by (1) *Tamarix dioica* - *Salvadora oleoides* and (2) *Prosopis juliflora* communities.

The dug wells or tubewell invariably have some specific introduced tree vegetation like *Ficus bengalensis*, *Ficus religiosa*, *Azadirachta indica*, *Tamarindus indica*, *Cordia myxa*, *Zizyphus mauritiana*, *Ailanthus excelsa* and *Moringa oleifera*. These are planted for providing shade to the working person and animals etc.

The abandoned fields and wasteland along the river Luni are found in highly exploited and degraded conditions. Non-palatable and less exploitable species like *Cassia auriculata*, *Indigofera oblongifolia* and *Tephrosia purpurea*, dominate these lands. Places with accumulation of water for a short period are generally invaded by *Xanthium strumarium*, *Solanum surattense* and *Tephrosia purpurea*.

The common associates of the above mentioned communities are:

(1) *Acacia leucophloea*, *Moringa oleifera*, *Bauhinia acuminata*, *Zizyphus mauritiana*.

(2) *Acacia jacquemontii*, *Calotropis procera*, *C. decidua*, *Leptadenia pyrotechnica*, *Indigofera oblongifolia*, *Cassia auriculata* and *Xanthium strumarium*.

(3) *Tephrosia purpurea*, *Convolvulus microphyllus*, *Crotalaria burhia*, *Digera muricata*, *Justicia procumbens*, *Amaranthus viridis*.

(4) *Cynodon dactylon*, *Desmostachya bipinnata*, *Cenchrus biflorus*, *C. prieurii*, *C. setigerus*, *Eragrostis pilosa*, *Digitaria adscendens*, *Eleusine compressa* and *Cyperas rotundus*.

(b) *Older alluvium with flat topography:*

Major portion of the tract comes under this ecosystem. These are almost flat lands with 0-1% slope. The soils are sandy loam, loamy sand to sandy clay loam which are moderately deep to very deep with lime kankar pan of indurated or semi-indurated nature on varying depth (30-150 cm below). Soil depth and type of induration, very much effects the plant growth of perennial vegetation. Plants capable of penetrating through the kankar pan are able to survive well and dominate this ecosystem. The natural vegetation is much modified due to regular cultivation. The common tree and shrub species of these plains are *Prosopis cineraria*, *Salvadora oleoides*, *S. persica*, *Acacia nilotica* Ssp *indica*, *Zizyphus nummularia* and *Capparis decidua*. These are distributed throughout the plains and form different plant communities in various combinations. Satyanarayan (1963) has described *Prosopis cineraria* - *Salvadora oleoides* community as the climatic climax of the region but nowhere it is found in its optimum condition due to regular biotic disturbances, since centuries. Here the vegetation is grouped as "Mixed Xeromorphic Woodland or Wooded Desert". Following are the plant communities of this ecosystem:

(1) *Salvadora oleoides*, (2) *Prosopis cineraria* - *Zizyphus nummularia* - *Capparis decidua*, (3) *S. oleoides* - *P. cineraria* - *C. decidua*, (4) *P. cineraria* - *S. oleoides*, *C. decidua*, (5) *P. cineraria* - *Acacia nilotica* Ssp *indica*, (7) *S. oleoides* - *P. cineraria* - *Z. nummularia*, (8) *Zizyphus nummularia* - *P. cineraria* - *C. decidua*, (9) *Acacia nilotica* Ssp *indica* - *P. cineraria* - *Z. nummularia* and (10) *Prosopis cineraria*.

The above communities are also variously modified and degraded to lower stages like (1) *Capparis decidua* - *P. cineraria*, (2) *Z. nummularia* - *P. cineraria*, (3) *Zizyphus nummularia*, and (4) *Salvadora oleoides* - *C. decidua* etc. In cases of extreme exploitation these tree and shrub species lose their natural life form and assume either bushy shape or prostrate form. The structure and composition of these communities are as under:—

(1) *P. cineraria*, *S. oleoides*, *A. nilotica* Ssp *indica*, *Tecomella undulata*, *Balanites aegyptiaca*, and *Zizyphus mauritiana*.

(2) *Zizyphus nummularia*, *C. decidua*, *Acacia jacquemontii*, *Calotropis procera*, *Indigofera oblongifolia*, *Mimosa hamata*, and *Cassia auriculata*.

(3) *Aerva persica*, *Crotalaria burhia*, *Tephrosia purpurea*, *Pupalia lappacea*, *Tribulus terrestris*, *Indigofera cordifolia*, *Boerhavia diffusa*, and *Achyranthus aspera*.

(4) *Eleusine compressa*, *Aristida funiculata*, *A. mutabilis*, *A. adscensionis*, *Cenchrus biflorus*, *C. prieurii*, *C. ciliaris*, *Dactyloctenium aegyptium*, *Digitaria adscendens*, *Eragrostis* sp., *Dichanthium annulatum* and *Cyperus rotundus*.

(c) *Older alluvium with hummocky and undulating topography:*

Extensive areas of alluvial plains are subjected to wind erosion resulting in the formation of hummocks. The land assume gentle undulation due to the hummocks which are 1-2m high. The hummocks have been built up against the raised fences and shrub species or these hummocks are colonized by psammophytic shrub species like *Calligonum polygonoides*, *Calotropis procera*, *Capparis decidua*, *Leptadenia pyrotechnica*, *Lycium barbarum*, *Clerodendrum phlomoides*, *Aerva persica*, *A. pseudotomentosa*, *Crotalaria burhia*, *Panicum turgidum*, *Lasiurus indicus* and *Cymbopogon jwarancusa*. The undulating terrain has 1-3% slope. The sandy loam soil of flat older alluvium is covered by wind sorted loamy sand of various thickness. Thus the vegetation of the area is represented by "Psammophytic Scrub Desert". Few scattered trees of *Prosopis cineraria*, *Tecomella undulata* and *Salvadora oleoides* are present. Low saturated, cushion like bushes which are usually one metre high make the following plant communities in western part of the districts of Jaisalmer, Barmer, Bikaner and Jodhpur etc.

- (1) *Calligonum polygonoides* - *Zizyphus nummularia*.
- (2) *C. polygonoides* - *Haloxylon salicornicum*.
- (3) *C. polygonoides* - *Leptadenia pyrotechnica* - *Aerva persica* - *A. pseudotomentosa*.
- (4) *Crotalaria burhia* - *A. pseudotomentosa* - *L. pyrotechnica*.
- (5) *Acacia jacquemontii* - *A. pseudotomentosa*.
- (6) *Mimosa hamata* - *Crotalaria burhia*.
- (7) *M. hamata* - *Clerodendrum phlomoides*.
- (8) *C. polygonoides* - *Lasiurus indicus*.
- (9) *C. procera* - *A. pseudotomentosa*.
- (10) *A. pseudotomentosa* - *C. burhia* - *C. procera*.

All these above species are good soil binder as well but grazing, cutting and removal of shrubs reduced the vegetal cover, resulting in wind erosion. Due to sand activity the overall vegetal cover is quite sparse, which is not conducive to better plant growth and its initial establishment. This results the process of succession very slow. The space between the hummocks is generally occupied by the annual species and few perennial species like *Cyperus arenarius* and *Citrullus colocynthis*. The structure and composition of the above communities in this eco-system is:

1. *Calotropis procera*, *Mimosa hamata*, *Lycium barbarum*, *Clerodendrum phlomoides*, *Leptadenia pyrotechnica*, *Aerva pseudotomentosa*, *A. persica*, *Acacia jacquemontii*, *Calligonum polygonoides* and *Haloxylon salicornicum*.

2. *Sericostemma pauciflorum*, *Crotalaria burhia*, *Echinops echinatus* and *Cassia obovata* (occasional).

3. *Citrullus colocynthis*, *Tribulus terrestris*, *T. alatus*, *Boerhavia diffusa*, *Indigofera linifolia*, *I. cordifolia*, *Farsetia jacquemontii*, *Corchorus tridens* and *Dipterygium glaucum*.

4. *Eleusine compressa*, *Dactyloctenium aristatum*, *Lasiurus ecuadatus*, *P. turgidum*, *Cymbopogon jwarancusa*, *C. parkerii*, *Cenchrus biflorus*, *C. prieurii*, *Aristida funiculata*, *A. mutabilis*, *Eragrostis* species, *Perotis indica* and *Cyperus arenarius*.

6. Sand dunes

About 58 per cent of the western Rajasthan is covered with sand dunes of different forms, magnitudes and orientations. (Pandey *et. al.* 1964). Here two families of dune complex have been recognised viz. (1) Free dune and (2) Obstacle dune. (Singh *et. al.* 1972).

1. *Freedunes*: There are four distinct types of free dunes viz. Parabolic, longitudinal, transverse and barchan which commonly occur in western Rajasthan. Density of parabolic dunes dominate the western districts of Barmer, Bikaner, Jaisalmer and Jodhpur.

2. *Obstacle dunes*: Are those dunes which have formed due to the obstruction i.e. (i) Hill side dune and shrub-coppice dunes.

Different type of dunes and their vegetation is described as under:

1. Free dune:

(a) *Parabolic dunes*: These are the oldest dunes formed in the prevailing direction of the south-west winds. They are stabilised dunes but the crest and upper slopes are covered with fresh sand, sometime in the form of barchan dunes. The height and length of these dunes vary from 25-60 m and 400 to 3,500 m respectively. (Saxena and Singh

1976). Their sand is compact, fine and calcareous and are invariably supported by tree vegetation. The windward face and the flanks of these dunes are moderately sloping and the leeward slope is frequently steep. Crest, flanks and windward slopes are mostly cultivated for kharif crops. Two major vegetation types (1) "Mixed Xeromorphic Thorn Forest" and (2) "Psammophytic Scrub Desert" have been recognised on these dunes depending upon the intensity of biotic disturbances and the amount of precipitation in which they occur. So far the following plant communities have been recorded on them.

- (1) *Acacia senegal* - *Prosopis cineraria*.
- (2) *A. senegal* - *Calligonum polygonoides*.
- (3) *Grewia tenax* - *Capparis decidua* - *Acacia senegal*.
- (4) *Calligonum polygonoides* - *Panicum turgidum*.

A. senegal - *P. cineraria* community seems to be the climatic climax of the dune ecosystem. This is found on these dunes which are religiously protected since centuries.

(b) (a) *Longitudinal dunes*: These dunes have been formed in the prevailing south-west direction of the wind. They are also stabilised with their sand compact. In most cases, due to biotic disturbances and severe drought, the flanks and crest are covered with fresh sand. Longitudinal dunes of low, medium and high heights are found in western Rajasthan. The height of the high and medium dunes varies from 30-60 m and 10-30 m respectively. The slopes of the crests and flanks of these dunes vary from 36-40% and 20-35% respectively. Low dunes are of 1.5 to 5 m in height with loose and calcareous sand. "Psammophytic Scrub Desert" type of vegetation prevail on these dunes. The plant communities so far listed on these dunes are (1) *Calligonum polygonoides* - *Panicum turgidum* - *Acacia jacquemontii*, (2) *Calligonum polygonoides* - *Panicum turgidum*, (3) *C. polygonoides* - *Clerodendrum phlomoides*, (4) *C. polygonoides* - *Calotropis procera*, (5) *C. polygonoides* - *P. turgidum* - *Lasiurus indicus*, (6) *C. polygonoides* and (7) *C. polygonoides* - *Crotalaria burhia* - *P. turgidum* (mostly cultivated).

(c) *Transverse dune*: Unlike previous two types of dunes these dunes have been formed due to the transverse direction of the wind. They are also well stabilised dunes with 20-25 m height. Their sand is compact and fine textured, lime concretions are found along the flanks. The slopes of the crests are 30-35 per cent and that of flanks 15-20 per cent. They are 500-5,400 m long. (Saxena and Singh 1976). Some low transverse dunes of 1-2.5 m are also met in western Rajasthan. Like other two dunes they are also extensively cultivated and

hence hardly attain optimum plant community. The following plant communities belonging to two vegetation type have been recognised.

- (1) *Prosopis cineraria* - *Acacia senegal* - *Calligonum polygonoides*.
- (2) *Calligonum polygonoides* - *Haloxylon salicornicum* - *Panicum turgidum*.
- (3) *C. polygonoides* - *P. turgidum*.
- (4) *C. polygonoides* - *Crotalaria burhia* - *Aerva pseudotomentosa* (cultivated dunes).

The distribution of the species on various aspects of the above dunes is worth-mentioning here as it provides a better and clear picture of complete dune.

Dune crest—They are invariably colonised by *Calligonum polygonoides* and *P. turgidum*, *Leptadenia pyrotechnica*, *Aerva pseudotomentosa*, *Crotalaria burhia*, occur in scattered patches while *Indigofera cordifolia*, *Cenchrus biflorus* and *Cyperus arenarius* are fairly common.

...Dune slopes of the right and left flanks—The common plants are *Citrullus colocynthis*, *P. turgidum* and *C. biflorus*. Few widely scattered trees of *Prosopis cineraria*, *Salvadora oleoides* and shrubs like *C. polygonoides*, *Clerodendrum phlomoides* are also met with windward side. Scanty vegetation of species like *C. polygonoides*, *Aerva pseudotomentosa*, *Crotalaria burhia*, *Panicum turgidum*, *C. biflorus* and *Lasiurus syndicus* occur on the slopes.

Leeward side—It is a depositional face. The loose sand accumulate in large amount. There are few countable trees and shrub like *Acacia senegal*, *P. cineraria*, *C. polygonoides* and *Acacia jacquemontii* along the slopes.

Few other species which are met with on these three types of dunes are *Dipterygium glaucum*, *Farsetia jacquemontii*, *Ephedra foliata* (liana), *Maytenus emarginatus*, *C. decidua*, *Calotropis procera* and *Lycium barbarum*.

(d) *Barchan dunes*: They are also formed in the prevailing direction of the wind. They are formed recently and are generally found near the settlement. These dunes have also been recorded on the crest of the parabolic dunes and flanks of longitudinal and transverse dune. (Saxena and Singh, 1976). They are 3-10 m height and 212-100 m in length. Here the sand is loose, generally non-calcareous with coarser grain size. The dunes are almost devoid of any vegetation. The fast blowing winds shift or pile the sand very quickly. The initial colonizer of such dunes on windward face are *Cyperus arenarius*, *C. biflorus*,

Gisekia pharnaceoides, *Mollugo nudicaulis*, *M. cerviana*, *Farsetia hamiltonii* and *Citrullus colocynthis*.

2. Obstacle dune

(a) *Hill side dune*: The windward face of the hills provide obstruction to the moving sand and it gets piled up in large deposits. The stabilisation of this sand is quicker due to large amount of water which flows down the hills. Thus stabilisation of sand and its severe dissection takes place by rain water. Deep to very deep gullies are formed. The sand is fine, compact and lightly calcareous. Distinct calcium concretion zones may be visible in the cut gullies at sufficiently lower depth. The dissected hill side dunes of Jalore Hill are fairly old whose crest is almost flat. They support medium thick forest. The trees are free from biotic interferences as it comes under Reserved Forest. It support "Mixed Xeromorphic Thorn Forest" type of vegetation. *Acacia senegal* - *Salvadora oleoides* is the dominating community. Other plant communities on such type of dunes are (1) *Salvadora oleoides* - *Maytenus emarginatus* - *Acacia jacquemontii*, (2) *Acacia senegal* - *Maytenus emarginatus*, (3) *A. jacquemontii* - *Leptadenia pyrotechnica* (degraded state), (4) *A. jacquemontii* - *Aerva pseudotomentosa*.

Other associates are *Pancium turgidum*, *Lasiurus indicus*, *Sericostoma pauciflorum*, *Heliotropium paniculatum*, *Cenchrus biflorus*, *Cyperus arenarius*, *Crotalaria burhia*, *C. biflorus*, *A. funiculata*, *Indigofera cordifolia* and *Tephrosia purpurea*. Trees of *A. senegal*, *S. oleoides*, *P. cineraria* and *Maytenus emarginatus* support lianas like *Ephedra foliata* and *Cocculus pendulus*.

(b) *Shrub-coppice dunes*: These dunes are generally formed in the sandy interdunal plain and sandy alluvial plains. The loose sand is picked up by the moving wind from the cultivated fields and ploughed dune slopes and deposited against shrubs and bushy growth of several species e.g. *P. cineraria*, *S. oleoides*, *M. emarginatus*, *C. decidua*, *Z. nummularia*. The slopes of these dunes are irregular and vary from 90 cm to 3.5 m in height. Sand is loose and non-calcareous and shifts quickly.

Interdunal areas—The vegetation of this interdunal area which are either flat or with undulated topography bear similar vegetation as in case of the flat older alluvial plain and undulating older alluvial plain respectively. The most common plant communities in "Wooded Desert" vegetation type are (1) *Prosopis cineraria*, (2) *P. cineraria* - *Tecomella undulata*, (3) *P. cineraria*, *S. oleoides* and (4) *P. cineraria* *C. decidua*.

7. Graded river bed

Beds of river Luni and its tributaries get the water flow for a week or so and for the rest period they are dry. The bed consists of coarse

gravelly sand. During course of water flow, sand bars of different dimensions and length (600-700 m long and 100-300 m wide) are formed due to the accumulation of sand along with the organic matter and silt. These sand bars are invariably dominated by an almost pure crop of *Tamarix ericooides*, attaining a height of about 1-1.5 m. The plants remain green throughout the year, due to the availability of moisture throughout the year. The community almost stabilises these bars due to high root ramification of this species. Other species of low statured are *Xanthium strumarium*, *Zygophyllum simplex*, *Trianthema pentandra*, *Alhagi pseudalhagi*, *Desmostachya bipinnata*, *Cynodon dactylon*, *Sesbania aegyptiaca*, *Polygonum plebium*, *Bergia odorata*, *Eclipta erecta*, *Alternanthera sessilis*, *Cyperus iria*, *C. bulbosus* and *Fimbristylis* sp.

8. Saline flats and depressions

The saline flats are almost level with 1 per cent slope. The runoff water from the surrounding areas brings silt and clay along with fine sand which gets deposited into thin layers. Here the soils are heavy clay deep and saline. The surface layer on drying is covered with a white crust of salt. Due to high salinity this ecosystem is devoid of tree and shrub vegetation but is dominated by halophytic nanophanerophytes and chaemephytes. The open scrub community on the outskirts of these flat saline areas is grouped under "Succulent Halophytic Desert" type of vegetation. Saline flat areas are locally called as "Rann". Some of these ranns are i.e. Thob Ka rann, Agar ka rann, Mitha rann, Kharia rann, Pokhran ka rann, Lawan ka rann, Sanwarla ka rann etc. On their outskirts sand gets deposited on these ranns and allow the halophytic vegetation to come up. The plant communities recorded on various ranns are (1) *Haloxylon salicornicum* - *Eleusine compressa* (Agar), (2) *Sporobolus helvolus* - *Cyperus rotundus* (Thob), (3) *Peganum harmala* - *Sporobolus marginatus* and (4) *Desmostachya bipinnata* - *Eleusine compressa*. Other common halophytic species of these communities are:

(1) *Suaeda fruticosa*, *Haloxylon recurvum*, *Salsola baryosma*, *H. salicornicum* and *Atriplex* sp.

(2) *Zygophyllum simplex*, *Cressa cretica*, *Portulaca oleracea*, *Trianthema portulacastrum*, *T. pentandra*, *Mollugo lotoides*, *Fagonia cretica*, *Euphorbia granulata* and *Sesuvium portulacastrum*.

(3) *Aeluropus lagopoides*, *Echinochloa colonum*, *Chloris virgata*, *Sporobolus helvolus*, *S. marginatus* and *Dichanthium annulatum*, *Eleusine compressa* and *Dactyloctenium aegyptium*.

Here the habitat itself is inhospitable but free grazing makes it still degraded. The outskirt zone merging with plain, dunes or rocks have few tree or shrub species like *Salvadora oleoides*, *Prosopis juliflora*, *Zizyphus nummularia*, *C. decidua*, and *Indigofera oblongifolia*.

9. Aquatic areas

Tank and water reservoir in western Rajasthan are mostly surrounded by the hillocks where rain water is collected. Some of the artificial ponds and lakes get filled during rainy season. Reservoirs with sandy bottoms are either exhausted soon or dries up by end of winter. Several places they are used for winter cultivation. Semi-aquatic or marshy plants like *Ammania baccifera*, *A. mutiflora*, *Bergia* sp., *Alternanthera sessilis*, *Cyperus* sp., *Scirpus* sp., *Polygonum plebium* and *Marselia aegyptiaca* are common. The hydrophytes which are recorded from the lakes and reservoir having water throughout the year are *Chara*, *Potamogeton*, *Najas*, *Vallisneria*, *Nymphaea*, *Limnanthium*, *Lemna*, *Wolffia* and *Hydrilla* etc. (Blatt. & Hall, 1918-21 and Santi Sarup, 1957). The aquatic communities recorded there are (1) *Hydrilla* - *Vallisneria*, (2) *Ceratophyllum* - *Vallisneria*, (3) *Eicchornia* - *Potamogeton*. In most of the lakes *Trapa bispinosa* is cultivated.

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PRIMARY PRODUCTIVITY OF DESERT GRASSES AND GRASSLANDS

S. K. Saxena

In recent years International Biological Programme has considerably increased the interest for studying the biological productivity of plant communities. There are several ways to approach the subject of productivity and the useful approach in ecological work is to consider production as an ecosystem process. One of the chief functional attribute of the ecosystem is the productivity of green plants (autotrophs) which provide the basic energy and matter for all other parts of the system. A number of publications on the productivity of grasslands in India have come up during the last six years which includes a few from Rajasthan as well (Singh 1968, Singh and Misra 1969, Varshney, Ambasht *et al*, Chaudhry, Singh and Yadav, Gupta *et al* (a & b) Vyas *et al*, all 1972, Joshi and Nigam 1971, Jain 1971, Ambhasht, Gupta, Mann and Ahuja, Saxena *et al*, Mal and Misra, Pathak *et al*, Shanker-narayan *et al*, all 1974). Present investigation were carried out at Jodhpur (W. Rajasthan) for a period of about five years (1968-73) and these are presented here.

Description of site

The studies were conducted at Jodhpur (situated 73°3' E long and 26°15' N lat.) on flat old alluvial plain. The soils are deep to very deep (120-150 cm) sandy loam, underlain by an indurated kankar zone. The surface contains fine sand to loamy sand, predominantly sandy loam below 30 cm and well drained with good water permeability.

The average annual rainfall of Jodhpur is 360 mm (long term average) but it is rather erratic. During five years of study the rainfall variation is from 92.9 mm to 595.1 mm/year. The onset of monsoon takes place during the last week of June with maximum rainfall during July and August. It occasionally extends to September and rarely to October. Thus the active growth period of the grassland vegetation is July to September. More than 90% of rainfall occur during monsoon season. Intensity of rainfall and number of rainy days also vary year to year. The variation of rainfall, its intensity and period effect the production pattern of the grasses and grasslands.

November to February constitute the winter season. January being the coldest month during the year. During this period the growth activity practically ceases. After February again the temperature starts

raising, thus giving the plant another growth phase. But this is immediately checked due to sharp rise in temperature and loss in humidity during March and April.

Three sampling sites were selected for the study, Site I and II are protected by barbed wire fencing and site III is outside the fenced area. Site I was kept undisturbed since 1964. While Site II was moderately grazed by sheep and the Site III always remained open for excessive grazing.

Vegetation of sampling sites

The vegetation of three sampling sites is sparse and open. Scattered trees and shrubs of *Prosopis cineraria*, *Zizyphus nummularia* and *Capparis decidua* are present. It may, however, be recorded that at site I and site II seedlings of *Prosopis* and *Zizyphus* were present and the grasses form the dominant ground vegetation during the monsoon season. At site III the grasses are soon grazed off by the animals just after their germination. Thus, the area is overgrazed. The most common grasses recorded on sites I and II are *Cenchrus ciliaris*, *C. setigerus*, *Aristida funiculata*, *A. adscensionis*, *Eleusine compressa* and *Dactyloctenium indicum*. At site I *Aristida* spp. are more in number while at site II *Eleusine compressa* and *Dactyloctenium indicum* dominate the basal cover. *Tephrosia purpurea*, an unpalatable perennial undershrub, dominates the landscape at site III. Maximum number of species were listed from site II (60 Nos.) including a large number of perennial palatable species. There is hardly any difference in the number of species between site I and II. Site III recorded remarkably fewer species (28 Nos.) as compared to sites I and II.

Sampling methods

There are several methods for measuring the primary production i.e. (1) Harvest method, (2) Carbon dioxide assimilation, (3) Oxygen production, (4) Radio-isotope, (5) Chlorophyll method. Here harvest method was employed for the present studies (Milner and Hughes 1968).

Ten randomly selected plots of 1×1 m size were laid out every month on each site and the plant parts within the quadrat were clipped by a sickle at the ground level. The data was regularly recorded at monthly interval and expressed in gm/m².

The underground biomass was studied by taking out a core of 10 cm × 10 cm × 30 cm, by means of an auger. Roots were separated

from the core, washed and dried at $100^{\circ}\text{C} + 1^{\circ}\text{C}$ for 24 hours. The data thus obtained was computed for calculating the net primary productivity on each day and year long basis.

RESULTS

Aboveground phytomass in sown grasses

The five years data have shown a distinct production pattern which depends on the amount and intensity of rainfall and duration of rainy days. With the onset of monsoon there is an episodic growth of the grasses and the peak growth period reaches within sixty days time by September or October depending upon the first effective monsoon shower. Later there is a gradual decline due to drying and shattering of aerial parts. There is again a very short growth period during March because of rains during February. The second growth phase, however, declines quickly due to rapid moisture depletion, high temperature and high wind velocity.

The trend of above ground phytomass of three desert grasses during different months and the years is listed elsewhere (Gupta *et al* 1972). The average minimum and maximum above ground phytomass of *Lasiurus indicus*, *Cenchrus ciliaris* and *C. setigerus* during different years varied from 7.7 to 31.6, 15.6 to 261.9 and 3.2 to 127.6 g/m²/year with rainfall variability from 92.9 to 595.1 mm. All the three desert grasses produced highest above ground phytomass of 427.9 g/unit in *Lasiurus*, 307.2 g/unit in *C. ciliaris* and 192.2 g/unit in *C. setigerus* during 1970-71. In general the average above ground phytomass production is highest in *L. indicus* followed by *C. ciliaris* and *C. setigerus* except during 1969-70, a drought year, (92.9 mm) when *Lasiurus indicus* produced lesser above ground phytomass than *C. ciliaris* as *Lasiurus* grass has a deep root system (Dabadghao *et al* 1963) and there are no active root zone in upper soil horizon. While in a normal rainfall year with well distributed moisture in profile, *Lasiurus indicus* showed prolonged growth. In abnormal year of drought and intermittent showers of low intensity and lesser duration, *C. ciliaris* with root mat in upper soil zone gave better growth. Amongst three grasses *L. indicus* has longest growth period and *C. setigerus* shortest.

Above ground phytomass in natural grasslands

With the onset of monsoon the annuals, mostly therophytes, sprout along with the perennial grasses. The herbage growth reaches to its peak by September month and sometime extends to October and later

gradually declines till May, except for a slight increase in April because of some shower during February or March. In most of the years, on all the three sites, May month recorded the least production. During the hot summer months (April-June) the dry grasses gets shattered by fast blowing winds and the broken parts carried to distances. The production pattern on the protected and medium grazed sites is almost similar. The overgrazed sites however, differ, and showed peak production within a month of effective shower, mostly in August and later the production gradually declined till November and once again shows increase in December. This later increase is associated with the withdrawal of grazing animals from the degraded land to the harvested crop fields where better forage is available. This increased growth during December is also largely due to non-palatable weeds like *Tephrosia purpurea*, *Heliotropium subulatum* and *Arnebia hispidissima*.

The three sites, protected, medium grazed and overgrazed showed maximum average above ground phytomass production of 146.7, 142.8 and 24.3 g/m², respectively, during 1971-72 and minimum 8.4, 4.9 and 2.5 g/m², respectively in the year 1969-70. Higher forage production, with a rainfall of 307 mm in 1971-72 as against, 595.1 mm in 1970-71 is attributed to a higher seed production per unit area in 1970-71 which showed its impact during the succeeding year while the year 1970-71 had recovered from two successive drought years. The year 1972-73 also showed comparatively lesser production than 1970-71 and 1971-72 on all the three sites, because of early showers of June-July 1972 which allowed the annuals to sprout but subsequent longer drought period of thirty seven days resulted in the casualty of majority of seedlings.

Underground phytomass

The underground phytomass in three desert grasses and the protected grasslands upto a depth of 30 cm was recorded for five years. The production pattern in all the three desert grasses and grasslands is very much similar in all the years. The production of underground phytomass in all the grasses and grassland is higher in all the year than the above ground. It is also observed that the above ground phytomass was more effected in a drought year than the underground phytomass. On an average the three grasses produced more underground phytomass in the year 1970-71 (595.1 mm) while it was observed that the grasslands gave best performance during 1972-73 (363.3 mm).

Irrespective of rainfall variability during years, *Lasiurus indicus*

attained the peak production of underground phytomass in the month of September thus indicating that it is a better adjusted species of grass in the variability of climatic conditions in arid zone. Under normal and timely rainfall years, *C. ciliaris* also gave peak production in September but delayed monsoon with long intervening drought periods, there was a delay in the maximum underground production. No definite trend has been obtained in case of *C. setigerus* and natural grasslands. Minimum underground phytomass was recorded in April and May in grasses and March in natural grasslands.

Net primary productivity

Productivity in g/m²/day has been calculated by dividing the net production for a particular period by the number of days in which the growth had taken place. The rate of production on year long basis has similarly been obtained by dividing the total average phytomass of whole year by 365 days.

The net primary production of the three desert grasses and the grasslands is variable from year to year. It is highest in August-September of 1970-71, 1971-72 extended to October-November in 1972-73 due to late rains. The productivity in g/m²/day during 1970-71 and 1971-72 with normal start of rainfall is from 0.26-7.69 in *Lasiurus* 0.66-9.73 in *C. ciliaris* and 0.95-9.94 in *C. setigerus* but delayed rains with short spell of rainy season of 10 days in August during 1972-73, the productivity ranges from 4.43-14.45 in *Lasiurus*, 0.06 to 21.02 in *C. ciliaris* and 1.07 to 22.67 (g/m²/day) in *C. setigerus*. Similar trends have been obtained in the grassland as well.

Net primary production and productivity obtained from the above ground and underground phytomass of grasslands are lower than *Dichanthium* and *Heteropogon* types of grasslands as reported by Varshney 1972, Singh 1963, Singh and Misra 1968, Chaudhary 1974, Singh and Yadav 1971 and Ambasht *et al* 1972 from higher rainfall areas.

The average net primary production per year ranges from 630-952, 662-977, 647-837 and 518-561 g/m² (1970-71 to 1972-73) in *L. indicus*, *Cenchrus ciliaris*, *C. setigerus* and protected grasslands respectively.

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AN APPROACH TO SYSTEM ANALYSIS

S. C. Pandeya

The understandings

Having known some of the methods for studying the driving variables, state variables, processes and control functions, it will now be to the place to talk of *System Analysis*.

Needed programme input:

- A. Between producer and consumer subsystems.
 - 1. Consumer effect on plant growth.
 - a. Consumption rates by various types of consumers such as insects, small mammals and birds.
 - b. Availability of reproductive parts such as flowering organs and seeds.
- B. Between producer and decomposer subsystems.
 - 1. Dead plant material.
 - a. Roots.
 - b. Litter (availability of labile and non-labile materials in these compartments).
 - 2. Rates of root respiration.
- C. Between consumer and decomposer subsystems.
 - 1. Decomposition rates of animal excrement for large herbivores, insects and small mammals.
- D. Between producer and abiotic systems.
 - 1. Infiltration rates of water.
 - 2. Evapotranspiration indices.
 - 3. Heat transfer coefficients for litter and leaf materials.
 - 4. Stomatal resistance to various types of plants.

- E. Between decomposer and abiotic subsystems.
 - 1. Infiltration rates.
 - 2. Temperature profile.
- F. Between nutrient subsystems and producer subsystems (Fig. 1.3).
 - 1. Levels of nitrogen in plant and the rate of transfer throughout the plant.
 - a. In roots.
 - b. In tops.
 - c. The effects of temperature and moisture on these transfer rates.
 - 2. The rate of transfer of mineral solution to a live plant.
 - a. The root biomass must be known.
 - b. The top biomass must be known.
- G. Between the mineral subsystem and the decomposer subsystem.
 - 1. Detailed values of carbon to nitrogen ratios in organic and soil components.
- H. Within the nutrient subsystem.
 - 1. Transfer rate of soil organic phosphorus or nitrogen to solution phosphorus or nitrogen.

In the past, much of ecological researches were single factorial, always keeping organism as the function and not to analyse the components of any eco-system as a highly integrated complex. We must by strategy of research, which at every step is redesigned in terms of problem fitting, integrate all the fragments together correctly at the end of research programme. Thus, there is an immediate need of "System Analysis" on any eco-system. System Analysis is the use of scientific method with conscious regards for the complexity of the objective study; and a system is a collection of parts, together with statements on the relationships of some kind between these parts. System simulation, system optimization and system measurements are other facets of the system approach.

The central motive of using 'system analysis' in ecology is the complexity of ecological processes. Nature of complexities may be: sheer number of variables, number of different types of variables (ecological, genetic, indigenous, exogenous to population), different levels of organization of ecological system (population, community), and non-homogenous and non-uniform distribution of entities in space and time. Further, in fact, one of the distinguishing features of the entire

eco-system analysis is the use of models (Bledson and Jameson, 1969). The model is an abstraction of serial system, and one of the major reason for modelling is to provide a frame work for bringing together the parts of the system which is too complex to organize and comprehend otherwise. The second major reason for having model is one of testing an experimentation.

In terms of Odum (1971), a model is a formulation dynamics, a real world phenomenon, and by means of which prediction can be made. In the simplest form, models may be verbal or graphic, but ultimately, statistical and mathematical. He further defines that the word 'statement' is in fact "word model" of ecological principles in question. Models may be evaluated in terms of 3 basic properties or goals: *realism*, *precision* and *generality*.

Realism refers to the degree to which the mathematical statement of the models, when translated into words, correspond to the biological concepts that it intends to represent. *Precision* is the ability of the model to predict numerical change and to mimic the data on which it is based. *Generality* refers to the breadth of applicability of the model. The number of different situations in which it can be applied. Indeed the questions asked of ecological models are often complex, and based on such diffuse problems as 'stability' and 'trophic efficiency'. Because eco-systems have random inputs, such as weather, it has seen unreasonable to construct model of high predictive power when basic inputs frequently cannot be measured or predicted. Thus, ecological models are often judged in terms of ability and generality to guide research efforts rather than on numerical predictive power (precision).

In models one or more system variables are used to characterise the state of each component. Flows or interacts between components are transfer functions or functional relationships. Inputs to the system (independent variable), of factors affecting but not affected by the components of the eco-system can also be called as "forcing" function.

System variables are sets of numbers which are used to represent the *state*, or condition of the system at any time. Thus, the *system state vector* can be represented by a single

$$\begin{matrix} (V_1) \\ (V_2) \\ V = (:) \\ (:) \\ (V_n) \end{matrix}$$

Here, V_1 represents the value at any time of the system variable 1, V_2 the value of variable 2 and so on.

To these factors 'differential equations' or 'difference equations' may be utilised to describe the system which change in time, i.e. dynamic

systems. In the dynamic transfer function several equations have been developed describing change in system components, like:

$$\frac{\Delta V_i}{\Delta t} = f(V_1, V_2, \dots, V_n, F_1, F_2, \dots, F_k)$$

Here V_i/t is some measure of the rate of change with respect to time of system component i , and $f(V, F)$ means "a function of V_1 , of V_2 , ...and of V_n , and of F_1 , ... F_k " where the V_i are system components as above and the F_i are the values of the forcing functions. The above equation can also be written as:

$$\frac{\Delta V_i}{\Delta t} = \sum_{j=1}^n f_{ij} V_j \text{ for } i = 1, 2, \dots, n$$

This is a type of linear, constant-coefficient differential equation model for a system of compartment concerned. f_{ij} here are proportionality coefficient. The compartments are represented by V_j and refers to amount of matter, energy or nutrient.

Intraseasonal herbage dynamics or intraseasonal changes in biomass, energy concentration or nutrient contents of various compartments are important aspects. There is well known translocation of material from the tops to the roots and seasonal shedding of live vegetation, transfer to standing dead, and decomposition of various parts. Concurrently, there is also varying amounts of photosynthetic inputs depending upon climatic conditions, that vary seasonably. Thus, for an intraseasonal dynamics model, the main interest will be in predicting the dynamics from days 1 to 365 in the year involving by what processes the state variable "live above ground plant biomass", which cause input into the system and which cause output. Photosynthesis and translocation up from the roots are two of the processes increasing the number of g/m² in a particular compartment. Herbivory, weathering, trampling, translocation down to the roots, and death are the processes causing removal of materials from that compartment. Each of these individual processes itself is a function of a series of either State Variables or driving variables. Thus at a lower level of resolution, photosynthesis rate will be a function of leaf area, soil moisture, solar radiation and temperature.

Affected by

Photosynthesis $f =$

Rate

— leaf area	— state
— soil moisture	variables
— solar radiation	— driving
— temperature	variables

In these respects individual flux equations accounting of each rate process, can also be worked out. Thus it will be desirable to find photosynthesis rate, as a dependent variable, as a function of the state variables and dynamic variables; and also the mathematical functions for translocations up from the roots, and for output processes such as herbivory, weathering, tremping, translocation down and death. All of these flux equations would be combined to give the net change in the above ground plant biomass at any unit of time. Combining above features in differential or differences equation system, it can be as:

$$\frac{dv}{dt} = f(\text{inputs}) - g(\text{outputs}) \quad \frac{\Delta v}{\Delta t} = f(\text{inputs}) - g(\text{outputs})$$

$$\text{Or } V = f(V, Z, t) \quad \text{Or } V = (Tt + t) = V(t) + t \left(\frac{\Delta V}{\Delta t} \right)$$

where

V = vector of state variables.

Z = vector of driving variables.

Basically, the program requires first reading or calculating the driving forces of functions, i.e., precipitation and temperature. The remaining variables in the program can be calculated from time-dependent functions, the levels of amount of materials in the compartments, and temperature and precipitation. Examples of generalized differential equation of the system represented in Figure 3 are provided in Table 1, note that all the process functions are given in italic letters and are time dependent. Many of the processes are affected by a given compartment, or the interaction of two or more compartments, as well as such variables as temperature and available soil moisture. We have here a non-linear model.

Photosynthesis is calculated to depend upon the maximum amount of radiation for the location, the slope of the radiation intensity function for that day, the slope of the soil water function for that day, minimal soil water levels, efficiency conversion factors based on leaf area, and amount of biomass and leaf area. The photosynthesis equation converts a percentage of the daily effective radiation through the amount of live vegetation of leaf surface, into photosynthate. The percentage of conversion itself decreases depending upon the radiation intensity and is modified by temperature in a sinusoidal function. There is a sharp linear decrease in photosynthesis below permanent

wilting. The temperature effects the photosynthetic rate through a Q_{10} function typical of enzymatically controlled biochemical processes.

NOTE:—In a limited space provided it is not possible to give details of working out simulation models. Those who are interested may contact us for details.

ECOSYSTEMS IN ARID ZONES

C. P. Bhimaya*

Before proceeding to discuss the above topic please permit me to express my gratitude to Dr. Mann for inviting me to talk to you. He has also permitted me to include in my talk any details that I may like, in dealing with this subject. This means I could ramble around and though it is a special concession to me, for which I am thankful to him, I am afraid to rambling around too much. Therefore I request you to please bear with me if I happen to stray away too much.

To talk about the eco-systems in the arid zones we have to first understand as to what are considered as arid zones. There is a concept that arid zones are arid in lands with intense blue skies, sparse vegetation, violent contrasts in temperature, dry atmospheric condition and a limited and erratic rainfall of less than 250 mm in a year. This was a definition worked around a simple concept of arid zone, defined as tracts getting less than about 350 mm rainfall per year, after this simple concept was considered too narrow by eco-climatologists. The late Dr. Thornthwaite, the noted eco-climatologist, pressed in the UNESCO—conference on arid zones, held in Karachi in November, 1957, that such simple definitions are very misleading and advocated the formation of a committee of experts to go into the question of a proper definition of arid zones, not only based on precipitation, but including all aspects of the environment such as climate, soil, vegetation, evapo-transpiration, aridity index etc. There were other claimants like Gaussen, Emberger etc. for the eco-climatological definitions. I am not quite sure whether a special committee has gone into this subject and evolved a clear-cut definition. Whatever it may be not a fresh concept which injects the albedo and the Vapour Column in the atmosphere, being developed.

Albedo as you all know is the term used to express the reflection factor of the solar radiation from the earth's surface which determines the intensity of whiteness to the earth's globe when viewed from space. This reflection from the earth's surface determines the degree of the atmospheric heating and cooling. When the heat is reflected hot columns of air move upwards into the upper layers of the atmosphere. When these hot columns come to the upper reaches they cool and come into contact with the vapour column of the atmosphere and modify it

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into clouds. But when a mass of fine soil particles keep floating, in the atmosphere, near the earth's surface this process is interfered with. The dust mass not only curtail the transmission of the sun's heat down, but also hinders the reflection of the heat upwards. Normally in the arid zones, the vapour column which is nothing but the expression of the total amount of vapour remaining suspended in the atmosphere, as a vertical column per unit area, is a restricted entity. Even, so, it has been found by Dr. Reid A. Bryson and his associates of the University of Wisconsin, U.S.A. who have made a study of his subject in India, that the Vapour column over Rajasthan is 100 mm which is almost identical with that over Calcutta. They have found that it is the interference of the dust mass floating over Rajasthan that curtails the rainfall and makes it arid.

On the other hand as there is no such inhibition over Calcutta the precipitation there is higher and makes it humid. It is for this reason that the Rajasthan desert is normally not considered as a true desert in as much as it is felt that it will bloom, if we could eliminate this dust mass floating over the area. However this aspect has almost become like the controversy as to whether the chicken has come first or the egg, since in this case it is argued whether it is the dust mass that has caused the desert or the desert is responsible for the dust mass.

There are various theories that considered Rajasthan desert as a man made desert or at least as the man maintained desert. From carbon dating, it has been worked out that Mohenjadaró and Harappa are just 5,000 years old while from pollen studies of the Birbal Sahni Institute (unpublished data) it is said to have been concluded that the Sambar lake was a sweet water lake just 2,000 years back. Historians have recorded that when Alexander the Great's army invaded India, it had to pass through dense sal forests in this region. These facts or theories make it rather problematical to visualise the climatic climaxes of this region and to equate the eco-systems of the region to these environmental factors.

These theories and problems are not peculiar to India alone. In Iran the south western province is known as Khwzistan: This in Farsi language is used to mean "land of sugarcane". It is said that when Alexander's army marched through this province they devastated the sugarcane fields. However, even at the beginning of this century, the entire province was an arid expanse of barren saline plains with patches of cultivation of salt tolerant wheat. But now after the construction of the dam across the Dez river around 1960, cultivation of sugarcane has been revived and there is already a sugar mill and a paper mill using bagasse as raw material, functioning in the province.

Therefore, whatever may be the prevailing eco-systems, the fact remains that the advent of irrigation water, in adequate quantities transforms the geomorphic features and the environmental conditions. Such miraculous transformations have occurred in the Imperial valley, California, U.S.A., Korfah lying about 1500 km, south-east of Tripoli in the Sahara in Libya and in the Ganganagar district of even Rajasthan.

Imperial valley in California was a perched desert with stony and gravelly plains, forming the hole of rattlesnakes and scorpions. But this has changed after the construction of the Hoover dam on the Colorado river, in the early thirties. This dam though lying about 1000 km upstream, supplies water to the 220 km. All American Canal running through the Imperial valley. In its course through the valley this Canal has three hydroelectric installations. With these facilities of irrigation and power and the efficient system of irrigation and drainage canals, this valley has become the richest agricultural valley in the world, out-beating the irrigation systems that had been developed in other arid tracts of U.S.A. itself in Utah, Arizona, Colorado etc.

In Libya, during the course of oil exploration, the French Engineers, had discovered large storage of good underground water near Korfah, on the northern edge of the Sahara desert. The source of this water is still being argued and it is being said that it could be the sub-surface seepage from the Nile river which flows about 1000 km away, in the east. Korfat gets practically no rainfall and the soil around is coarse sand. The area was inaccessible and was approachable only by air just five years back. Now roads through which trucks can ply are constructed. The water source is 800 metres underground. By tapping this underground source about 6000 hectares of land has been brought under cultivation. Wheat and berseem are being grown. 30 to 5 tonnes of wheat is harvested per hectare already. Just within the three years from 1970, a herd of 45,000 sheep have been raised from a nucleus herd of 500 ewes. The farms are developed in 100 hectare circles. A radial pipe, rotating around, irrigates this area stimulating rainfall through sprinklers. Individual farms are carved out by dividing the area into sectors, radially and allotted. The farm buildings are constructed along the outer periphery. There is a programme to develop about 60,000 hectares in the next ten years. If this is done it will not only transform this part of the desert but will also make Libya a grain and meat exporting country from an importing country.

Nearer home, in Ganganagar district, lying in the northwestern corner of the Rajasthan desert, we have another concrete example of land transformation from an arid waste to a highly productive agricultural tract, with the advent of the Ganga canal. Now with the

coming of the mammoth Rajasthan Canal, further transformation of this arid tract is in progress.

It is thus seen that we may define and demarcate different eco-systems, in much arid zones, by specifying the agricultural areas, forest areas, rangelands etc. but with modern technology and facilities, such definition and demarcation becomes redundant, even in the case of the Sahara desert. This is so far as large-scale development is concerned. But for the purpose of research, especially problem-oriented research, it is fundamental that such definition of eco-systems is done, so as to isolate individual areas of research.

Reverting to the Rajasthan desert it may be necessary to mention the different theories that are there about its origin. One of them is that it is the land area that was the bed of the Thetis sea. It is said that when the Himalayas emerged, the Thetis sea receded to the Arabian sea and left its bed exposed as the Thar desert. If this theory is correct then it runs counter to the theory that the Sambar lake was fresh water lake about 2000 years back. Further that the sambar lake was a fresh water lake since converted into the salt lake has a parallel, in the formation of the Iranian deserts, Dast-e-Kavir and Dast-e-Lut. These deserts with their extensive saline stretches.

Similarly, the more than 400 km² of waterspread of the Sambar lake is formed by the run off from the surrounding watershed, during the monsoon period. The soils in the watershed of this lake, especially in the vicinity of the lake, have also got high salinity. This could have contributed to the brine which produces the common salt contributing to the 60 per cent or so of the salt production of the country.

With reference to the situation described in relation to the condition prevailing on the Iranian mountain slopes, some U.S. experts working in Iran had come up with a project which they thought would be an answer to further waste of water and soil resources. They argued that as the run off from the hills and mountains get salinised during its traverse through the saline plains and gets ruined, being charged with the eroded saline soils and as whatever good soils are in the talus and pediment plains are ruined by the deposition of this saline sediment load they should try and hold this runoff near the source. Studies had revealed that some of the rivers carry as much as 93 tonnes of eroded soil per hectare of the catchment area and some of these rivers have large catchments. Therefore by holding this surface runoff at the headwaters through dams and bringing it down through controlled channels and using this good quality water for irrigation in the good agricultural areas and for leaching the partly salinised areas, we would stabilise agriculture and reclaim some of the lost land. This idea was fine provided there were enough storage areas and dam sites. But in

reality there are very few much areas and sites as the slopes are steep and the valleys narrow. Thus to solve arid zone problems many fine ideas can be projected but the eco-systems and other conditions being very complicated and undefined, like the very definition of the term "arid zone" itself, it is not all that easy to execute these projects.

Although it is ironical, it is only great wars and national catastrophes that pave the way for accelerated progress in this world. Wars give impetus to scientific development for developing weapons and in the process, as by-product, new technology for peaceful uses also emerge. Such technology, combined with the stress for food for the well fed armies and industrial raw materials, lead to over exploitation of land and other resources. Such over exploitation while leading to an ephemeral boost to the national economics, also lead to a high rate of inflation. Thus commodity prices which in normal periods fail to make the development of marginal lands for food, fibre and meat production automatically come in the purview of such development with these inflated prices. Such development automatically adversely affect the different eco-systems and environment. This is what contributed to the terrible upset of the ecological balance in the mid west of the United States of America, after the first World War, contributed to the march of the Rajasthan desert to the north, caused the unprecedented sand dune formation in Iran and other countries and the incidence of heavy sediment load movement in the streams and rivers of practically every country in the world. These consequences, though obvious to the knowledgeable scientists, were considered as routine factors which had existed for ages by some of politicians concerned. Thus the single handed crusade of Dr. Hugh Hammond Bennett for the formation of a Soil Conservation Service in the United States, to regulate proper and scientific land use, by land use capability classification went unheeded. It was only when the Capitol Hill in Washington, D.C. was totally enveloped with a blinding dust storm, blown from the ruined Wheat fields of the midwest, that the Congressmen heeded his crusade and enacted the bill sanctioning the formation of the United States Soil Conservation Service.

Similarly the muddy waters of the Colorado river and of the Damodar and its tributaries which as the saying went "were too thick to drink and too thin to plough", when they spread over the Imperial valley and the Midnapore plains, causing untold misery to the settlers here limelighted the problem. In the case of the Damodar river, the unimaginative construction Engineers were against the application of soil conservation measures in its catchment, adding that it will add to the capital cost of the dams and that even without these, the investment will provide 6 per cent return through the irrigation water and

power developed, although a life span of only thirty four years was given to the Panchet Dam on the main Damodar river. This narrow outlook was over-ruled by pointing out that every paise spent on the catchment will add to life span of the dam while without soil conservation, if the silting took place in thirty-four years, we would lose a non-replaceable natural resource like a dam site, thus leading to greater floods.

In the Nilgiris in South India, the Katiri hydro-electric project, the oldest project in India, built for providing power to the Cordite factory, Aravankadu, became almost non-functional after the first world war. It became totally non-functional after the second world war was due to the silting of the storage reservoir. A fraction of its capacity was kept functioning by clearing some of the silt deposits by operating fire engines and using the water jets to dislodge the silt and washing it down. Such silting was due to the heavy silt load rushing into the reservoir from the slopes of the Ketu valley which formed the catchment. Some of these slopes were as much as 100 per cent. Even these were being cultivated with potatoes, up and down the slope. When bench terracing was recommended, for this cultivation on these slopes, the local Member of Vidhan Sabha, who happened to be a member of the State Soil Conservation Board considered the recommendation Utopian and harassment of local people as such cultivation had been going on for ages and still there is soil for cultivation which indicated to him that no soil is being washed away. First of all this gentleman would not take the trouble to go down and see the Calamity that had occurred in the Kateri reservoir. Secondly, he could not see that the soil he saw being cultivated was just subsoil which happened to be quite deep here and he had no patience to consider the process of diminishing returns that this subsoil was yielding year by year. Above all he never realised that during the age old cultivation he was referring to it was generally the areas suitable for cultivation that were being in use and which were quite insignificant in extent that after during and after the two world wars, forest areas in steep slopes and valleys were cut away and any and every kind of land, fit or not fit for cultivation were brought under cultivation to provide potatoes for the British army. Though this instance has no direct bearing on arid zones and its eco-systems, mention of this is made here to show how the need of the hour makes us forget the wonderful provision of Nature through its eco-systems like "Sholas!" forest and grass covers to provide protecting mantles over earth's surface. The destruction of these pave the way for creating arid environments.

There are many examples to illustrate how our forefathers to whom we hesitate to give credit for sound thinking and planning protected their natural resources. If at all we recognised these we attributed these to mere superstition. In Coorg, strategic forest areas which formed the protecting covers for the spring sources of the head water streams forming tributaries of major river systems like the Cauvery, were dedicated to the village Gods or Goddesses. Such dedication, besides affording total protection to these forest covers, also made the villagers forest minded, in as much as, when traversing those forests to worship the deity, they were automatically impressed by the serenity and peace in Nature. In such dedicated forests, no cutting of any sort was permitted, for timber needs for community projects like building or repairing temples, schools, road bridges etc. The village elders would meet and decide to harvest dead, dying or moribund trees, after reaching unanimity. Now a days, we the "wise" successors have destroyed such forests and even steal the temple idols which formed the base for the beliefs and such protection. So where is the wonder if we are annually visited by devastating floods and ruinous draughts. Even in Rajasthan, where every village has its own deities and temples, the vast areas around the villages with tree and bush cover like *Zizyphus nummularia* Z. *rotundifolia*, *Capparis decidua*, *Prosopis cineraria*, *Gymnospora montana*, *Tecomella undulata* etc. were dedicated to these deities. No cutting of any kind was permitted. Only grazing by the village herds was allowed in these areas called "orans". What a wonderful idea to keep environmental protection in these tracts of dust storms and hot winds called "loos". Now these "orans" have also lost their sanctity and are being ruthlessly devastated. So no wonder in the desert extending and marching on. Although the stipulated movement of half a mile per year may not be there, as with such a rate of movement the desert would have reached the Himalayas already, the fact was there that the delicately balanced eco-systems were upset and the rather limited resources of the arid zone over exploited. This had caused visible conditions of the extension of the arid zone. With the impact being felt in the adjacent areas of both Haryana and Uttar Pradesh. This made the Parliament to take note of the gravity of the situation, as soon as the country became a sovereign Republic. Therefore an ad-hoc committee of experts was authorised to go into the causes of the extension of the arid zone and recommend remedies.

The ad hoc committee thus set up, studied the situation and recommended the setting up of a Desert Afforestation Research Station with the terms of reference to find ways and means to provide the know-how, to furnish the answer to the problems which they felt could be ameliorated through afforestation. One major suggestion by the committee

was to create a tree belt, all along the Indo-Pakistan border to a width of eight kilometres to prevent the aridity and sands from creeping across the border, in as much as the effectiveness of a shelter belt is belt could not technically be an answer to the march of the desert across the border. May be it was not realised at that time that such a belt could not technically be an answer to the march of the desert across the border in as much as the effectiveness of a shelter belt is correlated to height and so far as the affective width is concerned it does not extend beyond a maximum of ten rows planted 2 to 3 mm apart, between the rows. Further the eco-system of tall, medium and low grass cover that existed as the climax vegetation with a spaltering of trees and bushes was not a favourable indication for the creation of such a tree belt. It may be that the trees and bushes are an indication as to what could happen, if the dust mass overhead could be dissipated and the albedo normalised. To achieve this it will be necessary to carry out whole sale afforestation of the entire desert area under the existing conditions of soil-water plant relationship, where even good drinking water is scarce and people have to trek, often more than ten kilometres, to get a donkey load, such afforestation is next to impossible. The committee recommendation to establish the research station came into being in 1952 under the Forest Research Institute. Soon after this the State Government organised an aerial sowing along the border belt area in collaboration with the Research Station. About 15,000 kg of unpelletted and mixed lot of seeds were sown from air. If more thought had been given this project could have been deferred as it was not technically sound. This is so firstly because the area sown was interspersed with private and public lands and people were not tree conscious enough in the region to consider the resulting growth in their area to be of any value or consequence. Secondly the precipitation here is around the annual average of 100 mm, with a dry hot period of more than nine months. Which are extreme condition for survival and growth of sown material. Lastly the unpelletted seeds lying on the ground would be constantly blown away in this open area where summer winds easily attain storm velocities and even if some remained stable they would not germinate as the proper condition of humidity, light and temperature do not exist to induce this. Even if any seeds germinated, rodent and other animal pests, would not allow them to survive. The final results which were nit, confirmed this.

In 1957, after the Central Soil Conservation Board came into being, the Research Station came under its purview. The Board immediately realised that the crop-tree-grass relationship prevailing in the eco-system of the tract, required a more comprehensive approach to tackle the

problems of this region. So an integrated research programme with reference to the eco-systems was initiated and afforestation alone as the solution was considered inadequate. Thus the Research station was transformed into the Desert Afforestation and Soil Conservation Station. This Station initiated programmes of research in Agronomy, Agrostology, Range Management with soil conservation and enlarged its research programme in Forestry, to cover some aspects of eco-systems to begin with.

While these programmes were under execution the Government of India approached the UNESCO for its assistance, under its Major Project for Arid Zone Research. This project had been launched by the UNESCO in view of its realisation that the humid zones having been fully developed already, it is only the arid zones that offered scope for development to face the problem of feeding the exploding population of the world. With this background the UNESCO willingly agreed to help.

To begin with, it sent Mr. C. S. Christian, an Australian Scientist with wide experience in tackling the arid zone problems of Australia, during his work with the C.S.I.R.O. both to assess the problems of our desert and to evaluate the soundness of our approach through the research programme of the Desert Afforestation and Soil Conservation Station. He was impressed with the work done by the research station and recommended to not only the UNESCO to give assistance under its major project, but to his Government also to offer such assistance through the Colombo Plan, in equipment, experts, fellowships and money for buildings and library material. Thus the present Research Institute came into being in 1960.

After his visit to the entire arid tracts of Rajasthan, Mr. Christian made the interesting remarks that ours is a blessed desert while the other deserts like those in Australia are cursed deserts. He clarified this by saying that while there is great scope for receiving the resources of our desert, especially in respect of crop and animal husbandry, forestry and Range Management due to at least a portion of the monsoon rains coming during the cropping and planting season, in their deserts as there is nothing like the monsoon, they may not get any precipitation for years together and what is given as annual average precipitation may be that of quite a number of years with nil precipitation and others with excessive and out of season rainfall. With this background he projected the plan for research and development in our arid zones, with reference to the eco-systems. In this connection it may be appropriate to define the concept of eco-systems. It may be better to copy out here the definition given by the well known ecologist, E. P. Odum in his textbook 'Fundamentals of Ecology, quoted

by Jens Dragsted in his talk to the trainees in the course run by the FAO/DANIDA on Healthland and Sand dune Afforestation, in 1973, in Denmark and Libya, Odum defines eco-system as any units that includes all the organisms (i.e. the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles within the system. This clearly indicates that it is a dynamic system with a dynamic process, the latter depending on the conditions prevailing in the environment.

Mr. Christian felt that to formulate any research and development programme, it is fundamental to assess the natural resources, in relation to man, his animals, the soil, water and plant, mineral, energy etc. which interact in the different eco-systems. For this purpose he considered an integrated survey as done in the C.S.I.R.O. in Australia should be basic. Such a survey is done by a team of scientists including a Soil Scientist, Geomorphologist, Geologist, Ecologist, Systematic Botanist, Hydrologist and Climatologist in the field, assisted by a Plant Physiologist, Analytical Chemist and Cartographer in the laboratories. This Division which he designated as the Basic Resources Studies Division, was to determine the soil-plant-crop-yield relationships together with, both surface and underground water resources, including mineral and other resources to formulate development plans involving eco-systems and also to help develop power systems, communication systems and even defence strategy. These definitions and delineations were to be passed on to the other Divisions of the Institute to formulate research and development projects in different disciplines.

With the above background the utilisation studies Division was proposed to be set up to carry out soil-water-plant-animal relationship, by re-inforcing the set up of the Desert Afforestation and Soil Conservation Station. Since this research station had already an interesting collection of exotic tree and shrub species, and their study in relation to their provenances and amplitude had given indication of their usefulness in the arid zones. Silvicultural section was continued further studies. The introduction of *Acacia* from the Africa and the *Eucalyptus* from the Australian continents to the forest eco-systems, in the Agronomy section, intensive trials on bajra, jowar, gawar and other legumes had given indications that it may be possible to stabilise the agriculture in the region. Normally arid tracts like Barmer district depend on a good rainfall year which occurs in cycles of once in three years or so to get a good crop of bajra. If the rainfall is normal a bumper crop is produced. The grain from such a bumper crop is conserved for lean years and starvation stalled. This was however

quite a gamble. By stabilising agriculture such gamble is prevented and the production economy enhanced.

In the Agrostology section based on the lead given by the All India Grass cover survey scheme of the Indian Council of Agricultural Research, under which the different grass covers and their climax types were identified, research work taken up in the Research Station had revealed that grasses like *Lasiurus indicus* and *Panicum antidotale* which are native to the region, are wonder grasses. *L. indicus* is a grass which can grow breast high in desert sands of rainfall, as low as 100 mm. It had a crude protein content of around 8 per cent and is palatable at all stages. The magnificent growth put up by this grass, after monsoon rains, makes the Mohangarh region of Jaisalmer district look like an ocean of green, with fascinating wave like movement, along the surface of this "green ocean" the kind of movement one can see in the wheat fields of the mid-west, in the U.S.A. in spring. This vision made Dr. R. O. Whyte, the eminent pasture and Fodder expert of the F.A.O., insist that he had yet to see the real Rajasthan desert, if there is one. When he visited this area in 1961 and when I told him that we were in one of most arid part of Rajasthan desert. *P. antidotale* on the other hand is perhaps the grass which has the highest crude protein content among grasses. At its pre-flowering stage it has as much as 14 to 16 per cent. This grass is highly palatable in the tender stage. Rotational grazing or cutting at frequent intervals, keeps it tender, while if left to nature it becomes useless for grazing or hay. The seeds of this grass can be used as grain under famine conditions. Both these grasses have high yielding potential.

Grazing studies conducted in the ranges and forest grazing studies to determine the optimum utilization of extensive open forest areas in the arid zones, the animal equivalent and long term eve performance studies in cultivated pastures, under the Range Management and Agrostology sections are the first of their kind in India at least, if not in the world. That proper protection itself can enhance the production potential of these grazing areas, though not only increasing the cover, but also through the advent of perennial palatable grasses in the natural success and that reseeding combined with appropriate moisture conservation measures, on large scale, enhances the production of these areas multifold, in this tract, were also eye-openers. That by such protection and improvement of the pastures, we can eliminate burred grasses like *Cenchrus catharticus* and thus prevent the degrading and damage to wool, by such elimination increasing the sale price by as much as 40 per cent, was also revealed. Grazing in improved native pastures enabled clipping of wool thrice against the normal two clippings when grazed in the undeveloped pastures.

Since man-power becomes a limiting factor in arid zone development and the socio-economic factor is as significant as any other factor in the eco-system, studies of this factor was considered very necessary by Mr. Christian. Although this was a novel approach, I was whole heartedly in favour of this from certain instances that were in my knowledge where due to this factor having been ignored, even in densely populated areas, while initiating major projects on development and rehabilitation, great, set backs and financial losses occurred. In the Damodar Valley Corporation, villagers displaced by the storage reservoirs, were attempted to be rehabilitated in clusters of modern houses, with all amenities and particularly with ample space and ventilation. In many of these, the villagers refused to live saying that they were too cold in winter too hot in summer and above all hard to maintain. They demanded cash compensation for their old houses that were destroyed and got it and built their own crude design of houses, subjecting the corporation to great loss. It is said that Maharaja Ganga Singh of Bikaner, after bringing in the Gang Canal to his parched territory, at great effort and cost, found that his villagers in the command area neither had the know-how nor the inclination to carry out irrigated agriculture. It seems only his resourcefulness and farsightedness, that made him get suitable men from the Punjab, paying them inducement money and enabled the development of the wonderful irrigated agriculture that had made Ganganagar district the granary of Rajasthan. In Egypt the Government tried to sedentarise the Bediuns. Beautiful settlements were built and people came and settled. But soon they all left these settlements and went back to the desert only because they could not pray in open surrounds of the type they were used to in their desert tents. In Libya, large number of desert dwellers were moved to Tripits to contribute to the great development and building projects, in and around this capital city. These people refuse to live in hutments being built for their residence and prefer to live in shacks and primitive tents. In order to obviate such situations, the Human factory Studies Division was proposed. The wisdom of having such a division are now well established by the results from some of the studies like the failure for sedantarisisation of Gadoliya Lohars, the risk that would have been faced, had a programme to eliminate goats been launched, to the sheep breeding programme in arid tracts where one billy goat functions as a foster mother for about half a dozen lambs of enaciated ewes and the problems that would have been faced if there were projects to settle down other nomads without studying the implications.

The National Physical and Chemical Laboratories of the C.S.I.R. had worked out ways and means to harness wind power, solar energy,

desalinisation of water biogas etc. The applicability of these findings to the conditions of arid zones needed to be tested. So a Division to have liason with these institutions to get their results tested and also to devise ways and means to modify or augment these was also visualised. Now with the sudden emergence of the energy crisis, the farsightedness of this idea is more than justified.

Animal husbandry in the arid zones of India is really the backbone of the whole country's economy. This may sound surprising, but not when it is pointed out that the mainstay of the Delhi Milk Supply Scheme is the milk flowing from Bikaner and its surrounds through refrigerated rail cars and road vans. The Tharparkar breed of cattle of Rajasthan are one of the best dairy animals in the country. The demand for cows of this breed for crossbreeding elsewhere in the country is so great that the animals are in short supply. The seven breeds of sheep in Rajasthan supply 40 per cent of the wool needs of the country and earn lot of foreign exchange too. It is said that the chokla breed of sheep of Bikaner were imported by Australians to cross with the Merino to modify their wool quality. So an integrated approach of the studies on the correlation existing between the eco-system of these animals and the eco-systems studied by the Resources Utilisation Studies Division was visualised.

The arid tract has its own special rodent and vermin and other fauna with tremendous capacity for survival. Under extreme conditions of aridity and scarcity from studies done on gerbils it had been revealed that total deprivation of moisture both through drinking water and feed, by roasting. The latter before giving these, still enabled the animals to survive through the special adaptation of their kidneys and body fat content. The only set back was to their breeding habits. Still some animals could survive for more than fifteen months and when moisture supply was revived their breeding process too revived. These gerbils had a tremendous system of burrowing that not only enabled them to survive the attacks of predators like snakes but air-conditioned the burrows which enabled them to live in comfort and breed. The entire system of burrows were made within about 30 cm from the ground surface. Such burrowings affected the root system of the plants and this combined with their feeding and nibbling habits destroyed the improved rangelands and afforestation areas.

There was also the problem of the vanishing Great Indian Bustard of the Rajasthan desert and the diminishing number of the fleet-footed Chinkaras and black-buck due to the indiscriminate shooting from jeeps and trucks with army rifles. The latter animals could also survive and multiply areas with no drinking water. Till recently they

were rigidly protected, said to be due to the belief the agricultural community called "Bishnois" residing in the tract that these are their ancestors reborn. But now their belief was no match to army rifles. There is also the unique temple of "Karni Matha" at Deshnoké Village 30 km. south of Bikaner where house rats are dedicated to this Goddess. They are protected inside the walled temple, with wire netting above, to keep out birds of prey. These are regularly fed with milk and grain and during the non-feeding time these rats can be seen peacefully sleeping in the niches and verandahs. The villagers believe these are their ancestors born as such and hence this treatment. At the same time it is said that during the last 600 years of the existence of this phenomena no bubonic plague has visited this village. Thus there are many peculiar habits, beliefs and associated thoughts intermingled with the fauna and flora of the eco-systems of this arid zone. Therefore a Division for the studies of these special animals was visualised.

When an Institute such as this becomes functional problems are tackled one by one. Because of the special eco-systems prevailing, the problems being tackled keep on unfolding more and more complicated ones. It has to be mentioned to the credit of one and all of the planners and workers of the Organisation as a whole and the Institute in particular and also the generous aid given by the UNESCO and the Australian Government, in equipment, training expertise and money, that every one kept open minds and organised a research programme which has earned world wide approbation for the results achieved. Even in the early stages of the working of the Institute, it was realised that neither the annual reports nor the other periodical reports, could give adequate expression to the expression of the findings of the research workers. Thanks to the vision and enthusiasm of late Dr. P. C. Raheja, the first Director of the Institute, an Arid Zone Research Association, with the Annals of Arid Zone as its mouthpiece was established. It is gratifying to find that the scope of membership of the Association has extended all over the world and that the Annals is being regularly published. It is gratifying to note also that after he has assumed charge Dr. H.S. Mann has arranged to publish two bulletins highlighting the research works done by the Central Arid Zone Research Institute and its precursors. Although such publications cannot contain anything and everything personally I found some important findings left out. This was said to be due to just two individuals having taken over the burden of preparing these. If I am permitted to make a suggestion, in such cases competent individuals be entrusted the task of preparing such summaries, but before the drafts are finalised, the Head of Divisions or a Senior Scientist designated by him, if it is really

not possible for the Head of Division himself to do it, be asked to scrutinise the details to see that no important finding in any of the discipline, is left out.

Now friends, I am afraid I have rambled too much and taken too much of your time and patience. But before closing I thank you for your forbearance and thank Dr. Mann again for having given me this chance to meet you all, talk to you and talk to you as I did in so much detail. The topic being that it is and details given being so exhausting and mostly from what I gathered on my own, I am unable to give any bibliography for which I request to be pardoned.

PHYSIOLOGICAL ASPECTS OF CROP YIELDS IN RELATION TO WATER STRESS

A. N. Lahiri

Theoretical limits of yield and production

On the basis of the measurements of radiant energy and basic statistics on photosynthesis Loomis and Williams (1963) calculated that a crop like maize has the potentialities to produce 77 gms. of dry matter per square metre of land on a sunny day. Further calculations of Army and Greer (1967) and Goldsworthy and Palmer (1971) estimated that if this entire converted energy went to grain production in a 35-day active grain filling period, 26-27 tonnes/ha yield could be achieved. Swaminathan (1973) has indicated that yield of 14 to 19 tonnes, which are very close to the theoretical limit of productivity, have been reported from a number of countries. Low levels of crop yields in our country in general make us conscious about the diverse limitations which impeded the production, more so, in the arid and semi-arid areas where the climatic conditions run counter to increased plant production.

Identification of limitations for crop production in the arid areas and yield limitations under rainfed conditions

It is a common knowledge that establishment, growth and yield of plants are restricted in the arid areas due to diverse limiting factors like low precipitation, frequent droughts, intense radiation, high erosive winds, poor soil fertility and physical conditions and excess of salts in the soil and water. Among these, general shortage of water and prevalence of drought conditions are by far the most important drawbacks for maximising plant production in these areas. The problem of insulation of crops against the vagaries of nature, particularly from drought, is not confined only to arid areas, but has also importance in areas which otherwise receive high rainfall. It is now largely recognised that limitation of water is one of the main hinderances of rainfed agriculture in this country as a whole. The data presented in Table 1 amply establish that the average yield per unit area without irrigation is about half of that with irrigation. This gap in production becomes far more wide in the arid tracts.

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Table. 1. Average yields in kg/ha, of principal food grains in India under irrigated and unirrigated conditions—1964-65 (from a note on rate of growth during the 4th plan prepared by Planning Commission, in April, 1967).

Name of the crop	Irrigated	Unirrigated
Rice	137.1	899
Wheat	1173	766
Barley	734	536
Jowar	560	373
Bajra	1452	949
Maize	1009	741
Ragi	1159	736
Gram	873	610
Other cereals and Pulses	821	434

Quantification of yield variations in arid areas

General drought condition may, however, be of different nature, such as, (a) erratic rainfall conditions subjecting the plants to water deficit at different growth stages leading to poor production, (b) rains in certain years failing completely as it often occur in the arid areas and (c) initial drought at the seedling stage of crop leading to large mortality, poor plant density and consequent low yields. It is of interest to examine the magnitudes of yield variations due to these different conditions of drought.

The effects of phasic drought on the different indices of pearl millet have been studied (Lahiri and Kharabanda, 1965, Lahiri and Kumar, 1966) and it was found that susceptibility to drought increases with the age of the plant and although magnitudes of responses may alter in different phases with respect to different characters under consideration. It appeared that the climax of sensitivity for vegetative growth occurs during the period of fastest growth rate and the yield is affected most at the onset of reproductive phase. It was further observed that the yield may decrease to different extents depending upon the stage at which moisture stress was experienced. In certain cases early drought, if not severe, may increase the yield as it has been observed also in other crops like wheat.

It may be apt to mention here that the condition of sporadic drought is experienced not only in the arid areas but also in other parts of the country which otherwise receive high rainfall.

Often again in the arid areas rains may fail completely and the precipitation remain far below the average. Pearl millet which is one of the main crops of this area displays high yield in one year with favourable rainfall where merits of fertiliser use and improved varieties become discernable whereas, in a bad year with low precipitation, the yield

per plot may dwindle to almost nothing and varietal and fertiliser effects disappear completely. This poor yield in a bad year is generally associated with a marked drop in growth and water use. Ample data on this aspect are available in this Institute.

Instability in agricultural production in arid areas is largely due to conditions like this. The soil moisture conditions which normally display the familiar saturated, unsaturated and vapour phase flow after showers in a moderate rainfall year assume a dismal state in a bad year (Table 2) where severe limitations are imposed on plant growth.

Table 2. Per cent soil moisture at different depths in a Bajra field during kharif season of 1969 having 92.7 mm rainfall.

Depths in cms	Percentage soil moisture on different dates							
	13-8	23-8	2-9	12-9	22-9	3-10	13-10	25-10
0-5	3.6	1.6	1.0	1.8	0.5	0.5	0.3	0.2
5-25	3.6	4.4	3.3	2.0	3.3	2.4	1.6	0.2
25-50	2.8	2.1	3.3	3.5	5.1	3.9	2.9	2.2
50-75	2.8	2.5	3.8	2.0	2.8	3.1	2.7	2.6

Importance of water use

It has been found that when the rainfall is delayed and expected to be low during the kharif it will be advantageous to grow a crop which has a lesser water need (Lahiri, 1968).

This information is very useful in arid agriculture and indicates a way for production stabilisation under the second condition of drought. Legumes like guar, not only use less water but can also stand delayed sowing. Thus in a bad year such legumes are useful substitutes for bajra. It may, however, be apt to mention here that water use values as such may vary widely from one year to another depending on rainfall, temperature regime and other environmental conditions.

Significance of fallow

It has generally been observed that in arid areas land is often kept fallow for 1 to 2 year or more before a cropping. This is conducive for moisture conservation because the precipitation which is received after the deep drainage is held at the upper layers and little evaporation loss is theoretically possible due to the sand which serves as mulch because of the large inter space between the particles. Although this is advantageous in arid agriculture, little gains are actually derived in most places due to the infestation of weeds in fallow lands which use

up most of the moisture reserve. The weeds and grasses which invade the fallow lands normally transpire at very high rates. For instance, a weed like *Aerva javanica* may transpire as much as 10 gm. of water in a day per gm weight of leaf tissue and the rate of transpiration during the noon hours on a bright sunny day may exceed 1,000 mg/gm/hr. In an experiment undertaken at Jodhpur, grasses and other components of ground cover consumed as much as 163.8 mm. of soil water in a growing season and this value is comparable to that of pearl millet (Lahiri, 1965).

An excellent example of moisture conservation at weed-free site is available in Bikaner area where unstabilised dunes are kept completely weed-free. It leads to large moisture accumulation in these dunes, despite low precipitation in those areas. This conserved moisture is utilised by local farmers in the cultivation of *matira* and *kakri* which are grown on these barren dunes. Except for a litre of water at sowing the plants during the growing period do not receive any irrigation.

Short duration crop

It is but obvious that arid agriculture is more of a gamble because we have no control over the rainfall conditions. However, it is understandable that plants having a short growing period has a better chance of success. In this respect certain strains of minor millets like *Panicum miliceum* which complete their life cycle within 40-45 days seem to have considerable promise. Such plants which have been identified by Dr. M. B. L. Saxena and his associates in this Institute can be sown in event of a shower in June and harvested in July. The fields are thus available in July for kharif crops like Bajra, Guar etc.

Stabilisation of production under sporadic drought conditions

Intermittent droughts as mentioned earlier, occur virtually in all rainfed areas. It creates a situation where soil moisture goes up during the wet period and goes down again during the dry spell. The magnitudes of tensions which develop during the dry spell may, however, vary widely due to precipitation and soil conditions.

Diverse facts which have emerged from our studies on plant reactions under the foregoing conditions have been discussed here in brief.

(a) Transpiration potential in droughted plants after irrigation

In the course of our studies it was observed (Lahiri and Kharabanda, 1966) that irrigation after a period of water stress develop high transpiration potential. As a matter of fact, it was demonstrated that the

transpiration increases progressively more, on rewatering, depending on the period and intensity of drought. It is also known (Jansen, 1962) that water and nitrate absorption follow uniform rates and an increase in suction increases the rate of uptake of both water and nitrates. Therefore it was reasoned that the level of nitrate in plants should normalise under favourable soil moisture conditions after a period of drought.

(b) *Nitrogen uptake under water stress*

It was further observed that nitrogen uptake rates of pearl millet varieties remain virtually unaffected over a wide range of tensions and impediments in the intake process occur only when plants pass through cycles from field capacity to 15 atm. tension (Lahiri and Singh, 1970). Therefore, if we consider a single period of drought (till wilting), it may be possible that establishment of higher water and nitrate uptake may normalise the nitrogen status of plants although the pattern may undergo changes in different growth stages because of the variation in the impact of the drought at different phases of plant development (Lahiri and Kharabanda 1965, Lahiri and Kumar 1966). The two distinct peak periods suggest the need of split applications of nitrogenous fertiliser.

(c) *Nitrogen metabolism under water deprivation*

Results obtained on the effects of water deprivation on nitrogen metabolism (Lahiri and Singh, 1968) indicated that moisture stress impede the synthesis of proteins and hydrolysis, if any, takes place only at wilting. It was interesting to note again that rewatering after a cycle of drought, enhances the synthesis of protein and consequently protein content after the drought is higher than the initial.

For this reason it was found (Lahiri and Singh, 1970) that plants which grow under low soil moisture regime not only display high concentration of total nitrogen (presumably due to the decrease in dry matter) but also high concentration of proteins at all stages of growth, as compared to plants grown under high soil moisture conditions.

It may be mentioned in passing, that results have also indicated that moisture stress decreases the yield, as such, but concentration of nitrogen in the grains which are formed remains very high (Table 3). This is due to the fact that moisture stress impedes the transport of carbohydrates to the dividing shoot apex but the transport of nitrogenous substances is not affected to that extent.

Table 3. Nitrogen contents in the grains of var. Hybrid, RSK and T55 grown under different moisture regime.

Variety	Total N (%) in grains under different moisture regime			
	F.C.	1 atm.	8 atm.	15 atm.
Hybrid	1.44	2.31	1.79	3.54
RSK	2.33	3.52	2.50	3.49
T55	2.09	2.33	2.59	2.71

In the recent years it has been established (Ferrari and Verner 1969, 1970; Glassiou 1969) that the activity of nitrate reductase depends largely on the substrate concentration. Although evidences collected so far (Lahiri and Singh, 1968) suggest inactivation of this enzyme and impediment in protein synthesis during drought, fast rate of protein synthesis was recorded on rewatering. All these informations suggested a rational possibility of inducing greater vigour in plants, inspite of drought, if adequate level of external supply of nitrogen is provided along with other nutrients.

(d) *Nutrition induced vigour as a measure for drought evasion*

In order to verify this concept experiments were conducted with two varieties of pearl millet (viz. var. RSK and HBI) which were grown in sand culture with nutrient solution of Gregory under three levels of nitrogen (viz. full, 1/3 and 1/81). Drought till wilting was imposed to separate sets at 20, 30, 40, 50 and 60 days from sowing. Results of the findings (Lahiri *et al* 1973) proved, in a generalised way, that adverse effects of short duration droughts may be evaded and substantial production may be achieved despite drought, if optimum plant vigour is induced by adequate soil fertility. Considerations of large number of indices of plant performance and nitrogen status of the tissue helped us to reach this conclusion.

When the nitrogen content per plant was determined from the termination of a drought till maturity it was observed that the drought decreased the absolute quantity of nitrogen but the nitrogen level of droughted plants under full dose of nitrogen was comparable with that of the control (undroughted) plants under 1/3 nitrogen dose. Again, nitrogen content of droughted plants under 1/3 nitrogen level remained much higher than the control plants under 1/81 level.

It seems therefore that higher nitrogen level in plant may be maintained, in spite of drought, if an adequately high external supply is maintained.

Reports are also available (Fawcett and Quirk, 1962) that absorption of phosphorus increases with increasing soil phosphorus, at all levels of water stress. Thus increase in phosphorus level in tissue may also be envisaged with high external supply under drought conditions.

(e) *Metabolism under hyperthermia and induction of enzyme stability under moisture and temperature stresses*

It was further observed that temperature stress induces protein breakdown leading to large formation of soluble nitrogenous compounds (Lahiri and Singh, 1969). Due to this metabolic derangement, ammonia accumulates in the tissue and this is highly toxic. However, under conditions of high fertility it has been observed (Lahiri and Kathju, 1973) that proteins and enzyme systems of pearl millet leaf tissue become more stable.

Again, it was observed that wheat plants raised under high fertility display high ATPase and Amylase activity. This high activity was also maintained under conditions of desiccation (Table 4).

Table 4. Activities of ATPase and Amylase of the leaf tissue of 20 days old wheat plants under high (HF) and low fertility (LF) conditions. Control and Treated indicate measurements at zero hour and after 200 mins. of desiccation at 24°C.

Treatments	Relative turgidity		ATPase mg P liberated/gm fresh tissue		Amylase mg starch hydrolysed/gm fresh tissue	
	HF	LF	HF	LF	HF	LF
Control	89.6	78.68	21.60	3.00	14.17	5.25
Treated	46.6	48.70	28.09	9.60	22.95	9.82

(f) *Prospects of higher production with little irrigation water*

In the desertic areas, water, after all, will always remain a precious commodity. Therefore, areas which have water potential, need intensification of agriculture with techniques which bring increase in production with minimum use of water. It is now known that irrigation based on monitoring of soil moisture, plant potential and tissue turgidity provides a most rational use of water. Our findings suggest that substantial production can be achieved with less water by optimizing the inputs. As a matter of fact one can obtain different levels of production at the same level of water use, under irrigated conditions, by progressive optimisation of inputs. The basic finding has far reaching

applied interest in arid areas. A farmer in this area, having well irrigation with limited discharge, can still expect a reasonable yield. Again it may be possible to divert the limited water resources over a large area.

Under these conditions regulation of plant nutrition through fertilisers is one of the simplest and most effective means for production regulation. The data presented under Table 5 indicates that even under conditions of most rigorous curtailment of irrigation water (dry condition) substantial production of wheat could be achieved under high soil fertility (e.g. dose of 80 kg/ha each of N and P_2O_5 and around) whereas ample supply of water without fertilisers has given extremely poor yield.

Table 5. Yield (in Q/ha) of wheat (var. RS 31-1) under dry and wet conditions

P_2O_5 kg/ha	Dry condition (F.C. to PWP)				Wet condition (Maintained at close to field capacity) 60 to 100% availability			
	N in kg/ha				N in kg/ha			
	0	40	80	120	0	40	80	120
0	5.59*	9.22	9.27	7.10	6.45	6.52	3.85	7.43
	9.74**	9.19	9.31	8.61	15.5	14.3	14.3	14.9
40	5.68	10.14	12.85	16.31	18.92	21.30	16.65	34.03
	8.99	9.71	9.86	9.98	13.4	13.6	15.5	17.5
80	4.66	15.89	20.80	11.60	5.81	25.33	39.58	33.10
	8.96	10.10	10.18	10.02	15.4	16.35	18.2	17.4
120	3.15	15.40	16.53	13.23	7.34	25.91	38.72	31.77
	8.96	9.70	9.70	9.74	16.2	17.9	18.7	17.6

* Yield in Q/ha.

** Quantity of irrigation water added in inches.

Thus the experimental results so far obtained help us to derive a strategy for maximising production despite short duration drought or limitation of irrigation water.

The foregoing account gives us a glimpse of the diversity and complexity of the problems of plant production in the arid areas. If we aim at a greater production from these areas, where the returns are usually low due to the hazards of nature, intensive researches in soil water-plant relationship are necessary to meet the challenge with

greater confidence. Human endeavour to this date has at least suggested many promising strategies.

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DRYLAND FARMING TECHNOLOGY

R. P. Singh*

Crop production on drylands of the arid zone is beset with many intriguing and challenging problems. The yields of dryland crops are dismally low and unstable. Crop production as a business is unremunerative. An acute ecological imbalance of the components of productivity is primarily responsible for low biological productivity in the arid zone. A sizeable decrease in the area used for grazing and a phenomenal increase in the population of grazing animals during the last decade is one classical example of ecological imbalance. Because of more population (both human and bovine) pressure on land, the cultivation of crops is extending to marginal and submarginal lands, the cropped area having increased from 26 to 38 per cent of the total area between 1960 and 1970.

Major problems limiting crop production

In order to improve the biological productivity of the arid zone, the main thrust of efforts will have to lie in the restoration of a proper ecological balance in these areas. Before attempting to formulate a viable crop production technology for the drylands, the major problems limiting crop production have to be identified and quantified. Some of the major problems confronting successful and remunerative crop production on drylands of the arid zone are listed below:

1. Low annual rainfall (366 mm.) with its frequent erratic distribution from season to season, coupled with high solar incidence (450-500 cal. per cm²/day) and high wind velocity (20 KMPH), giving rise to high P.E.T. (6mm/day) and high mean aridity index (78%).
2. Wind blown desert sandy soils (85% sand) low in O.M. (0.1 to 0.45%), with poor water holding capacity (25-28%) and high infiltration rate (9 cm/hr).
3. Scant groundwater resources and deep water table (40-50 meters) coupled with brackish underground water (EC 1.25 to 10.0 mmhos/cm) at many places.
4. Soil salinity and alkalinity to the extent of 45 per cent of the unirrigated area.
5. Surface crust formation after sowing following the light showers.
6. Limited choice of crops, low cropping intensity and low yield potential of the conventional crops.

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It would be clear from the above that none of the factors of crop production, viz. climate, soils, underground water, crops and varieties grown etc. are favourable for obtaining remunerative returns from crop production. However, plenty of land and sunshine are assets to be reckoned with. Water, not land, is the most limiting factor. An attempt has been made in this paper to highlight some of the approaches adopted and results achieved at the Dryland Research Main Centre towards increasing and stabilising crop production on drylands.

1. *Cropping programmes matching the rainfall patterns*

1.1. *Moisture availability and choice of crops*

In order to formulate a suitable cropping strategy for any area/situation, it is necessary that the availability of rainfall water and period of moisture availability for cropping, is properly studied and quantified. With a view to finding out the availability of rainfall water in a good, normal, average and below average rainfall distribution years, as also during periods of prolonged drought occurring in second fortnight of July or August, corresponding to seedling and flowering stages of kharif crops, six weather models have been prepared. A careful analysis of the annual rainfall data of Jodhpur for 73 years (1901-1973) has resulted in four main categories, designated as models A, B, C, D, corresponding to good (>400 mm), normal (350-400 mm), average (250-350 mm), and below average (<250 mm) rainfall years, representing 23, 12, 17 and 21 years with a mean annual rainfall of 560, 366, 293 and 196 mm, respectively.

On the basis of the experience gained during the past three cropping seasons (1971 to 1973), moisture losses that occur in the form of evapo-transpiration, run-off and deep percolation have been computed. Run-off and deep percolation losses have been estimated at 40, 35, 25 and 10 per cent of the total rainfall received during the kharif season for models A, B, C, D, respectively. The availability of water for each situation represented by different models has been worked out and the period of moisture availability for crop production has been assessed, assuming the mean evapo-transpiration to be 3 mm/day. Based on the above, appropriate crops have been suggested (Table 1).

It is seen from Table 1 that models 'A' and 'B' together account for 50 per cent of the total number of years under study. The contribution of kharif rainfall to the total annual rainfall ranges from 84 to 90 per cent and as a consequence substantial quantity of water (214 to 284 mm) are available for crop production. As such, the choice of crops is large enough to make crop production a remunerative proposition. In case of models C, E and F, the share of kharif rainfall to annual rainfall is 76 to 80 per cent, accounting for 166 to 173 mm of water availability

Table 1 : Availability of water for crop production in the various rainfall distribution patterns.

Models	Description/rainfall limits	No. of years	Annual rainfall (mm)	Kharif rainfall (mm)	Percent to annual rainfall	Run off percolation losses (mm)	Ratio of run off to rainfall %	Availability of water (mm) (col. 5-7)	Period of moisture availability for cropping (days)	Choice of crops
1	2	3	4	5	6	7	8	9	10	11
A	Good rainfall distribution (> 400 mm)	23	564.9	472.5	83.6	189.0	40	283.5	95	<i>Bajra, jawar, cowpeas mung, til, sunflowers, castor.</i>
B	Normal rainfall distribution (350-400 mm)	12	366.0	329.1	89.9	115.2	35	213.9	71	<i>Bajra, cowpeas, mung, til, sunflowers.</i>
C	Average rainfall distribution (250-350 mm)	17	292.0	229.6	78.4	57.4	25	172.7	58	<i>Bajra, mung, til, sunflowers.</i>
D	Below average rainfall distribution (< 250 mm)	21	275.5	138.0	78.6	13.8	10	124.2	42	<i>Kharif pulses (moth, guar, mung)</i>
E	Rainfall distribution with drought in second fortnight of July	11	258.7	207.4	80.2	41.5	20	165.9	55	<i>Bajra, mung, moth.</i>
F	Rainfall distribution with drought in second fortnight of August	20	278.0	211.4	76.0	42.3	20	169.1	56	<i>Bajra, mung, moth.</i>

(Source: Ramakrishna, Y. S. and Singh, R. P. (1974): Crop production strategy in the arid zone in relation to rainfall distribution models. Seminar on 'Desert Technology', C.A.Z.R.I., Aug. 30-31, 1974).

for crop production. The lowest water availability (124 mm) is obtainable in model 'D' and as a consequence only short duration kharif pulses can be grown.

1.2. Alternate cropping strategies for different weather situations

Alternate cropping strategies for three abnormal seasons, viz. (a) normal onset of monsoon followed by long gaps in rainfall, (b) delayed onset of monsoon and (c) early stoppage of rains towards the end of the season, have been suggested. The situation where the monsoon sets in at the normal time (last week of June or first week of July) followed by long drought spells are quite common in this part of the Arid Zone. During the past 73 years (1901-1973), such a situation has been encountered in 11 years. For such a situation, water harvesting *in situ* and sowing the crops in the inter-row water harvesting system has been found to tide over the long spells of drought. Application of surface mulches has been helpful in checking excessive evaporation of moisture from the soil surface. Cultural practices like, (a) deep sowing with a minimum soil cover, (b) planting grain legumes and oilseed crops in the paired row system, (c) thinning within the row in the event of moderate drought spell (15-20 days), and (d) splitting the fertiliser dose, have been seen to result in good seedling vigour and proved useful in cutting down the competition for limited moisture. In the event of occurrence of showers after drought, gap filling/transplanting of cereals like *bajra* has been found to be particularly useful. Here again, growing drought tolerant varieties of crops with suitable maturity patterns like *moong* S8 or *cowpeas* FS68 and use of appropriate crop mixtures in inter cropping systems like grass (*C. ciliaris*) + *moong*, sunflower + *moong*, etc. are the key to success.

In the event of delayed onset of monsoon, adoption of an alternate cropping strategy viz. sowing of pulses like *moong* (S8, S9) and oilseed crops like sunflower (EC 68414) instead of cereals like *bajra*, inter-cropping of annual grain legumes in perennial grasses, inter-cropping of sunflower and *moong*, growing of sunflower instead of *til*, use of surface mulches and adopting an appropriate water harvesting system to collect run-off, are advisable.

1.3. Choice of efficient crops and varieties

Selection of dryland crops should be based on the criteria of their adaptability and efficient utilization of limited moisture. An efficient crop is one which has an high yield potential and completes its life cycle within the period of moisture availability. Among cereals, *bajra* has

been found to be the most efficient crop in normal rainfall years (around 360 mm). In a good rainfall year (>500 mm), even sorghum (CSH-1) could be successful, giving an yield of 51 q/ha, also providing diversification to the cereal-based economy of drylands.

Crops that start flowering and grain setting during the period when the probability of rainfall is the highest (August 3rd and 4th weeks), are bound to succeed on drylands. For instance, *mung* beans maturing in 60 to 65 days and *bajra* maturing in 80 to 85 days, fit in very well into the existing rainfall pattern, which, at best, can ensure availability of moisture for a period of 10 weeks (70 days) or so. Obviously crops like *arhar*, *jowar* and soybean, having a maturity period (seed to seed) of more than 100 days do not hold any promise. Castor, a long duration crop (110-120 days), is an exception. It succeeds well on drylands because of deeper root system (more than 1 meter), giving an yield of 10-12 q/ha with improved agronomic practices. Of the new introductions, sunflowers has shown promise as a substitute to *til* on drylands. In normal rainfall years, it is capable of giving 8-10 q/ha seed yield with good quality edible oil.

On the basis of performance of various crops under varying rainfall conditions over a period of 4 years (1971-1974), it has been observed that perennial forage grasses such as *Cenchrus ciliaris*, *C. setigerus*, and *Panicum antidotale*, annual fodder crops like *bajra* and *jowar*, grain legumes like *moong*, cowpeas, *guar*, *moth* and among oilseed crops like sunflower and castor showed a consistent degree of performance despite a wide variation in rainfall patterns. These crops can be considered plastic or adapted crop types. Cereals like *bajra* and sorghum, and oilseed like *til* were found to yield well when the distribution of rainfall was normal. These crops failed under late monsoon conditions, despite a satisfactory quantum of rainfall.

Of the traditional crops, *bajra* and *mung*, HB3 and J41 *bajra*, S-8 and 288-8 *mung*, fit in very well into the existing rainfall pattern of this area. Besides early in maturity (80-85 days), the above *bajra* hybrids give an average yield of 10 to 12 q/ha, in contrast to local varieties like RSK which gives an yield of around 5 q/ha, taking more than 95 days to mature. The moisture use efficiency (MUE) of HB3 and J41 varieties of *bajra* is around 8 to 9 kg grains/mm of water used, as against 4.8 in the case of RSK. Similarly, *mung* S-8 gives an yield of 10 to 12 q/ha in 60-65 days, the M.U.E. being 3.4 to 4.6 kg grains/mm/ha. Variety 288-8 is an equally efficient utiliser of rainfall and stored soil moisture. In contrast, variety RS4 recommended by the Department of Agriculture, Rajasthan, possesses a spreading and a more vegetative plant type, with an yield of 7-8 q/ha leading to a MUE of 2.7 to 3.5 kg grains per mm/ha.

Variety FS68 of cowpeas, possessing a compact plant type, maturing in 65 to 70 days, with an yield potential of 9-12 q/ha, is a promising variety for this tract. FS277 of cluster beans (*guar*), T13 of *til* and EC68414 of sunflowers, Aruna and GH3 of castor, have been found to be promising for this area.

2.0. Water harvesting techniques for successful crop production

For rainfall distribution models of the type B, C, and D, various water harvesting techniques have been found to go a long way in successful crop production on drylands of the arid zone. It has been observed that the ratio between run off to rainfall is 35-40% in good rainfall years (more than 350 mm) and 10-25% in bad to average years (less than 350 mm). Several water harvesting techniques (including inter-plot and inter-row) are being tried at this centre. Of special interest is the water harvesting technique designed for successful production of vegetables on drylands. In this technique microcatchments of inverted 'V' shape with 6% slope are made in such a way that the vertical run on the catchment culminates into a pit. The catchment area of each pit is 4.5 m.sq. The pits are 75 cm. deep having a circumference of 50 cm., dug with the help of a power auger. Seeds of vegetable crop are dibbled round the circumference and the centre at the onset of the monsoon. The evaporation and deep percolation losses are cut down appreciably with the help of bajra husk mulch and bentonite clay layer provided at the surface and the bottom of the pit, respectively. The results of the studies carried out on this water harvesting system during kharif 1974 (rainfall 136 mm) are presented in Table 2.

Table 2. Effect of sub-surface barriers, surface mulches and run off concentration on the yield of tinda.

Treatments	Yield (q/ha)
A. <i>With catchment</i>	
1. Barrier	43.1
2. Barrier mulch	45.1
3. Mulch only	22.1
4. Control	18.2
B. <i>Flat</i>	
5. Barrier	19.7
6. Barrier mulch	23.9
7. Mulch only	14.2
8. Control	13.4

(Source : Annual Progress Report Kharif 1974, Dry Farming Research Main Centre, C.A.Z.R.I., Jodhpur).

Treatments with run-off, in general, yielded higher than respective treatments under flat conditions. Application of mulch alone resulted

in 4 quintals extra yield of *tinda*, whereas the placement of a barrier and application of mulch gave about 27 q higher yield over control (18.2 q/ha). The additional yield of *tinda* obtained under the treatment, barrier + mulch, pays off the costs of the treatments. The treatment, barrier + mulch, exhibited its efficiency under the flat system also, giving about 10 q higher yield over the control (13.4 q/ha).

The moisture status in the soil profile, studied at periodic intervals, revealed that treatments with run-off micro-catchment and barrier, in general, stored more moisture as compared to flat and no-barrier treatments. Similarly treatments with surface mulch stored more moisture as compared to unmulched treatments.

For long duration and high value crops like castor, a new system of water harvesting has been designed which consists in making pointed elevated ridges terminating into trenches 30 cm wide and 15 cm deep. The ridges (50 cm wide at the bottom having 45 cm slope width) are mechanically made with the help of a soil inverting plough. In between two trenches, the micro catchment of 50 cm width is created, the ridge to ridge distance being maintained at 1.85 metres, the centre to centre distance of the trenches being 1 metre. Seeds of castor are dibbled in the centre of the trenches which get additional run off from the ridges as also from the micro-catchments provided in between the trenches. This system seems to work very well for widely spaced long duration crops like castor grown on arid lands, which are often subjected to wind action. The evaporation losses could be cut down appreciably by applying any organic mulch (hajra husk or dried grass) in the trench.

3.0 Cutting down evaporation and deep percolation losses—the effective way

An effective way of cutting down deep percolation losses by putting a barrier of bentonite clay in vegetable pits has already been described under the water harvesting systems explained above. Field experiments on the use of surface mulches for controlling evaporation in dryland crops conducted for two successive years have shown that baira husk mulch applied @ 4 to 6 tons/ha in between rows of baira HB3 can be effective in increasing the yields of bajra grains by 2.5 t/ha and cutting down the evaporation losses by about 50% (Table 3).

Bajra husk, being a complete waste, seems to be an ideal material for mulching unlike wheat or barley straw which is considered as an important cattle feed. Polyethylene, on the other hand, is a very costly material and hence may not prove economical in our conditions. Late sown castor and *til* and *raya* sown in *rabi* responded to the ap-

Table 3. Total moisture use and moisture use efficiency as influenced by different mulches.

Mulches	Estimated moisture use at seedling stage(mm)	Moisture content in 90cm deep soil profile on 2-9-72 (mm)	Moisture content at harvest (mm)	Total moisture use (mm) (col. 2+3-4)	Grain yield (kg/ha)	Moisture use efficiency (kg grains/mm)
Polyethylene	42.0	113.8	39.5	116.3	1183	10.2
Bajra husk	42.0	111.4	40.3	114.1	1178	10.8
Wheat straw	42.0	111.1	37.1	117.0	1030	8.8
Dust Mulch	42.0	109.1	37.8	114.3	964	8.4
No mulch	42.0	108.4	36.6	114.8	930	8.1

(Source : Progress Report Kharif 1972, Dry Farming Research Main Centre, C.A.Z.R.I., Jodhpur).

plication of bajra husk mulch, giving 56 and 25% higher seed yields, respectively, over no mulch treatment, besides making efficient use of moisture, particularly in the presence of fertilisers.

4.0. Efficient use of limited moisture through fertiliser use

HB3 hybrid bajra can give significantly higher yields (10.6 q/ha) with the application of 40 kg. N and 20 kg. P_2O_5 /ha 10 cm. deep at the time of sowing than the unfertilised crop (6.6 q/ha), resulting in the highest fertiliser use efficiency (10 kg. grain per kg. N) and returns per rupee invested in fertiliser use (Rs. 4.00).

Experiments have shown that grain legumes like *moth* (Local) and *guar* (FS277/Sona) can yield 46 and 175%, respectively, more yield than unfertilised crops when fertilised at 15 kg. N and 40 kg. P_2O_5 /ha.

Oilseed crops, *til* (T13), sunflowers (EC68415) and castor (Aruna) have also shown yield increase of the order of 24% to 47% with a fertiliser application of 40 kg. N and 40 kg. P_2O_5 /ha.

The yields of fodder and forage crops can be increased to high levels by judicious fertiliser application, in spite of acute drought as occurred in kharif 1972. *Bajra* and *jowar* fodders with 60 kg. N and 40 kg. P_2O_5 /ha, fodder mixture like *jowar*+*guar* and *bajra*+velvet bean with 40 kg. N and 40 kg. P_2O_5 /ha have yielded 160% to 265% more fodder. Forage grasses like *Panicum antidotale*, *Cenchrus setigerus* and *Cenchrus ciliaris* (357 and 358) responded spectacularly to fertiliser application at 30 kg. N, 30 kg. P_2O_5 and 20 kg. K_2O , yielding 273, 56 and 50 per cent, respectively, higher quantity of forage.

5.0. *Evolving a code for good rainfall years*

It has been pointed out earlier that of the 73 years studied (1901-1973), about 23 years have been such which provided an opportunity to dryland farmers to harvest good remunerative crops on the drylands of the arid zone. The year 1973 was a very favourable year, both from the point of view of rainfall distribution and total quantity. Such good rainfall years should be capitalized upon by following the steps noted below:

- a. *Run off collection and recycling of collected water for supplemental irrigation or to grow rabi crops on conserved soil moisture.*
- b. *Application of organic manures like F.Y.M. and suitable quantities of fertiliser nitrogen (around 40 kg. N/ha) to cereals and oil-seed crops. Smaller quantities of nitrogen (20 to 30 kg/ha) will be appropriate for forage and fodder crops.*
- c. *Covering larger areas with suitable varieties of cereals, pulses, oil-seeds and vegetables which would lead to fertiliser economy and high levels of production.*

Ex:	Bajra	—	HB3, J41
	Moong	—	S-8
	Cowpeas	—	FS68
	Guar	—	FS277
	Sunflower	—	EC68414
	Castor	—	Aruna
	Til	—	T13
	Jowar	—	CSH-1
	Vegetables	—	Tinda

- d. *Increasing the cropping intensity with a good quantum (365 to 500 mm.) of well distributed rainfall, it is possible to enhance the cropping intensity by sowing fodder crops like bajra and jowar at the onset of monsoon (usually in the last week of June) which would be ready for harvest by the first fortnight of August, giving a green fodder yield of 240 to 320 q/ha. After harvesting the fodder crops it would be possible to grow a crop of moong (S9, S8, RS4), cowpeas (FS68) or sunflower (EC68414) which would result in a grain yield of 4.5 q/ha (Table 4).*

Table 4. Yields of fodders and grain crops grown after harvest of fodders in kharif 1973 (rainfall 533 mm).

First crop	Yield (q/ha)	Second crop	Yield (q/ha)
Jowar fodder	284.0	Sunflowers (EC68414)	4.3
Jowar fodder+guar fodder	242.0	Moong (S-8)	4.2
Bajra fodder+moth fodder	324.0	Cowpeas (FS68)	4.7

(Source: Crop Production strategy in the Arid Zone in Relation to Rainfall distribution models. Ramakrishna, Y. S. and Singh, R. P. Symposium on 'Desert Technology', CAZRI, Aug. 30-31, 1974).

- e. Growing long duration crops like castor (Aruna, GH3), hybrid sorghum (CSH-1) with advantage.
- f. Growing crops like raya (T59, KB2), safflower (A-300) or sunflowers (EC69874 or EC68414) on stored soil moisture (100 mm. or more) after the cessation of monsoon.
- g. Establishment of perennial forage crops like *Cenchrus* and *Lasiurus* spp. and shelter belts with species like Israeli babool (*Acacia tortalis*), Vilayati babool (*Prosopis juliflora*), neem (*Azadirachta indica*) and Siris (*Albizia lebbek*) etc. to provide adequate insulation against wind erosion in subsequent years. Forage grasses also permit inter-cropping of pulses like moong or cowpeas without any additional moisture and nutrients.
- h. Planting seedlings of fruit trees especially grafted ber (Gola, Seb, Mundia, Jogia).

6.0. Stabilizing crop yields on drylands

6.1. Grow dependable crops

In a bad rainfall year like 1974 (136 mm.) it was observed that whereas crops like *bajra* completely failed, grain legumes like *mung* (S-8) and cowpeas (FS68), planted in the paired row system, gave yields of the order of 2.0 to 2.5 q/ha. Castor (Aruna), planted as late as August 1, gave an yield of 9.0 q/ha. Fodder crops like *guar*, *bajra*, and *jowar*, planted in the inter-row water harvesting system yielded 20 to 33 q/ha of green fodder in 42 to 53 days.

6.2. *Follow inter-cropping systems*

As inter-cropping offers insurance against complete crop failure during seasons of acute drought, it is necessary to evolve complementary inter-cropping systems with the important crops.

Inter-cropping of annual grain legumes in forage grasses

Although forage grasses like *Cenchrus* are important in arid areas, they will be more acceptable to farmers only with inter-cropping system which would yield some additional quantity of grain. Earlier work carried out at the Central Arid Zone Research Institute, Jodhpur, showed that annual grain legumes like *moong* and *moth* could be inter-cropped in the sown pastures of forage grasses, without any adverse effect on the yield of forage. Studies have shown that *moong* varieties like T44 and RS4 are capable of yielding around 2 q of grain per hectare, at the same time enhancing the forage yield by 26% (on dry weight basis), when inter-cropped with forage grass like *Cenchrus setigerus*.

Inter-cropping in sunflowers

Sunflowers as oilseed crop is becoming popular on the drylands of Western Rajasthan, in view of its higher yield and suitability for late sown conditions as compared to *til*. It has been observed that grain legumes like *moong* (S8), *moth* (Local), and cowpeas (FS68), when inter-cropped in sunflowers, would yield 5 to 8 q of grains per hectare without impairing the normal yield of sunflowers (7 to 8 q/ha).

From the foregoing, it is evident that by an appropriate selection of crops and varieties, to fit into a suitably managed cropping pattern, there exists a definite scope to evolve a remunerative crop production strategy, which could maximise production in a favourable year and stabilise the yields under scanty rainfall conditions.

HORTICULTURE IN THE ARID ZONE ECO-SYSTEM: FRUIT GROWING

O. P. Pareek*

Introduction

Man is an important part of the biosphere. Advancement in his civilization has disturbed the equilibrium of the natural ecosystems. This has been happening continuously with an ever increasing speed and has often created harmful imbalances. The "population explosion" in recent years has further necessitated search for new areas of production. Since the arid lands cover a large percentage of the total land surface of the world, these would not be left unexplored. In order that the natural ecosystem of these regions does not develop harmful imbalances, a nearly balanced system in which every unit is a harmonious partner—will have to be carefully worked out.

Horticulture—growing and utilisation of fruits, vegetables and ornamental perennials and annuals—is an integral part of the activities of the civilized man. Fruits and vegetables provide the protective class of food materials. The ornamental horticulture is a source of psychological satisfaction for the weary mind as also for the aesthetic urge. Horticulture, as a whole, offers a civilized landscape to the biome. These horticultural activities must, however, conform to the climate, soil and water components of the region. Fruit growing in this context has been discussed here.

Fruit development synchronous to soil and atmospheric water availability

The hot Indian arid zone is characterised by the conditions of high aridity, with low average annual rainfall ranging from 180 mm in Jaisalmer, 290 mm in Bikaner, 300 mm in Barmer to 360 mm in Jodhpur. The rainfall is confined to the period from July to September with 9 to 21 rainy days out of 12 to 30 in the whole year (Fig. 1). The moisture storage capacity of the shallow and light sandy soils is very low. The atmosphere is very dry with a vapour pressure deficit (v.p.d.) of more than 24 mb in April and more than 30 mb in May and June. The v.p.d. remains well above 15 mb during the monsoon through November. In December and January, it does not go below 9 mb and

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the deficit again rises above 12 mb in February and above 18 mb in March. These conditions cause a great deal of transpirational loss of water. The plants are thus put under moisture stress—both through soil and through the atmosphere. Therefore, the fruit crops selected must be such that their maximal growth period falls during the period of maximum water availability in soil and low vapour pressure deficit in the atmosphere. Ideally most part of the reproductive cycle, i.e., the period from flowering to fruiting, must also fall during this period and the fruit ripening must be completed before the onset of summer when the v.p.d. is still below 20 mb. Fruit crops like the *ber*, pomegranate, guava and custard apple conform to this prerequisite. These crops flower during the rainy season. Fruit ripening in *ber* is over by February and in pomegranate and guava by December.

Drought tolerance mechanisms:

The fruit crops having deep root system have the capacity to draw water from deeper layers of soil profile and would, therefore, be capable of surviving droughts. Some crops, as for example, *ber* and *gonda* (*Cordia mixa*) conserve moisture by shedding their leaves during summer. This is a very useful drought evading mechanism. Conservation of moisture is also brought about by certain water binding chemical constituents in the tissues resulting in high 'bound water' contents e.g., in fig. Other xerophytic leaf characters, e.g., wax coating, hairiness, sunken and covered stomata are characters which minimise loss of water through transpiration. Some fruit crops like fig, *phalsa*, *ber* and *cordia mixa* have such characters.

Temperature for fruit development:

Crops like date palm, however, require hot dry conditions during its fruiting period from March to July for ideal performance. Date palm requires 4200 to 5000 degree days above the base temperature of 50°F for proper maturity of its berries (Tate and Hilgeman, 1962). Trials at Jodhpur have shown that date palm flowers during the end of February to early March and the berries mature by the end of July (Muthana *et al.*, 1974). The heat unit accumulation during this period is from 5510 in Kutch, 5758 in Jaisalmer, 5886 in Barmer, 6196 in Jodhpur to 6365 in Bikaner (Table 1). Even upto June the heat unit accumulation in these regions range from 4443 to 5041. Another essential for date palm cultivation is a minimum of rainfall during fruit maturity season. Only few districts are, however, sufficiently dry during this period e.g., Jaisalmer in Rajasthan (Fig. 1).

Table. 1. Heat unit accumulation with reference to date palm and grape in four arid zone districts

Districts	Heat Unit accumulation in degree days (base 50°F)				
	Date Palm			Grape	
	March-June	March-July	March-August	15th April-May	15th April-June
Jaisalmer	4524	5758	6914	2469	3128
Barmer	4692	5886	6999	2484	3113
Bikaner	5041	6365	7593	2573	3264
Jodhpur	4995	6196	7307	2473	3118
Kutch (Bhuj)	4443	5510	6530	—	—

It can be seen that in Kutch district of Gujarat the month of July is the wettest. In this region the heat unit accumulation is also slower (Table 1) and therefore the maturity would coincide with the reasonably dry month of August.

Grape also requires dry and warm weather during flowering and fruiting. *Thompson Seedless* grape berry requires about 2500 degree days of heat units above the base temperature of 50°F for maturity. In the arid regions the heat unit accumulation is about 2500 degree days by the end of May and 3100 by mid June. The accumulation of heat units is in a period of about 30 to 45 days inducing fast sugar accumulation in the berries. This results in exceptionally early maturity under the arid zone climate avoiding the risk of berry splitting and fungal infection due to the humid weather during rains. *Beauty Seedless* variety matures by the end of May and *Thompson Seedless* in the first week of June. The extremely high temperatures (37-42°C) during the maturation period is perhaps the cause of a poor development of flavour and the development of a thick leathery skin in grape cultivars.

Viral and fungal diseases which limit papaya cultivation in the more humid regions of the country are of a little occurrence in the arid zone. The fruit attains an excellent flavour under the dry and hot conditions of this region. A characteristic odour, a definite disqualification from the point of view of consumer acceptability, develops in the fruits grown under the climatic conditions of other regions. Perhaps the extremely high day temperatures in the arid regions become lethal for the development of the constituents causing this odour. Whether it is due to the high v.p.d. or to a lack of their biosynthesis during the faster rate of ripening are the questions to be sorted out. Arid zone, however, offers potential for the production of excellent quality papaya.

While the climatic conditions for sour lime, oranges and papaya are favourable, they would invariably require irrigation. Low winter

night temperature and warm summer are essentials for the production of good quality sweet oranges. Good colour development in the pulp takes place only in regions with low winter temperature. Warm and dry summers are required for ripening and the development of sweetness. One of the finest quality *Blood Red* malta oranges are produced in the climatic conditions of Sriganganagar.

Sun burn and radiation utilization:

During the months of March through July the solar radiation is above 500 cal/cm²/day reaching upto 650 cal/cm²/day in the month of May. This creates a problem of sun burning in the developing fruits. The varieties like the *Kinnow* mandarin offers promise to avoid this hazard. This variety is quite drought tolerant and bears the fruit shaded inside its well formed canopy. A well formed canopy exposing the foilage uniformly to the solar radiation results into a high photo-synthetic efficiency and high fruit yield.

Wind damage to fruit crops

The wind velocity is high, often more than 20 km per hour in summer. This would cause mechanical damage to the fruits and branches, excessive transpirational loss of water resulting in water stress and desiccation. Dust storms occur during the period of ripening of dates. The soft and sticky date berries attract dust and become unfit for consumption. Cold winds in winter also cause damage to fruit crops. This can be avoided by making a closely spaced, single row plantation of hardy, upright growing trees, of *Acacia nilotica* ss. *cuppressiformis*, around every fruit block of 1-2 ha area. This would also create a favourable micro-climate in the vicinity of fruit trees. For a more effective windbreak for a larger area, double row planting with trees like *Acacia tortilis* should be done on the windward side.

Soils for fruit growing

For fruit growing, the depth of the soil and the nature of the sub-soil are of more importance than the texture of the surface soil. The soils of the arid zone of Rajasthan are generally sandy, structureless and poor in fertility. The water storage capacity of the soil is low (F.C.=6.9%). The infiltration rate is high (9 cm/hr.). They are often shallow and are underlaid with a layer of carbonaceous concretions at a depth of 0.2 to 1.5 m. The thickness of this layer varies. This is hard to penetrate for the roots of many fruit species and

therefore limits the depth of soil profile upto which their roots can scavage for water. Such fruits are not likely to be drought tolerant and would have more irrigation water requirement. The trees adapted to these regions strike their roots across this layer and develop an extensive root system. They survive droughts. Ber roots were found 4.5 m. deep in soils having 1 m thick hard calcareous layer at a depth of 1-1.5 m. Pomegranate and guava also develop fairly deep root system in these soils. Custard apple does not require deep soils and can withstand high amount of lime. However, the soils should be well drained.

Varieties of *Vitis vinifera* are deep rooted. The root system extends 6-10 feet or more deep in soils if its penetration is not obstructed. Ideally soil structure that favours extensive root development is preferred if they are well drained. Light soils are ideal. In California, *Perlette* and *Thompson Seedless* varieties are grown in hot desert—the Borrego, Coachella and Imperial valley—on sandy or sandy loam soils as these soils induce early ripening. Most vinifera grapes tolerate high concentrations of lime in the soil—50-70 per cent carbonate. The soil conditions of arid zone are, therefore, quite suitable for viticulture. When grown in light shallow soils adequate attention must be paid on its balanced nutrition. Recently the problems of barrenness and decline of grape orchards have tended to reach alarming proportions in western Rajasthan. One reason of this undoubtedly is loss of vine vigour due to deficiencies of some micronutrients. The deficiencies develop after few years of plantation at least partly due to recurrent over-feeding with selected macronutrients.

Sandy soils are ideal for citrus growing provided they are well drained and well supplied with nutrients. One of the finest date palm gardens in California are in deep sandy loam soils. It can do well in coarse sand as well but would require excessive fertilization and irrigation. The soils underlaid with more retentive layers somewhere in the first 1.5 m. would reduce leaching of mineral nutrients.

Arid zone soils are poor in moisture storage capacity and dry out quickly. Moisture conservation by careful management is, therefore, one of the essence of success. The structureless character of the surface soil which often acts as mulch offers a unique opportunity for this. The main portal of moisture loss to the atmosphere from such soils is transpiration through the vegetation. Keeping the orchard soil completely weed free, therefore, assumes great importance in these regions.

Irrigation water resources for fruit growing

In the arid regions, availability of water and its quality have been

important deciding factors for the cultivation of fruits. Of the 3.21 lakh sq. km. of the hot Indian Arid Zone, 61% is in western districts of Rajasthan. Of this only about 4,000 ha. is under orchards. Seventy-three per cent of this area is in Sriganganagar district alone, mostly under citrus. About 1,000 ha. is under fruit crops in arid regions of Gujarat. Most of these orchards are irrigated.

About 62% of the total irrigated area (5 lakh ha.) is in Sriganganagar district almost whole of which is under canal command. On completion, the Rajasthan Canal Project would cover an area of about 21.9 lakh ha in Bikaner and Jaisalmer districts. Canal irrigation water is generally of good quality. This region would be most suitable for extending the cultivation of fruits which attain their best quality in dry summer, e.g., dates, grapes, sweet oranges (*Malta* and *Musambi*, grapefruit, *Kinnow mandarin*, sour lime, papaya. etc.

Ground water is the main source for irrigation in the other districts. About 36% of the irrigated area in Rajasthan arid zone (about 2.9 lakh ha) gets water from wells and tubewells. A very rich aquifer has now been discovered in Jaisalmer district, called the *Lathi* series. The underground water is often brackish and is, therefore, unsuitable for crop production. The fruit crops like the date palm and pomegranate can, however, withstand such brackish water and, therefore, their cultivation offers unique opportunity. The other fruits which can tolerate certain amount of salinity in irrigation water are *ber*, *aonla* and mulberry. Sour lime, guava and grape are less tolerant. But the other citrus fruits and papaya are susceptible.

Water harvesting for fruit production

Irrigation water resources in the arid zone are limited. Hardly 4% of the area is under irrigation in the arid zone of Rajasthan. Most of this too is localised in the districts of Ganganagar, Pali, Sikar, Jalore and Jhunjhunu. Even after harnessing more irrigation resources hardly 11% of the region would get irrigation. A vast area of the arid zone will, therefore, have to depend on natural precipitation for its water supply. Average yearly rainfall is, however, very low and makes fruit growing difficult. Water becomes a limiting factor. Nevertheless there is about 25% rainfall to run off ratio even in light soils with high infiltration rate under 250-300 mm rainfall distribution (Ramakrishna and Singh, 1974). The run off is more than 40% in flood years with over 400 mm rainfall. Water availability to the tree can therefore be increased by run off concentration. Optimum production from orchards could then be possible.

The runoff is expected to be even more from slopy lands, hills and rocky areas. The hills and uplands in Rajasthan have a slope of

15 to 25% at hill sides and 5-15% at the foot hills (Sen, 1972). Even the dune area has a slope upto 20%. Abichandani and Yadav (1974) have estimated that about 2500 sq km of the area under rugged high and low hills, rocky plateaux and pediment plains, gravelly aggraded plains and eroded land surface exposing kankar beds in Jodhpur district can yield 10,000 ha m of runoff water even in a drought year and 30,000 ha m in a normal rainfall year. About 11.6% of the area of the arid zone of Rajasthan i.e., about 24,000 sq km is under barren and uncultivated land. A large proportion of this area is with rocky and gravelly surface. The run off water from these areas could be profitably utilized by making suitable micro-catchments for growing fruit trees.

A rational management of the catchment would yield much higher run off than from a natural watershed. Evenari *et al.* (1971) have reported that under 100 mm rainfall conditions in Avdat highlands of Israel, a 0.1 ha catchment with 10% slope would produce 160 m³ per ha of run off. The run off was 100 m³ per ha from a 20 ha catchment and only 50 m³ per ha from a 300 ha catchment. They obtained 30% further increase in run off from the small catchments by stone clearing. Sub-dividing the catchments into micro-catchments considerably increased the run off. Even in a drought year (50 mm rain), they have obtained 80-100 m³ per ha run off from micro-catchments when there was no run off from the watersheds of more than 50 ha size. Whereas the run off from small water sheds (1-7 ha) was less than 10%, it was 35-50% from the *negarin* plots (micro-catchments). Evenari *et al.* (1971) found that a 500 m² *negarin* produced the highest run off yield in Avdat highlands. Further reduction in the *negarin* size resulted in reduction of run off yield also. A suitable treatment of the micro-catchment can also increase run off yield. The run off increased from 12-13 mm to 17.5 mm by bentonite clay plastering on a sandy catchment at Pali with slope of 4-6%.*

The Israel workers made a square basin, shaped in the form of a flat inverted truncated pyramid at the lowest point in the *negarin* plot, for planting the fruit trees. The fruit trees were planted on 125-1000 m² catchments. A good number of varieties of fig, almond, plum, olive, pomegranate, pistachio, peach, apricot, vines, sour and sweet cherries and apple have been tried in Avdat and Shivta highlands. It can be seen that most of these fruit crops flower during spring when there is maximum water availability from the winter rains in Israel. At Shivta, fig, vine, pomegranate, olive and carob succeeded the best. Carob proved to be the most drought tolerant.

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Olive, almond and pomegranate were also quite drought tolerant. Figs. suffered from drought during the initial years but later developed well.

At Advat, peaches, apricots, almonds and loganberries were the most successful. The capability of apricot to survive droughts much better could be due to the fact that its roots had already penetrated through a good volume of the soil profile in a short time. Peach cultivars grafted on root stock A 10 developed well and produced 52.75 kg (*Robin*) and 35.53 kg. (*Early Red Free*) yield per tree. Of the four apricot varieties, *Colomer* gave best results (26.37 kg/plant). Loganberry produced 1.7-3.9 kg berries and almond 2.4 kg dry shelled kernels per plant.

In pomegranate, the difference in growth rate and height of the trees grown in various micro-catchments was small (Evenari *et al.* 1971). The height of trees in 100 m², 500m² and 250 m² catchments was 210 cm, 222 cm and 183 cm respectively. This means that even 250 m² catchment is good enough in the rainfall conditions of Advat and about 40 pomegranate trees per ha could be planted by the negarin method.

The run off can be used for growing trees in such a way that each tree has its own micro-catchment area. The lay out of the micro-catchment in relation to the location of tree would depend upon the topography of the area. On hill slopes or on foot hills the fruit tree will obviously be planted at the lower end of the catchment. In the plains the catchment area may either be all around the tree or on its two sides. For determining the size of the micro-catchment for a tree species, various factors will have to be kept in view. Every fruit tree has a water requirement for its optimum production. This must be met by the local precipitation and by run off from the micro-catchment. It also has its own characteristics of root depth and spread. These factors determine the volume of the soil profile which would supply water to the roots. The run off water should be concentrated for storage in this soil profile. This would also mean that the run off from the micro-catchment at one recharge should not ordinarily exceed this moisture storage capacity. Considering the rainfall and catchment characteristics in addition to the above factors, size of the micro-catchment for a fruit tree can be worked out. Assuming that a ber tree in sandy plain of Jodhpur, having a canopy area of 36 m² requires about 660 mm of water in one fruiting season. Of this, 360 mm is expected to be provided through rain. There is, therefore, a deficit of 300 mm to be met through run off. The run off coefficient of a sandy catchment with a slope of 5% is nearly 4 (Frevert *et al.* 1955). The size of the micro-catchment would then work out to be 75 m².

This means that one *ber* tree could be planted in an area of about 110 m². Likewise, the plant population of a fruit tree to be grown with the run off from different types of micro-catchments can be estimated (Table 2).

Table 2. Catchment area per tree and plant population per hectare with different slopes of a sandy catchment (annual rainfall—360 mm).

Fruits	Canopy area	Run off supplement mm	Catchment slope %	Catchment area m ²	Area per tree m ²	Population per ha
<i>Ber</i>	36	300	0.5	100	136	74
			5	75	111	90
			10	60	96	104
Pomegranate	20	800	0.5	148	168	60
			5	111	131	76
			10	89	109	92
Guava	56	800	0.5	415	471	21
			5	311	367	27
			10	249	305	33
<i>Cordia mixa</i> (<i>Gonda</i>)	36	200	0.5	67	103	97
			5	50	86	116
			10	249	305	33
<i>Aonla</i>	56	500	0.5	259	315	32
			5	194	250	40
			10	156	212	47
Sour lime	36	1000	0.5	333	369	27
			5	250	286	35
			10	200	236	42
Custard apple	20	300	0.5	56	76	132
			5	42	62	161
			10	33	53	189

Experience in Avdat highlands has shown that even with a 12 mm rain a 500 m² loss soil catchments could produce 41% runoff. Assuming that the run off from the hilly and rocky areas in Indian arid zone would be about 50%, the catchment size for various fruit trees can be worked out (Table 3).

Table 3. Catchment area per tree and plant population per hectare for some fruit trees in rocky and gravelly slopes (annual rainfall—360 mm)

Fruits	Canopy Area m ²	Catchment area m ²	Population per hectare
<i>Ber</i>	36	60	104
Pomegranate	20	90	91
Guava	56	250	33
Fig	56	250	33
<i>Aonla</i>	56	156	47
Custard apple	20	35	182
Sour lime	36	200	42
<i>Cordia mixa</i>	36	40	132

The foregoing discussion on the conformity of fruit growing with the components of the arid zone eco-system belies the general belief that fruit production is not possible in arid regions. While water harvesting methods make growing of certain fruits possible in the dry-lands, cultivation of some of the other fruits is possible only in the climatic conditions of the arid regions with irrigation resources.

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PHYSIOLOGICAL ADAPTATIONS OF PLANTS IN DESERT ECO-SYSTEM

A. N. Lahiri

Introduction-Concepts of desertic adaptabilities

A striking manifestation of the indispensability of hydrature for the existence of plant life is aptly demonstrated by the maximum development of plant systems in the rainy climate and by its lowest ebb in the semi-arid and arid areas where the paucity of natural precipitation is coupled with other environmental impediments like high wind and thermal regime, poor water retention by soil, excess of salts in soil and water, etc. which directly or indirectly influence the plant-water relations. Thus, it is useful to bear in mind that plants, in general, are never 'droughtphilic' but are 'drought-phobic'.

However, natural selection and evolution have produced plant types highly fit to survive under the trying conditions of arid areas. These plants, generally designated as 'xerophytes' (Greek word *xeros*=dry, flaccid, and *phyton*=plant), can not only withstand drought but also, intense heat and radiation, impacts of high winds and lashing sand storms.

The foregoing concept, which was introduced by Scheuw (1822), had numerous lacunae and shortcomings. It was soon noted that not all plants which grow in the desert are adapted to drought and others have diverse in-built mechanisms to evade it. The rain-born 'ephemers' have virtually no adaptive characters but complete their life-cycle at a fast pace within the favourable period of soil-water regime. Again there are other types of plants in the desert which are termed 'pseudo-xerophytes' (Kamerling, 1914, Genkel, 1946) or 'phreatophytes' (Meinzer, 1923), have deep-penetrating root system and hardly ever display economy in water use. Apart from these, perennials having underground water-storing organs do not show any xeromorphic adaptation.

In view of these Kearney and Shantz (1911) classified the plants of the dry region as drought 'escaping', 'evading' and 'enduring' types. The first group consists of annuals which quickly complete the life cycle during favourable period. The other type of plants which evade the adverse effects by extensive or deep root systems or in some cases restriction of water use, fall under the second group. The true-xerophytes

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are the 'enduring' types like Cacti, Euphorbias etc. which can sustain prolonged water deprivation.

Various other attempts (Schimper 1903, Maximov 1929, Lemero 1946, Genkel 1946, Oppenheimer 1960) have been made to define xerophytism from time to time and the old concept of Schimper (loc. cit.) as regards low water use of arid plants was questioned. Modern researches have shown subsequently that plants residing in deserts are of wide varying characters. Oppenheimer (*loc cit*) in a critical review on this subject indicated that xeromorphic characters like sunken stomata, thick and cutinised epidermal cells, sclerenchymatous hypodermal tissue, hard and thick leaves of reduced size etc. do not serve as an index of 'xerophillous' nature of plants and provided ample ecological and other evidences to show such plants may be found under diverse habitat from the Mediterranean climate to the arctic circle. It was thus concluded that arid adaptabilities cannot be speculated from structural and anatomical peculiarities.

Induced xerophytism

The classical concepts of xeromorphism has primarily emerged from the works of Velkens (1887, 1890). These are well known and a detailed account is available in the paper by Oppenheimer (loc. cit). Recent investigations (Walter, 1951, Shields, 1950) have indicated that these adaptabilities are not effective in retaining water and these can be induced in plants under conditions of bright illumination to enhance rapid transpiration. Under these circumstances they tend to develop the following characters :

1. Greater thickness of leaf vein per leaf surface.
2. Greater number of stomatal openings per suit surface area.
3. Smaller size of stomata, epidermal and mesophyll cells.
4. Greater number of smaller hairs per surface.
5. Thicker outer walls of epidermis and cuticle.

Internal moisture balance

It seems apparent, however, that the leaf water maintenance is an important factor in many plants for surviving drought. Lundegordh (1949) thus considered the common mark of xerophytes to be a "far reaching resistance to wilting". It is true that in nature, wide differences in osmotic pressure and diffusion deficit are encountered and it is believed that these are indices of relative resistance. Recent studies have indicated that the diffusion pressure deficits at the lethal point

of drying are 45, 90 and 130 atms in tomato, privet and *Acacia aneura* respectively. Although, such differences are real, Parker (1968) has questioned whether such high DPD value is a real advantage to plants or it is merely a means of survival.

Leaf fall and surface reduction

Many desertic and semi-desertic species possess a mechanism of leaf drop and curtailment of the surface area of leaf under adverse soil water condition. This aspect has been studied (Lahiri and Kharabanda, 1966) in detail in *Tecomella undulata*, a tree of the Indian desert. It was found that plants grown under different soil water conditions hardly demonstrate any significant changes in their relative rates of transpiration per unit of leaf area. However, it was observed that the total water out-put is definitely reduced in plants grown under low soil water regime because of the reduction of total leaf area of plants under low soil water conditions. Thus it may be concluded that moisture shortage may not often influence the rate of transpiration per unit area or weight of leaves but total water turn-over may be restricted by the reduction of leaf area.

Transpiration potential and soil-water of pre-drought growing conditions

Experimental evidences (Lahiri and Kharabanda, loc. cit.) are now available which indicate that plants which during their growing period have experienced moisture stress develop high transpiration potential after a drought period. It was observed that plants which have been subjected in the past under longer period of water restriction display fastest water turn-over rate immediately after the termination of a drought. This process is again associated with quick protein synthesis and normalisation of metabolism (Lahiri and Singh 1968, 1970).

It is reported again that leaf rolling in certain grasses also reduces transpiration (Oppenheimer 1960). Some investigators like Bennet-Clark (cited in Grieve, 1955) were, however, unable to confirm the usefulness of this adaptability.

Influences of stomata, leaf hair and leaf coating

It is very obvious that stomatal closure retards transpiration. Slatyer (1960) indicated that stomatal resistance does not however, become significant until the apperture is reduced by about half. Jarvis and Jarvis (1963) indicated that the boundary levels of leaf water potential and relative turgidity per cent for stomatal closure vary widely in

different species. The relationships between transpiration, soil moisture and relative turgidity percentage with special reference to stomatal control in a drying cycle have been derived by certain workers like Slatyer (1960) and Lahiri and Kharabanda (1966). The reaction stages were outlined as follows :

(a) *The initial constant rate phase* :—Transpiration rate and relative turgidity remain unaltered and presumably little stomatal control is exercised.

(b) *The falling rate phase* :—Soil moisture reaching the vicinity of wilting point and this is coupled with a decline in both rate of transpiration and relative turgidity. Stomatal closure increasing the resistance.

(c) *The cuticular phase* :—A sharp drop in the relative turgidity accompanied with minimum of transpiration. Water loss only through cuticle, stomatal resistance being maximum.

(d) *Rehydration phase* :—Restoration of tissue hydrature and establishment of normal transpiration, stomatal resistance decreasing to the minimum.

Stomatal closure thus has a great significance in relative drought resistance but the CO_2 utilisation out-weighs the advantage. In most desert perennials, however, stomatal control is hardly exercised due to root adaptations and thus transpiration and photosynthetic processes are not affected.

Early works of Wiegand (1910), Yapp (1912) and Sayres (1920) suggested that presence of hair is a xeromorphic character for reducing transpiration but subsequent studies have shown that these hairs possibly serve other purposes like scattering incoming radiation or in breaking up soil reflected radiation, preventing insect attack and helping to cool the leaf by increasing total radiating surface. The involvements of hair in actual reduction in transpiration may be insignificant because *Aerva javanica* which abounds here in the sandy plains and dune habitat transpire at very high rates (1000 mg/gm/hr or more at peak hours) despite the presence of abundant leaf hair (Lahiri, 1971).

Loss of water through the cuticle assumes a significant proportion only under certain extreme conditions. It is rather questionable (Parker, 1968) whether cuticular thickness alone has any implication in water loss behaviour as such. Muller *et al.* (1954) were of the same opinion but work of Morello (1955-1956) suggested that resinous coatings might aid moisture retention in the tissue when moisture stress has closed the stomata.

Root growth

It will not be wrong to state that the degree of desiccation resistance is often a function of root growth behaviour of plants. It is a general observation that in the desert most of the shallow rooted plants disappear after the rainy season while the perennials with their deep and extensive root system flourish without any difficulty.

It will be apt here to relate some of the available informations on the remarkable root growth characteristics of desertic perennials which enable them to tap water from great depths and make them indifferent to soil water conditions of upper soil layers. Root excavation of *Prosopis cineraria* was undertaken by Late Prof. B. E. Nikolaevitch, UNESCO expert to CAZRI, who could go down to 8-10 metres and even at that point roots with thick secondary growth were found to go further down. The roots penetrated the stratified kankar layers in the course of their growth. In one case a two feet high *Aerva persica* plant extended its tap root system far beyond 20 ft. (Lahiri, 1968). Root of a *Acacia* sp. was found at a depth of 30 metres when Suez canal was dug. Kusmin (1929-30) found that *Medicago coerulea* and *Glycyrrhiza glabra* which grow in the western shore of Caspian sea display branching only at depths between 10 to 15 metres. It has been reported again that *Welwitschia mirabilis* has been found to go upto 18 metres in the dry river beds in the south west African Namib Desert (Herre 1954).

Transpiration behaviour of several deep rooting perennials of our desert has been studied. It has been found that most of these transpire at a very high rate. For instance in *Tecomella undulata* 9 to 10 gm of water is lost in a summer day per gm of fresh leaf tissue. However, in winter, water loss is reduced due to low dawn temperature and shorter day length. But the high rate of transpiration during the noon hours was more or less similar in both the seasons. There is again differences in transpiration rates of different species. In plants like *Salvadora oleoides* rather low rates are encountered which rarely exceed 500 mg/gm/hr. On the contrary *Prosopis cineraria*, which abounds in the desertic sandy plains, transpiration rates in a clear afternoons may often exceed 1500 mg/gm/hr. Studies on the water loss of this tree species indicated (Lahiri and Kumar, 1967) that approximately 222 mm of water may be lost to the atmosphere through transpiration from a hectare of land consisting of about 50 trees. Studies on water balance (Lahiri, 1965) indicated that fluctuations of soil water tension of upper soil layers have hardly any effect on the internal moisture balance of this tree. It flowers and fruits during the summer

and maintains the RT percentages around 80 when the upper 100 cm soil layer contain moisture below the wilting percentage.

Root growth of grasses and root penetration in rocks

The grasses and other native vegetation which dry up beyond October have also well developed root systems. Investigations of Dabadghao *et al.* (1962) indicated that maximum depths of root system in grasses (19 months' old) like *Cenchrus ciliaris*, *C. setigerus*, *Panicum antidotale* and *Dichanthium annulatum* extend upto 117-196 cm. In case of *Lasiurus sindicus*, a native grass of Jaisalmer, roots went upto 403 cm.

It is often found that the root systems of grasses like *Lasiurus* and trees like *Acacia tortilis* penetrate the rocks and display ramifications. It is surprising again that plants growing in such barren rocks display high transpiration (Oppenheimer, 1949). It is presumed that roots follow the foot steps of physical weathering and acidic root exudates help in rock disintegration. Kusmin (1929-30) suggested that porous stones can absorb moisture during the rainy season and release it to the invading roots in summer. This may be a possibility as our field observations indicate flash of growth occurs in *Lasiurus* in March in Pokran-Jaisalmer areas having often little top soil (and rocky at the bottom). Similarly certain other species like *Cordia charaf* and *Maringa ceccanensis* of rocky habitat also flower and fruit about the same time.

Root-shoot ratio

In the desert habitat root growth of plants is generally more than the shoot portion. The reason for this disparity lies in the fact that the roots are subjected to less environmental stresses than the shoot portion and the moisture content of the surrounding environment is more favourable for growth in case of root meristems as compared to those of shoots. Oppenheimer (1960) however has quoted several instances where plants growing in extreme desert areas have less developed root systems. In certain plants like *Zygophyllum dumosum* of Near East desert, short-lived thread-like extension roots occur from the main root (0-50 cm) to tap water from greater depths. But these roots are not maintained throughout the year due to general shortage of water.

Germination regulating mechanism in desertic environment

It is understandable that the natural propagation by seeds in the desertic environment is very much handicapped due to a number of

factors like poor or incomplete seed setting, hard seed-coat, adverse environmental conditions like inadequate moisture etc. In order to evade these difficulties certain plants have successfully adopted vegetative propagation. *Aerva tomentosa* is one such plant in our desert. It sends out long runners at a depth of about 20 cm from the surface and new plants are formed from vegetative buds on such runners. A large number of plants may thus arise from a single plant in sandy habitat. Although flowering is abundant in this species it is hard to find a plant regenerating from its seeds. Easy rooting capacity is another adaptability. *Calligonum polygonoides*, which is one of the most important component of our desert eco-system, can produce roots from its aerial parts, once it is buried in the sand. It is likely that breaking of its shoot portion during browsing by camels, or by other means and subsequent burial of such plant parts in the sand may indirectly help in plant propagation. In *Euphorbia* and *Cactus* breaking of shoot portions due to aging or by other means, leads to regeneration of new plants from old parts.

Studies on grasses like *L. indicus*, *C. ciliaris* and *C. setigerus* have shown (Lahiri and Kharabanda, 1961) that their glumes contain different proportions of large and small seeds. The large seeds produce seedlings of greater vigour than those obtained from small seeds. Thus only a small proportion of the total seed out-put are effective in producing seedlings which may withstand the rigorous conditions of the desert. It has further been observed (Lahiri and Kharabanda 1963) that the glumes of these grasses contain inhibitors which permit the germination of enclosed seeds when sufficient rains occur to leach away the inhibitors. This is an important desertic adaptation which ensures plant establishment only under conditions of adequate rains. Investigations of Went (1948, 1949) have furnished convincing proof that many desert seeds and propagative bodies possess germination inhibiting substances and this fact has met with support in the studies conducted by other workers (Koller and Negbi 1955, 1958, Larner *et al.* 1959).

Quick water uptake and fast speed of germination is another characteristic of successful desert species. Studies on promising desertic grasses of Indian arid zone (Lahiri and Kharabanda 1963) indicated that they all reach the plateau of water uptake curve within 2 to 6 hours of soaking under optimum conditions and plumule and radical elongation commences within 20-24 hours. The conditions are, however, very different in the desertic tree species like *Prosopis cineraria*, *P. juliflora* and *Albizzia lebbek*. These hard coated seeds under normal conditions take considerable time for adequate water inhibition for germination. Under optimum conditions germinative period may

extend as long as 15 to 30 days or more for full germination of a given sample. It is rather hard to obtain favourable soil water conditions for such a long period under desert conditions. Thus natural regeneration of desertic trees is at its lowest ebb and raising of plantations with adequate care is the only means for quick establishment of trees in most deserts.

There are again differences in temperature requirement for germination in different species. The grasses generally prefer temperature around 30°C. While tree species prefer temperature around 40°C. Certain grasses like *Panicum turgidum* prefer different temperatures during the day and at night. Oppenheimer (1960) has reported that *P. antidotale* can be established better if seeds are pre-soaked at 6°C and dried subsequently. A trailing desert plant *Citrullus colocynthis*, has a hard seed coat and it germinates with great difficulty if the seed-coat remains intact. It otherwise prefers high temperatures for germination.

Desiccation resistance

True desiccation resistance for the continuance of life processes is a remarkable adaptability of desertic perennial grasses. During the dry period the foliage dry up completely, but the apical meristems, under the protection of leaf bases, remain alive and sprout again under favourable soil water condition. Although, no specific data are available, it may be surmised that certain root tissues also remain alive which resume nutrient and water-uptake immediately after the showers. Certain other species like *Aristida* and *Heteropogon contortus* may become dry during the rainless period but regain green colour after showers. Classical investigations on these problems have been undertaken by Walter (1939), Henrici (1927) and Glending (1940). It seems apparent that water retention of root, shoot and leaves initials is the main reason of their survival and Walter found 70-90 per cent moisture in such tissues.

Bio-chemical adaptabilities

It is not desired here to relate the biochemical aberrations which are caused by the environmental stresses. However, it will be apt to mention certain current thinking regarding the biochemical indices for adaptability which has relevance in the present context.

(a) *Nitrogen metabolism.* It is known that extreme conditions of moisture and temperature stresses cause proteolysis with an associated increase in soluble nitrogenous substances like amino acids, amides,

ammonia etc. Among these, ammonia being toxic, inflict injury to plants. Prianishnikov (1945) postulated that plants which have the capacity to produce more of amides, as a measure to render ammonia harmless, may be better adjusted under temperature stresses. The phenomenon of increased ammonia formation has subsequently been studied by others (Lahiri and Singh 1969). Evidences are now available (Lahiri and Singh, 1968) which indicate that metabolic adjustments suggested by Prianishnikov (loc. cit.) may also hold good under water deprivation although metabolic alterations caused by moisture and temperature stresses are somewhat different. In a recent study by Singh *et al* (1972), increased proline accumulation has been considered as an index of drought hardiness in barley although nothing is known about the adaptability of native plants of the desert.

(b) *C₄ cycle of photosynthesis*: In the early 60's Hugo Kortschak in the laboratory of Hawaiian Sugar Planters' Association observed that sugarcane plants photosynthesizing in $C^{14}O_2$ atmosphere give rise to labelled Malic acid (a four carbon compound) instead of phosphoglyceric acid (a three carbon compound) which is the first product of the well known Calvin-Benson cycle of photosynthesis. This enigma was soon resolved by two Australian workers, Hal Hatch and Roger Slack, who demonstrated that there exists in the nature certain types of plants which fix atmospheric CO_2 in four carbon compounds like malic and aspartic acid in contrast to other groups of plants which fix CO_2 into a three carbon compound like phosphoglyceric acid following the usual Calvin-Benson cycle. The flow Fig. 1 indicates the photosynthetic pathways of C_3 and C_4 plants.

It may be mentioned here that to this date C_4 pathway is known to exist in about 100 genera of 10 plant families, both monocots and dicots and the number of C_4 species are counted in hundred. It is interesting to note that different species of a genera may be a C_3 in one case and C_4 in the other. Detailed informations on this subject are available in many recent literature (Hatch and Slack, 1966; Hatch *et al.* 1971, Bjorkman and Berry, 1973).

Without going into further details it will be sufficient to mention here that certain plants of the hot arid environment have evolved this unusual C_4 pathway which endows them with the capacity to fix CO_2 with great efficiency. It is known that rates of photosynthetic reactions are dependent on several factors, such as, intensity and quality of light, temperature, CO_2 concentration of air etc. The C_4 plants have been found to photosynthesize more efficiently than C_3 plants under conditions of high temperature and radiation and low CO_2 concentration. Partial stomatal closure caused by moisture stress may stop photosynthesis in C_3 plants which need higher CO_2 concentration while in

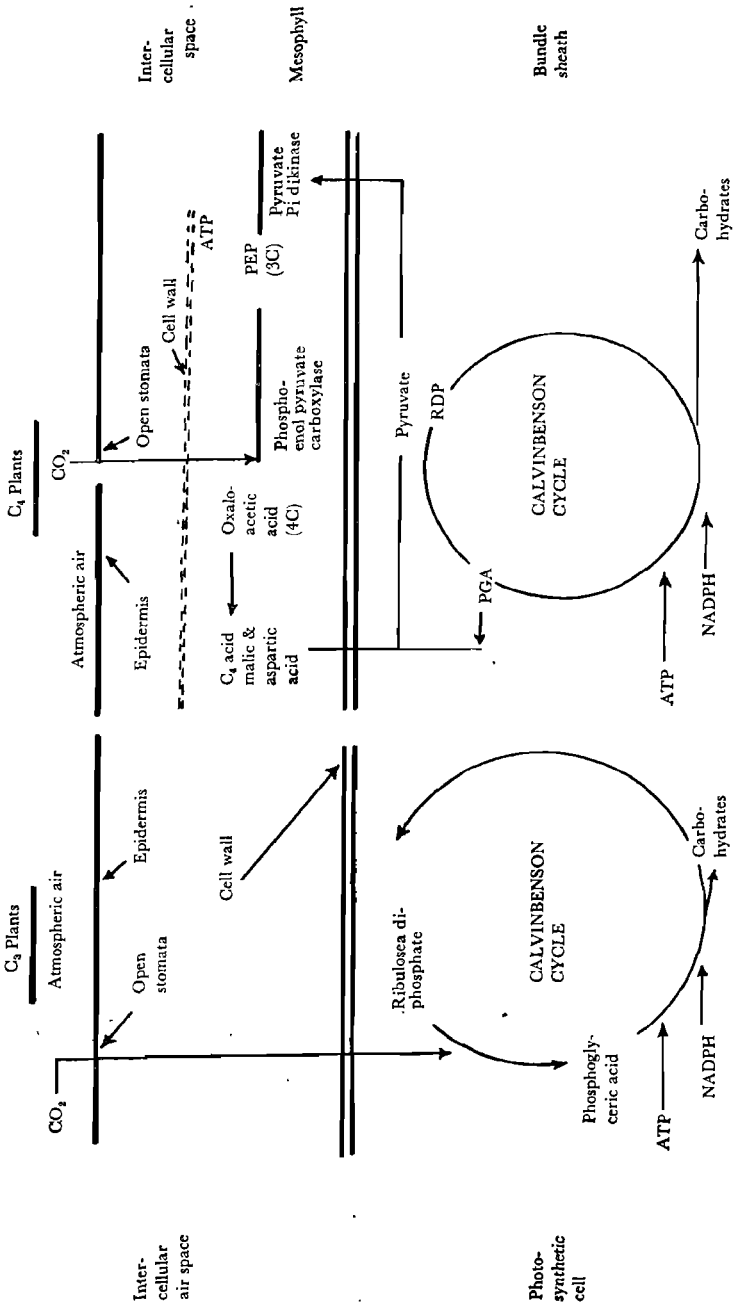


FIG. 1 Photosynthetic pathways of C_3 and C_4 plants

a C_4 plant this process may remain unimpeded due to its low CO_2 need for photosynthesis. Since transpiration and photosynthesis are linked by stomatal control, it is understandable that in C_4 plants water use may be reduced without any significant effect on dry matter production when the stomatal resistance is high and thus water use efficiency remains high in a C_4 plant as compared to C_3 plant under moisture shortage. Absence of photo-respiration in C_4 plants is also an added advantage. It is obvious therefore that C_4 plants are relatively better adapted to xeric habitat. The main differences between the two types have been outlined in Table 1.

Table. 1. Relative differences between C_3 and C_4 plants

C_3	C_4
1. Mostly temperate plants e.g. Beets, beans, cotton, pisum, glycine, wheat, barley, oat, rice etc.	Mostly tropical grasses like crabgrass, fox-tail, sorghums, corn, rhodes grass, <i>Eragrostis</i> , <i>Atriplex</i> , <i>Amaranthus</i> , <i>Panicum</i> , sugarcane etc.
2. Mesophyll cells loosely packed around vascular bundle, due to which CO_2 can easily diffuse out.	Mesophyll cells closely packed around V. B. due to which CO_2 cannot diffuse out.
3. Compensation point high (15 to 150 ppm) with photorespiration.	Compensation point low (0 ppm) without photo-respiration.
4. CO_2 evolution in light-high	CO_2 evolution in light-apparently none.
5. CO_2 assimilation rate low (15-35 mg CO_2 /dm ² /hr)	CO_2 assimilation high (50-70 mg CO_2 /dm ² /hr.)
6. Carbon pathway-Calvin cycle.	Carbon pathway-Hatch & Slack leading to Calvin cycle.
7. Translocation rate from leaf low.	Translocation rate from leaf high.
8. Light saturation low (2500-5000 ft c.)	Light saturation high (8,000 ft c. or higher)
9. Activity of PEP carboxylase low	Activity of PEP carboxylase high.
10. Leaf anatomy Fastucoid type (as described under item 2)	Leaf anatomy Panicoid type, dimorphic chloroplast, bundle sheath cells are large, centrally arranged chloroplast.

(c) *Iso-enzyme concept*. Resistance to environmental stress is widely recognised as a colloidochemical property of the protoplasm. Thus alterations in the protein complex and enzyme properties under environmental rigours have become an important field of study. Recent investigations of Feldman (1966) have indicated that thermostability of the same enzyme acid phosphatase may be different in two species of *Leucojam*. This suggested iso-enzyme production of dissimilar thermostability in two species of the same genera. Further evidences of the modulations of enzyme thermostability have been obtained under different soil fertility conditions (Lahiri and Kathju, 1973). Some unpublished data of our laboratory also suggest that nutrition conditions may change the enzyme activities under moisture

stress. The implications of these findings in the context of arid- adaptabilities remain to be explored.

(d) *SH-concept*. This concept is one of the several metabolic indices of environmental adaptability which remains yet to be established as an inherent character of desertic vegetation. It has been considered that tolerance to heat, cold and dehydration is related to resistance against oxidation of sulphhydryl to disulphide (Levitt 1972).

Attempts have been made in these pages to relate some of the diverse thinkings which have developed as regards plant adaptations in the arid environment. It is rather interesting to note that the seeds, by and large, are more resistant to stress conditions but the plants which emerge subsequently are often far less resistant. Thus it appears that apart from the phylogeny, ontogeny has also a significant role. The basic issue, however, pivots around the protoplasmic stability and denaturation of the proteins. Alterations in the RNA and protein synthesis (Zholkevich and Koretskaya 1959, Shah and Loomis 1965, Lahiri and Singh 1963) under moisture shortage are direct pointers to the involvement of DNA-RNA mechanism in the overall problem of adaptability.

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GENETIC IMPROVEMENT OF PULSE AND OILSEED CROPS

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INTRODUCTION

Pulse and oilseed crops have an important role in the agricultural economy of the arid areas, by virtue of their ability to yield harvestable produce despite moisture shortage which is a characteristic feature of arid areas. The total area under *kharif* pulses in the arid districts of Rajasthan forms about 82-85% of the total acreage of the state. Among the oilseeds, *til* is the most important crop of Western Rajasthan, followed by rape and mustard. The acreages under these crops (*til* and rape and mustard) in the arid regions of the state constitute about 68% and 22% of the total acreages under these respective crops in Rajasthan State. However, the statistics show that (i) The acreage under *kharif* pulses and oilseed crops has almost been constant in Rajasthan, (ii) the average yields fluctuated between 0.5 q/ha to 2 q/ha and (iii) the total production and the average yields are directly related to the quantum and distribution of the rainfall. The most disturbing fact is that the acreage and production of *kharif* pulses and oil seeds in India is decreasing.

The main reasons for low per acre yields of these crops are as follows:

1. Narrow range of adaptability.
2. Susceptibility to pests and diseases during the monsoon season.
3. Lack of high yielding varieties with conspicuously high yield potential.

All these point out clearly that varietal improvement of these crops is the inevitable necessity at the present juncture, to improve the production of pulses and oilseeds, as most of the pulse and oilseed crops, except rape and mustard are grown in the arid areas during *kharif* season under rainfed conditions. So, varieties of these crops should possess (1) drought tolerance, (2) early maturing habit, enabling the crop to complete the life cycle within the period of moisture availability, (3) a high degree of yield potential and (4) resistance to diseases and pests.

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Pulse Crops of the Arid Zone

The important pulse crops, viz. (1) *moong* (*Vigna radiata*), (2) *moth* (*V. aconitifolia*) and (3) cowpeas (*Vigna unguiculata*) are grown in *kharif* season under rainfed conditions. *Guar* (*Cyamopsis tetragoloba*) although not a pulse crop, is another grain legume grown extensively on the drylands of Western Rajasthan. The existing local varieties of these crops possess excessive vegetative growth leading to late maturity. Thus, they do not fit into the short season of crop growth prevalent in this region. Also the local varieties have very low yield potential.

1. Studies conducted by Khanna and Sinha (1973) show that the pulse crops like cowpeas and *moong* have very much higher sink potential than the cereal crop like wheat (Table 1). However the realization of the sink potential in the form of yield is very low. The breeding efforts have to be oriented towards the higher realization of the potential already present in this group of crops.

2. Another draw back with this group of crops is their narrow adaptability. That is, a variety suited for a set of agro-climatic conditions usually does not perform well under a different set of conditions, unlike the high yielding varieties of wheat. Hence it is necessary to evolve varieties with a broader adaptability pattern. This can be done by screening a wide range of genotypes with established high yield potential under different agro-climatic conditions. If a variety shows a high mean yield and regression around unity, the variety can be considered a highly adaptable variety (Eberhardt and Russel, 1966).

3. Research carried out by Sinha *et. al.* at I.A.R.I. (Khanna and Sinha, 1973) has indicated that the pulse crops suffer a sharp decline in leaf nitrogen content at flowering stage, consequently leading to a striking decline in the photosynthetic activity. This is mainly due to the degeneration of root nodules at the flowering stage. As a result, leaves have to support the growth of roots and the reproductive parts. This ultimately is reflected in excessive flower drop we notice in these crops.

In order to solve this problem one has to breed strains of pulses with a high photosynthetic activity at flowering stage or induce and sustain nodulation even at flowering and pod development stages. Another approach would be to breed or identify a strain or strains of *Rhizobia* which fix nitrogen and supply to the plant throughout its life cycle. One of the feasible genetical approaches would be to breed varieties of pulses with pod bearing branches projecting upwards out of leaf canopy, enabling the green pods actively participate in photosynthesis. This would be very useful as it is known that rate of photosynthesis per unit of chlorophyll of a green pod is much higher than that of a

leaf. In that event competition for photosynthetes from leaves to nodules and fruits would be reduced and the leaves might still support nitrogen fixation. Variability for this character has been observed in mung beans and cowpeas. Development of photo and thermo insensitive varieties in pulses would go a long way in enhancing the adaptability of these crops, as the photo and thermo insensitve varieties can be sown early or late depending upon the onset of monsoon without much reduction in yield.

A desirable plant type: The pulse breeding work in India during the past five years has been greatly influenced by the concept of improved plant type which has proved so very useful in the improvement of wheat and rice. Based on the experience gained in wheat and rice the plant types of the pulses have been re-examined. The examination has shown that a change in the plant type can even be more rewarding in the pulse crops, which have received much less attention (Swaminathan and Jain, 1973).

A major reconstruction of the plant type in pulses has required a reduction in their spreading and bushy growth habit so that more plants can be raised per unit of land. Associated with this has been an improvement in their harvest index (weight of grains, i.e. the economic yield/total plant weight, i.e. the biological yield).

A high harvest index, which obviously is of such great value in crop plants offers no particular advantage when plants grow in a wild state. The process of domestication and subsequent selection of crop plants during the past thousands of years brought some improvement in their harvest index. But the transformation is by no means complete. Thus a major breeding objective in recent years for crops like pulses has been to cut down their excessive vegetative growth, improve the harvest index and reduce the maturity duration. Recent studies have emphasised that one of the objectives should be to breed pulses for greater seed production per unit of vegetative growth. One method to achieve this, would be to have a greater number of pods per plant (Swaminathan, 1973).

In the absence of adequate genetic variability for important yield components like pod number, mutation breeding, exploiting induced variability would be of great use. The data presented in Table 2 show that variability for pod number can be brought about through induced mutations (Singh *et. al.* 1973).

When a proper recombination of characters becomes difficult through conventional breeding procedures, biparental method of breeding can be employed to bring about an appropriate recombination of characters without much negative associations. Methods like mutation breeding and biparental approach would be of immense use in pulses where

the available genetic variability is not very wide and often the problems of appropriate recombination of characters crop up (Prasad, 1973).

Nutritional improvement

Pulses are known to be characterised by a high protein content. So, improvement for yield has received a major attention. However, attempts have also been made to increase their protein content and the content of such essential amino acids as Methionine and Cystine, which tend to be low and so limit the biological value of protein in these crops. Studies conducted by Kaul and associates (Anonymous 1971) have shown a considerable variability which could be used for upgrading the nutritional value of pulses. A negative correlation has been observed between methionine and sulphur in most of the pulses except *mung* and *urad*.

Resistance to diseases and pests

A wide range of variability for resistance to pests and diseases was observed among the germplasms of currently cultivated pulse crops (Anonymous 1971). Among cowpeas K-11, T2 and T-5286-3 showed tolerance to bacterial blight, while suwanee, Iron, Victor & Brabham were resistant. Among moong varieties Jalgaon-781 was highly resistant to bacterial leaf spot. Resistance was found to be dominant over susceptibility. PLMO-2, 5, 10, 11, 14, 16, 18 and IC-8833 lines of moth were found to be resistant to bacterial leaf spot.

Strains P1078, P1147, P1145, P710, P549 and P249 of cowpeas proved to be resistant to *Madurasia obscurvella* (galerucid beetle) and strains P1129, P523, P81, P273, P78, P69, P517 and P267 were found to be resistant to *Empoasca kerri* (Jassid).

Some of the important improved varieties of grain legumes found to be suited for the drylands of Jodhpur tract are described in Table 3.

Oilseed Crops of Arid Zone

1. *Sesamum*: *Til* (*Sesamum indicum*) is the traditional oilseed crop of the area. The local varieties in spite of their drought tolerance are leafy with excessive vegetative growth. As such they possess low harvest index, a prolonged period of growth and poor adaptability. Hence these are caught up in drought at the crucial flowering phase leading to very low productivity. Another problem associated with the land races is their high degree of susceptibility to pests (particularly *Antigastra*) and diseases (especially phyllody). Added to all this, there is

excessive shattering of mature pods in the local varieties. Another disadvantage associated with this crop is its high thermo and photo sensitivity. As a result, the crop is a failure under delayed monsoon conditions in Western Rajasthan.

Improvements needed: As in the case of pulses even in *til* the (1) earliness in maturity and a high degree of adaptability are essential.

(2) The yields can be very much pushed up by enhancing the harvest index. (That is, a higher proportion of siliquae to the total biological production). This can be brought about by making the plant (a) single stemmed with (b) 4-6 capsules per every node. This way it would be possible to increase the population density per unit area which ultimately would lead to higher yield levels.

Most of the desired characters are simply inherited and as such improvements can be brought about by suitable breeding procedures. With regard to quantitative characters, sesames from east group of countries, such as Manchuria, Japan and North Western China were extremely early. Similarly variety B-45 is one of the early maturing varieties. This variety possesses single stemmed character also. Early forms also occurred in Asia-Minor, whereas late forms occurred in most of the other countries. Sesames from Palestine region were marked for high weight of seed and oil content. Indehiscent (non-shattering) characters can be observed in some of the promising American varieties from Nebraska. Venezuela-52 variety from Venezuela combines good vigour, drought resistance, single stemmed character with three pods per leaf axil and aphid resistance. Varieties ES21, ES22, Patan 64, UT43, Til No. 1 and T12 possess a very high oil content (more than 58%). All these varieties can be used as parents in breeding programmes for their respective characters. Regarding resistance to Phyllody disease, it has been observed the *sesamum prostratum* a wild relative of *sesamum indicum*, is resistant to this disease. This was used as a parent in the breeding programme at I.A.R.I. and variety NP6, with a high degree of field resistance to phyllody was evolved. NP6 is a good agronomic type also. (Joshi 1961).

It should be observed that the protein content of seed is negatively correlated to the oil content. Hence selection for high protein types might result in low oil content. Some of the improved varieties of *til* are described in Table 3.

2. Sunflower (*Helianthus annuus*): Sunflower is an important oilseed crop in temperate countries like U.S.S.R., Bulgaria, Rumania, Canada etc. where it is raised as a spring crop from April-May to September-October. Sunflower is a rich source of oil (45% to 50%). The oil is considered to be a high quality edible oil because of its non-cholesterol and anti-cholesterol properties.

Exploitation of sunflower as a source of oil is not entirely a new idea in this country. A number of varieties of sunflower were introduced into the country about 15 years back, but the crop did not catch the imagination of research workers due to the low oil content of these varieties (25%) and high susceptibility to virus diseases.

Interest in the crop was revived again when Russian varieties which reportedly had high oil content (50%) were available. In September 1969, four varieties of Russian origin viz. (i) Vniimk 8931-EC68413, (ii) Peredavik-EC68414, (iii) Armavirskij-3497-EC68415 and (iv) Armaverts-EC69874 were obtained from U.S.S.R. These varieties along with an earlier introduction of Canadian origin viz. "Sunrise" were tried by the ICAR during rabi 1969-70 and 13 research centres. The trials were repeated at 31 centres in eleven states during kharif 1970-71. These trials indicated that the crop could not only be cultivated successfully in the country, but has many advantages.

A comparison of groundnut, sesamum and sunflower was made at six locations under the All India Coordinated Research Project for Dryland Agriculture during kharif 1971-72. At all the six locations, sunflower has out yielded groundnut and sesamum. Work carried out at the Dry Farming Research Main Centre, C.A.Z.R.I., Jodhpur showed that sunflower fits into the cropping season of Western Rajasthan very well. The crop can be sown early or late depending upon the onset of monsoon. Sunflower has a definite advantage over *til*, especially when sown late, as *til* fails completely under late sown conditions (Singh *et. al.* 1974).

The crop is sensitive to drought at the capitulum initiation stage. However, under normal sown conditions, as this stage falls in the month of August which happens to receive substantial quantities of rainfall (136 mm) the crop is likely to be least affected by drought. Studies on the performance of different varieties of sunflowers carried out at this Institute showed that variety EC68414 has done better than the rest. The main advantages associated with the crop are as follows:

1. Drought tolerance, particularly its ability to recover from the adverse effect of drought following receipt of showers.
2. Low rate of planting seed per unit area.
3. Photo insensitivity.
4. High oil content (45%-50%).
5. Good quality of oil (72-75% of Linoleic acid).
6. Hybrids on the horizon promise 100% increase in yield.

The problems associated with the crop are given below:

1. Uneven germination and poor stands.
2. Inability to tolerate water logging and lodging.
3. Losses of maturing and planted seed to birds and rats.

4. High frequency of empty seeds in the final harvest.
5. Lack of uniformity particularly after first generation and lack of adequate quantities of quality seed for sowing.

Breeding problems to be attended to

1. The material available at present are mostly of Russian origin. There is need to enrich the collection particularly with those reported to be high in oil content like HS-53 (Rumania), High Oil Franslever GOR-1, GOR-4.

2. The material currently being handled are heterogenous populations rather than varieties. On account of environmental segregation these are characterised by lack of uniformity not generally met within their native habitats. These populations need to be evaluated for genetic variances for yield and its component traits, earliness, hull content, oil content, etc. and rendered uniform for traits like maturity, oil content, and hull thickness. However, homozygosity should not be aimed at.

3. Hybrid programmes involving nuclear or cytoplasmic sterility or self incompatibility should be planned.

4. At present the breeding end point should be a type of synthetic building, rather than evolution of hybrids or pure lines. A recurrent selection programme, in which high general combining genotypes identified by progeny testing (to gather additive genes), are raised in isolation in a panmictic population is desirable.

5. Resistance breeding programme using wild species *H. tuberosus* should be initiated with particular reference to rust, *sclerotinia*, *Alternaria*, *Rhizoctonia*, *Verticillium* and other diseases.

6. The problem of high incidence of unfilled seeds may be approached from the consideration of:

- (i) availability of insect pollinators and temperatures at blooming
- (ii) presence and partial development of axillary flowers
- (iii) correlation with size of heads
- (iv) micro nutrient deficiency
- (v) inbreeding degeneration and
- (vi) self incompatibility.

7. In order to achieve higher yield levels of this crop, it is absolutely necessary to use quality seed for sowing. The harvest of commercial crop should not be used for seeding the crop. In this connection organisation of a sound seed production programme to supply quality seeds to the farmer assumes immense importance.

Oilseed crops for rabi season

In view of the paucity of adequate irrigation resources and absence of rainfall during rabi season, wheat crop which requires 8-10 irrigations, may not be a remunerative *rabi* crop for the arid districts of Rajasthan. Work carried out at the Dry Farming Research Main Centre, C.A.Z.R.I., has shown that *Raya* (*Brassica junica*) and safflower (*Carthamus tinctorius*) crops can yield remunerative yields with 1-2 irrigations. Thus it is necessary to improve the yield potentials of these crops to maximise the output per unit of water.

Raya (*Brassica junicea*): This is one of the remunerative oilseed crops of our country. The oil content of the seed is around 40%. *Raya* has been observed to possess a higher yield potential than *sarson* (*B. campestris*) even under the conditions of limited moisture supply.

1. Under the conditions of Western Rajasthan, where the winter is of short duration, varieties with long period of growth and maturity may not yield well. Hence the varieties for this region should be early maturing.

2. Varieties with a higher member of primary and secondary branches possess larger number of siliquae and as such yield higher.

3. Varieties with low Erucic acid content are to be preferred.

Among different varieties of *raya* tested at the Central Arid Zone Research Institute, Jodhpur, variety KYSR gave the highest yield of 13 q/ha maturing within 90 days. The other promising varieties are BR-40, KB-1, T59, KRS and KB-2 (Table 5).

Safflower (*Carthamus tinctorius*): The crop is predominantly grown in Deccan belt. Safflower is a hardy crop adapted to stress conditions. Traditionally, safflower is grown as a mixed crop and relegated to borders to prevent trespass of cattle and seldom as a pure crop. As a result of selection pressure, both human and natural, for competitive ability under mixed stands, the available varieties are characterised by potentially low yields, inefficient plant architecture. The pericarp of the seed (hull) which has no food value constitutes nearly 50% of the whole seed by weight and is responsible for low oil per unit weight. In this crop substantial variability is available for characters like total yield per plant, number of capsules per plant, seed number per capsules, capsules weight and seed weight. Developmental characteristics like days to first flowering, blooming interval, maturity, hull and oil content exhibit limited variation in the material. That indigenous material is characterised by high individual performance as reflected by high capsule number, high seed weight, capsule weight, hull content and hence low oil content, unlike the exotics which are

mostly shy bearers with low seed weight, low hull content and high oil content, with identical maturity periods.

Yield was found to be inherited independent of hull content, seed weight and oil content reflecting the possibility of breeding for high yield and high oil content without detrimentally affecting seed weight. The relationship between oil content in the seed and hull content was found to be highly negative while hundred seed weight is positively associated with hull content and negatively correlated with oil content. It would appear that hull content influences both seed size and oil content (Rao 1974). Experiments carried out at the C.A.Z.R.I., indicated that safflower crop could give remunerative yields levels (around 5-6 q/ha) with one or two irrigations in *rabi* seasons. The data presented in Table 5 indicate the performance of a wide range of varieties of safflower at Jodhpur with two irrigations including a pre-sowing irrigation in *rabi* 1973-74.

In addition to regular and conventional breeding approaches oriented towards evolving high yielding varieties of pulse and oilseed crops, it is necessary to maximise the production of these crops in arid areas, by evolving (1) suitable plant types suited for inter-cropping in perennial forage grasses which are important in arid areas, and (2) complementary varietal blends, which could yield higher than the individual component varieties, as such types of blends would have an advantage over the pure varieties under conditions of uncertain rainfall distribution.

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Table 1. Sink potential and its realization in wheat and cowpeas. (UNIT AREA BASIS)

	WHEAT	COWPEAS
Population	500 tillers/m ²	16 plants/m ²
Sink	50 florets/tiller 50 ovules/tiller 25000 ovules/m ²	75 flowers/plant 750 ovules/plant 12000 ovules/m ²
Sink potential	1 kg grain/m ² (40gm/1000 grains) 10 tons/ha	1.2 kg grains/m ² (100 gm/1000 grains) 21 tons/ha
Realization	7.5 tons/ha	2 tons/ha
Percent realization of sink potential	75	16.6

Table 2. Induced variability for pod number in moong

No./treatment	Description of the mutant	Pod number/ plant	No. of seeds per pod	Grain yield per plant
EMS 0.2%	G65 (Parent)	12.2	9.5	5.60
	1 Profuse bearing mutant—1	25.0	12.0	11.25
	2 " " —2	29.0	13.1	11.80
	— RS4 (Parent)	13.5	8.5	8.05
	5 Early maturing mutant—1	25.0	9.2	11.20
	7 Dwarf mutant—2	32.0	14.2	12.50
	8 Early maturing mutant—2	34.0	9.4	15.00
	10 Early maturing mutant—4	34.0	12.4	15.32
EMS 0.3%	12 Early maturing and profuse bearing mutant	48.0	10.8	21.33
	14 Dwarf mutant—3	28.0	10.8	10.10
	16 Dwarf mutant—5	23.0	12.9	12.5
	Madira (Parent)	12.5	9.4	5.40
EMS 0.2%	22 Late maturing mutant with good seed colour	42.0	11.2	21.30

Table 3. Varieties of pulse and oilseed crops for Drylands during kharif season

<i>Crop and variety</i>	<i>Salient features</i>	<i>Yield (q/ha)</i>
<i>Moong</i>		
SB	Semi compact, matures in 60 days, profuse bearing	10—12
288—8	Spreading matures in 70—75 days	9—10
RS4	Spreading, matures in 70—75 days	8—10
S12	Semi spreading, matures in 70—75 days, profuse bearing	10—12
<i>Moth</i>		
PLMO—2	Spreading, matures in 85—90 days, susceptible to mosaic virus	3—5
PLMO—1	Spreading, matures in 85—90 days, susceptible to mosaic virus	3—5
<i>Cowpeas</i>		
FS68	Compact and erect, matures in 65—70 days, profuse bearing pod splitting (shattering) after maturity	6—8
C 20	Spreading, matures in 80—90 days	6—8
C 13	Spreading, matures in 80—90 days	6—8
JC 10	Spreading, matures in 80—90 days	6—8
K 11	Compact, matures in 70—75 days	6—8
<i>Guar</i>		
Durgapura	Branched, matures in 100—115 days	4—7
Saffed		
FS 277	un Branched, matures in 90—100 days	4—7
<i>Til</i>		
T 13	Branched, white seeded matures in 80—85 days	3—6
B—45	Single stemmed, brownish seed, matures in 75—80 days	4—8
N—32	Mostly single stemmed, white seed, matures in 80—85 days	4—8
Var 4-2	Branched, white seeded, matures in 80—85 days	4—8
<i>Castor</i>		
Aruna	Dwarf compact, matures in 90—95 days	5—6
GH3	Dwarf compact, matures in 95—100 days	5—7
<i>Sunflower</i>		
EC 68414	Matures in 75—80 days	7—8
EC 69874	Matures in 65—70 days	7—8
Bulgarian	Matures in 80—85 days	7—9

Table 4. Performance of Raya varieties

Variety	Yield (q/ha)	Days to flowering	Days to maturity
KYSR	13.1	34	98
BR 40	10.0	37	101
KB—1	9.8	38	112
T 59	9.2	43	101
KRS	9.1	39	101
KB—2	8.1	39	117
T 5909	7.9	43	117
P 16/21	7.3	40	117
T 16	6.0	47	120
630—32	6.0	47	123
SEm ±	0.70		
CD 5%	2.08		

Table 5. Performance of safflower varieties

Variety	Yield (q/ha)	Days to flowering	Days to maturity
7—13.3	7.0	80	137
A—300	5.6	83	139
129—3	5.6	81	140
N—7	5.5	75	130
N62—8	5.3	76	133
Gila	4.2	79	137
U3—10	3.5	82	143
SEm ±	0.54		
CD 5%	—		

GENETICAL IMPROVEMENT POSSIBILITIES FOR CEREAL CROPS

M. B. L. Saxena

INTRODUCTION

Millets which form the staple food of millions in India comprise *Jowar* (greater millet), *Bajra* (pearl millet) and minor millets. *Bajra*, *ragi* and other minor millets are mainly grown under rainfed condition all over India, particularly in areas of severe drought, so are traditionally arid crops. (Anonymous, 1970). Amongst the millets *Bajra* occupies the chief position in western Rajasthan. More than 60 per cent of cultivated area in Kharif is put under this millet either as a single or mixed crops. (Misra, *et. al.* 1966)

The importance of *Bajra* in comparison with other cereals under rainfed condition can be understood by the Table 1. The perusal of table shows that even with no nitrogen, bajra yielded four and eight times more than Maize and *Jowar* respectively. As such the small farmers are benefitted more by growing *Bajra* even without fertilizer and also with low dose of nitrogen (20 kg/ha) than other cereals in drought areas. (Anonymous, 1977). Nevertheless, *Bajra* has unique advantage of being more hardy crop than other cereals and can grow in all climate except very cold and very humid climate. However, it grows best in warm dry climate with adequate moisture. It can withstand atmospheric drought and soil moisture stress to very great extent. The sandy desert soils of Rajasthan are capable of producing very good *bajra* crop provided soil and moisture conservation practices are followed (Misra, D. K. 1964). Besides, *bajra* seeds are also rich in sulphur containing amino acid which confers wide adaptation and drought resistance to the plant (Anonymous 1970). With these, its water requirement is also low. Therefore, these special features have mostly helped *bajra* crop to adapt to arid conditions.

In India, *bajra* is cultivated over about 11.2 million hectare and out of it more than 50% area alone is accounted from arid areas of Rajasthan and Gujarat States which contribute 82% of arid region of India. Though more area is covered under this crop in arid zone but the yield and production levels are quite low. The main reasons for poor yields are unpredictable climate and cultivation of unsuitable

* Breeder (Millets) Central Arid Zone Research Institute, Jodhpur.

and low yielding varieties. As such attempts to achieve higher grain yield in *Bajra* have to be made.

To improve the yield and productivity of *bajra* crop in India, a number of open pollinated varieties were developed and released for general cultivation in respective States. Breeding of new varieties is a continuous process where varieties developed earlier have to be replaced by still better varieties for future. Therefore, attempts to achieve higher grain yield in *Bajra* were made, which met considerable success when a few hybrids namely HB-1, HB-2, HB-3 and HB-4 were developed. Out of these, HB-2 and HB-3 were specially recommended for areas with limited rainfall and arid regions such as Gujarat, Mysore and western Rajasthan of India. HB-4 was recommended for regions of adequate rainfall. (Murty, B. R. 1969 and Utkhede, R. S. 1972). The suitability of HB-3 for arid region can be adjudged by the Table No. 2 and 3 where it out-yielded others under subnormal and normal condition of 1972 and 1973. Hetrozygosity coupled with short duration enables hybrid *Bajra* HB-3 to perform relatively better than the local varieties during normal as well as drought years (Anonymous, 1970).

Research programme and work done in arid zone

Presently hybrid *Bajra* HB-3 is a recommended variety for arid areas. This hybrid is high yielding and early maturing but highly susceptible to diseases. Consequently the yields are reduced to considerable extent. On the other hand local varieties currently cultivated in arid areas are only able to survive in atmospheric and soil drought condition but do not have the yield potential and also lack plant architecture capable of responding to inputs. Therefore, breeding programme to develop better varieties of *bajra* possessing drought tolerance, early maturity, high yield and disease resistance for arid region was taken up at Central Arid Zone Research Institute, Jodhpur. It is mainly concentrated on:

1. Identification and intensive breeding for early maturing, drought tolerant and disease resistant inbreds.
2. Development of new disease resistant and high yielding hybrids better than the existing ones.
3. Improvement of local variety.
4. Development of composites in view of their advantage over hybrids in respect of seed production and disease tolerance.

Varieties suitable for different purposes and adapted to different conditions can be developed by selecting them from a diverse genetic

source and with different breeding technique can be tailored for specific requirement. To meet such requirement, the breeding programme on Bajra crop was initiated with a collection of about two thousand genetic stocks which were evaluated and classified during kharif 1972 under limited moisture supply and kharif 1973 under adequate rainfall. Identification and selection of superior genotypes was done. The material selected in 1972 for drought tolerance was again screened for yield and disease resistance under favourable conditions of 1973. As such the selections of the Centre have been combined with high degree of drought and disease tolerance beside high yield. Concentrated and consecutive selection and selfing of the better types have been carried out for three years. Consequently, some inbreds with permutation and combination of characters such as early maturity, drought and disease tolerance, dwarfness, better ear character and high yield have been developed, which have now reached the third selfed generation and are leading towards homozygosity.

These promising selections and inbreds were categorised into different groups of maturity and height. Some of them have been tested against checks like HB-3, J-41 and RSK in replicated row trials during 1974. Two early maturing selections, namely GP3-4 and YT3-10 (Table 4) gave higher yield than checks and two promising selections, viz. ET-3-6 and CAZRI-1 also gave higher yield (Table 5). These were also found free from diseases. Among inbreds, dwarf awned and from promising entries L4-4, yielded higher than checks (Table 6 and 7). The selection, selfing and testing of inbred lines are in progress and better ones will be utilized in developing disease resistant and high yielding hybrids for the arid zone shortly.

To achieve a quick high grain production of Bajra in arid zone, till new hybrids or composites are developed, a short term programme of improvement of local types was initiated in 1972 at Central Arid Zone Research Institute, Jodhpur. As such a large collection of local varieties of Bajra was made and evaluated during kharif 1972. Among locals two varieties, Acc No. 476 and 577 from village Bhawad and Akhtali gave higher yields than checks RSK and RSJ. Besides being high grain yielder these two had early maturity and were also found drought tolerant. Before varieties can be selected for improvement, it is desirable to judge their performance for two-three seasons. Therefore, the local collection was again evaluated during kharif 1973 for disease susceptibility and yield potential. This time variety Akhtali local gave also the highest grain yield of the order 25 q/ha which was an increase of 10% over the checks. The other local variety of village Bhawad which gave high yield during 1972 produced significantly low yield than Akhtali local. The main reason of its low yield was

that it suffered badly from diseases in comparison to Akhtali local. Since, Akhtali local produced higher yield over two seasons constantly, therefore, this variety was selected for the improvement. Mass selection of superior plants possessing disease resistance and good agronomic character was carried out in this variety. The desirable selected plants were bulked. The bulk progeny was sown during kharif 1974 for further testing and to carry out selection of desirable plants. The bulk progeny of selected plants out yielded the checks by 12.5% increase. The process of recurrent selection will be repeated for a few more years, till the frequency of desirable types reaches to maximum and variety becomes homogeneous.

Although the composites do not yield as high as hybrids in Bajra on account of pollination mechanism yet it will be worthwhile to develop composites for this region, for following reasons: (a) Composite variety can permit fine adjustment to varied impact of environmental conditions by virtue of its wide germplasm base of greater variability, (b) disease free composites can be produced by marking an aggregation of different lines, resistant to diseases and (c) once a satisfactory high yielding composite is produced there will be no problem of producing seeds every year like that of hybrids and farmers will be able to produce their own seed. Considering all this the work on development of composites for arid areas has already been initiated and is being taken up with priority at this Institute. The selected inbreds have been categorised into three groups of maturity and height. The general combining ability of these inbreds will be tested in near future. The good combiners will be used to form composites synthetics of different categories.

Breeding work done for the improvement of minor millets, at C.A.Z.R.I. Jodhpur

Rajasthan covers about sixty thousand hectares of land under minor millet crops and produces 23.5 thousand tonnes annually. They are mainly grown in the southern districts of Rajasthan, namely Banswara, Dungarpur, Sirohi and Udaipur. A very little area is covered under these crops in the arid districts of Rajasthan though minor millets are highly drought resistant, capable to thrive well in areas of low rainfall and poor soils. A study of data presented in table 8 shows that the area and production of these crops have almost stabilized and that the influence of weather variation is more marked on bajra than on minor millets. And that the yield of minor millets on per unit area basis was more than Bajra in under normal as well subnormal years. The cost of production of these millets is low as to other cereals (Table 9) there-

fore they can be adopted by the poor farmers of this region easily. They are also capable of producing good emergency green fodder within a short period of 40-45 days. Beside these, the keeping qualities of their seed are good enough due to the thick seed coat, hence grain can be stored for longer period as a famine reserve (Guruswamy Raja, V. D. 1973). All these features are in favour of their cultivation in arid tract. Therefore, breeding work on minor millet was taken up at Central Arid Zone Research Institute, Jodhpur with the objectives of (i) Assessment of minor millets for their adaptation and yield potential in arid tract and (ii) selection, testing and release of high yielding strains of minor millets for western Rajasthan.

During kharif, 1972 a collection of minor millets which included *Panicum miliare* (Little millet), *Panicum miliaceum* (Proso millet), *Setaria italica* (Foxtail millet), *Eleusine coracana* (Finger millet) and *Paspalum scrobiculatum* (Kodo millet) was made and evaluated. The study revealed that among minor millets only two crops, i.e. *Setaria italica* and *Panicum miliaceum* can be grown successfully and are quite suitable for the region. Others do not mature during the crop season. Therefore, breeding work to develop suitable strains of above two crops was taken up, which is reported in the following paragraphs.

Setaria italica: This is called Kangni in local language. Number of early maturing and high yielding selections were screened out. The high yielding selections were evaluated against checks during Kharif, 1973. The yield data are presented in table 10. Selections Se-21, Se-22 and Se-23 gave higher grain yield than checks which was of order 11.41, 11.79 and 10.83 q/ha and were also earlier in maturity than others. However, these three selections were further tested in Kharif 1974 with the improved entries of All India Coordinated trial. The result presented in Table, 11 reveal that three selections viz. Se-21, Se-22, and Se-23 of this Centre flowered early and selection Se-22 was significantly earlier than check CO-3. Among them selections Se-21 and 22 also gave higher yield than check. An early maturing strain of *Setaria italica* with recorded maturity of 50-55 days has been developed. No such strain of *Setaria italica* is on record which matures in such a short duration. Beside the early maturity it has high yielding ability of 8-9 q/ha. (70 per cent higher than that of local variety). The short maturity period of this strain will be quite useful in multiple cropping pattern of arid areas. Strains with early maturity and low yield and some with late maturity but high yield have been developed. So, further breeding programme for this crop will be to have combination of earliness and high yield in a variety.

Panicum miliaceum: This minor millet is locally known as Chena. Seven early maturing and a few high yielding pure strains were selected out during 1972 and 1973. The early selections mature in a recorded period of 40-45 days and have yield potential of 2.1-3.2 q/ha, whereas improved variety CO-1 matures late i.e. 60-65 days. There is no record of such early maturing strain of *Panicum miliaceum*. Therefore, with the availability of these early strains two crops can be grown in a season in place of a single long duration crop and at least one crop can be ensured even in climatically bad year. Among high yielding strains developed two strains namely PM-21 and PM-31 were tested with the other improved varieties of All India Coordinated trial, at Central Arid Zone Research Institute, Jodhpur to judge their performance during Kharif, 1974. The results presented in table 12 reveal that these two strains i.e. PM-21 and PM-31 matured significantly earlier than check CO-1 and even then they although these strains did not flower earlier, matured earliest. Beside early maturity these strains also gave significantly higher grain yield than check CO-1, which was of order 12.2 and 13.9 q/ha for PM-21 and PM-31 respectively. Uneven maturity of ears and shedding of grains on delayed harvesting are some of the problems now being faced in this crop. Therefore, efforts to solve them through suitable breeding programme have to be taken up shortly.

The genetical improvement work on some of the important cereal crops of arid zone has already made headway and the possibilities of achieving success are bright.

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Table 1. Yield of kharif cereals grown under rainfed condition (yield q/ha).

Dose of nutrient	Maize (Gange-5)	Jowar (CHS-1)	Bajra (HB-1)
Control	4.83	2.23	19.08
20 Kg N/ha	17.70	4.07	29.86
40 Kg N/ha	28.34	3.26	30.22

Ref : A new technology for dry land farming.
I.C.A.R., New Delhi, 1970.

Table 2. Performance of new hybrids under limited moisture supply during kharif 1972 at C.A.Z.R.I., Jodhpur.

S. No.	Variety No.	Days to 50% flowering.	grain yield q/ha	Fodder yield q/ha
1.	HB-1	60	16.73	66.00
2.	HB-2	58	14.57	60.50
3.	HB-3	57	17.51	93.50
4.	HB-4	64	16.17	66.00
5.	HB-5	62	16.92	93.50
6.	Hyb J934	61	12.95	82.50
7.	Hyb J-104	57	15.75	71.50
8.	Babapuri	72	6.11	77.00
9.	R S K	62	11.85	110.00
10.	R S J	61	10.59	99.00

Table 3. Performance of hybrids and composites of Coordinated Bajra Trial No.1 at C.A.Z.R.I., Jodhpur during Kharif 1973

S. No.	Variety No.	Days to 50% flowering.	Grain yield q/ha	Fodder yield q/ha
1.	23A x J87	44.3	24.0	70.5
2.	23A x J108	39.5	27.3	69.4
3.	PHB-11	48.3	22.9	74.0
4.	PHB-27	47.8	27.1	77.6
5.	Vijay composit	51.8	22.6	71.5
6.	Lam composit	49.0	22.2	74.4
7.	23A x 16	41.5	27.5	69.1
8.	23A c D-1369	40.8	21.9	75.0
9.	23A x 221	43.0	25.6	75.7
10.	23A x D111	52.8	22.3	71.2
11.	H 269	47.8	26.6	79.2
12.	H 323	41.5	26.1	82.6
13.	HB-3	38.0	27.9	72.9
14.	HB-5	49.0	27.9	81.9
SEm $\pm$		.037	.248	—
C.D. 0.05		2.596	.050	—

—Not significant.

Table 4. Grain yield performance of early selections and improved varieties of *Bajra* under limited moisture supply, Kharif 1974, at C.A.Z.R.I., Jodhpur.

S. No.	Varieties	Source	Average yield in gm/plot.
1.	GP3-7	1879 (CAZRI)	50.00
2.	GP3-3	1838 "	41.66
3.	GP3-26	1831 "	136.66
4.	GP3-21	1987 "	53.33
5.	GP3-6	1875 "	61.66
6.	GP3-25	J-104 "	133.33
7.	GP3-27	J-1472 "	111.66
8.	GP3-4	1842 "	166.66
9.	GP3-5	1864 "	143.33
10.	GP3-24	1999 "	68.33
11.	GP3-20	1957 "	93.33
12.	GP3-23	2001 "	50.00
13.	YT3-1	1892 "	91.66
14.	YT3-10	1981 "	146.66
15.	YT3-2	1879 "	56.66
16.	J41- (Check)	Jamnagar	118.33
17.	YT3-12	1999 "	95.00
18.	HB-3 (Check)	Jamnagar	113.33

Significant.

SEm $\pm$	35.52
C.D at 5%	65.69

Table 5. Assessment of the selections with improved varieties of *Bajra* during Kharif, 1974 at C.A.Z.R.I., Jodhpur

S.No.	Variety No.	Source	Average yield in gms.
1.	ES-1—1	S-72 (CAZRI)	235.00
2.	ES-1-2	S-83 "	233.33
3.	ES-1-3	S21/21 "	190.86
4.	EAS-1-4	S174 "	286.76
5.	EAD-1-1	S 81 "	228.33
6.	EAD-1-2	S 165 "	213.76
7.	ES-2-1	Ac 773 "	201.76
8.	ET-3-2	Ac 1942 "	208.33
9.	ET-3-6	Ac 1916 "	343.33
10.	ET-3-7	Ac 1921 "	225.00
11.	CAZRI-1	Jodhpur	335.00
12.	J-41 (check)	Jamagar	328.33
13.	HB-3 (Check)	Jamnagar	261.66

Not significant.

SEm $\pm$	72.78

Table 6. Comparative performance of dwarf inbreds and improved varieties of *Bajra* during 1974 Kharif at C.A.Z.R.I Jodhpur

S.No.	Variety No.	Source	Average yield in gms.
1.	VDT-3-4	Ac 1981 (CAZRI)	210-00
2.	VDT-3-5	Ac 1982 "	210-00
3.	VDT-3-7	Ac 1984 "	185-00
4.	VDT-3-9	Ac 1986 "	179-66
5.	VDT-3-10	Ac 1988 "	190-00
6.	DT-3-1	Ac 1830 "	180-76
7.	DT-3-5	Ac 1989 "	194-33
8.	AD-1-1	S-81 "	208-33
9.	AD-1-2	S-165 "	236-66
10.	LD-3-4	Ac 1981 "	245-00
11.	LD-3-6	Ac 1984 "	178-00
12.	LD-3-10	Ac 1990 "	310-00
13.	Awned	S-143 "	316-66
14.	J-41 (check)	Jamnagar	218-33
15.	HB-3 (check)	Jamnagar	311-66

Not significant.

SEm $\pm$

65-30

Table 7. Yield trial of promising entries of *Bajra* under sufficiently limited moisture conditions, Kharif, 1974, at C.A.Z.R.I., Jodhpur.

S. No.	Entry No.	Source	Average yield in gms.
1.	Ac 276	L7-10 (CAZRI)	25-00
2.	Ac 1921	L4-5 "	28-33
3.	Ac 25	L7-3 "	31-66
4.	Ac 577	L7-3 "	25-66
5.	Ac 1895	L4-3 "	54-33
6.	Ac 1144	L7-12 "	25-00
7.	Ac 1982	L4-20 "	23-33
8.	Ac 1987	L4-25 "	45-00
9.	Ac 1893	L4-21 "	25-00
10.	Ac 605	L7-8 "	15-00
11.	Ac 1916	L4-4 "	138-33
12.	Ac 1922	L4-6 "	59-33
13.	Ac 1986	L4-24 "	16-66
14.	Ac 1551	L4-13 "	41-66
15.	Ac 463	L7-1 "	86-66
16.	Ac 429	L7-6 "	63-66
17.	Ac 1942	L4-11 "	50-00
18.	Ac 953	L7-11 "	31-66
19.	Ac 1892	L4-1 "	86-66
20.	Ac 1943	L4-12 "	63-33
21.	Ac 1928	L4-9 "	48-33
22.	Ac 1926	L4-7 "	42-33
23.	Ac 1927	L4-8 "	46-66
24.	Ac 1981	L4-19 "	39-00
25.	Ac 1950	L4-13 "	28-33
26.	Ac 1890	L4-2 "	87-66
27.	Ac 25	L7-3 "	27-00
28.	Ac 1985	L4-23 "	27-66
29.	Ac 1988	L4-26 "	44-00
30.	Ac 20	L7-2 "	33-33
31.	HB-3 (check)	Jamnagar	71-66
32.	RSK (check)	Jaipur	43-33
33.	J-41 (heck)	Jamnagar	58-66

Significant.

SEm $\pm$
CD 5%

18-57
36-39

Table 8. Area, Production and average yield estimates of *Bajra* and minor millets crops—in Rajasthan during 1963-73

Year	C R O P S					
	Bajra			Minor millet		
	Area	Production	Yield	Area	Production	Yield
*1963	4323	821	1.90	79	31	3.92
1964	4853	1271	2.62	67	14	4.22
*1965	4880	940	1.93	83	35	2.43
*1966	5115	1229	2.40	74	18	NA.
1967	4891	1423	2.67	81	33	4.12
*1968	4557	499	0.98	64	6	1.04
*1969	4329	801	1.81	76	18	2.41
1970	5135	2676	5.21	71	33	4.79
*1971	5100	1363	2.67	67	26	3.91
*1972	5234	864	1.65	57	6	1.19

*Drought year.

Ref: Agriculture statistics and plan progress (1971-72 and 1972-73) Directorate of Agriculture Rajasthan.

Table 9. Economics of per day production of various cereals.

Crop	Expenditure per day (Rupees)	Production per day (Kg.)	Duration (days)	Cost of production per Kg. (Paise/day)
Paddy	10/-	25	120	40
Sorghum	5/-	20	90	25
Bajra	5/-	20	90	25
Ragi	5/-	20	90	25
Kangni	2.50	12	75	20
Chena	1.60	10	60	16

Ref: Data based on the inaugural address delivered by Dr. G. Rangaswamy, Vice Chancellor, Tamil Nadu Agricultural University, Coimbatore at I.C.A.R., Annual All India Sorghum and millet Workshop, May, 1973.

Table 10. Grain yield trial of 22 varieties of *Setaria italica* at C.A.Z.R.I., Jodhpur, during 1973.

S.No.	Name of variety	Source	Yield q/ha.
1.	Local		3.09
2.	Se 2	C.A.Z.R.I.	5.70
3.	Se 3	"	4.41
4.	Se 4	"	6.35
5.	Se 5	"	6.09
6.	Se 6	"	8.13
7.	Se 7	"	4.35
8.	Se 8	"	8.48
9.	Se 10	"	8.36
10.	Se 11	"	4.70
11.	Se 12	"	5.84
12.	Se 13	"	5.07
13.	Se 14	"	10.50
14.	Se 16	"	5.42
15.	Se 17	"	7.29
16.	Se 21	"	11.41
17.	Se 22	"	11.79
18.	Se 23	"	10.83
19.	Se 24	"	9.01
20.	Se 25	"	10.37
21.	Se 26	"	6.65
22.	Check CO-3	Coimbatore	10.15

SEm $\pm$
CD 5%

0.512
1.674

Table 11. Performance of *Setaria italica* varieties of Jodhpur Centre and the entries of all India Coordinated trial, at C.A.Z.R.I., Jodhpur-Kharif, 1974.

S.No.	Entries	Source	Character			Yield q/ha
			Days to 50% flowering	Days to maturity (average)	Average yield in grams.	
1.	ISc 119	Coordinated trial No. IX.	49-25	86-25	57-45	3-19
2.	ISc 201		51-00	90-50	118-40	6-58
3.	ISc 279	"	53-75	88-75	73-02	4-57
4.	ISc 358	"	50-50	85-50	29-45	1-64
5.	ISc 480	"	49-25	84-25	26-62	1-48
6.	ISc 700	"	47-75	81-50	57-37	3-18
7.	ISc 701	"	54-75	86-50	72-12	4-01
8.	ISc 702	"	55-50	87-50	44-22	2-46
9.	ISc 703	"	62-00	91-75	55-47	3-08
10.	ISc 704	"	58-25	86-25	44-52	2-47
11.	ISc 709	"	61-50	90-25	54-65	3-07
12.	JNSE 7A	"	58-00	87-00	65-22	3-62
13.	JNSE 9A	"	58-25	88-50	53-32	2-96
14.	JNSE 26	"	62-50	92-25	68-75	3-82
15.	JNSE 55	"	54-50	84-25	54-90	3-05
16.	JNSE 56	"	60-25	85-75	56-77	3-15
17.	SR-102	"	60-75	86-25	26-80	1-49
18.	SR-118	"	47-75	81-00	80-00	4-49
19.	SR-179	"	49-25	79-75	36-42	2-02
20.	Arjuna	"	48-00	82-50	140-55	7-81
21.	SI 5307	"	53-00	86-25	110-80	6-16
22.	SI 76/4	"	51-75	86-75	90-30	5-02
23.	SI 80/2	"	50-00	84-50	50-72	2-82
24.	CO-3	(Check)	49-00	79-75	66-20	3-68
25.	AZ Se 21	CAZRI	47-25	80-25	98-07	5-45
26.	AZ Se 22	CAZRI	45-25	79-00	90-60	5-03
27.	AZ Se 23	CAZRI	47-25	81-00	47-22	2-62
28.	Tenai	Coimbatore	49-50	82-50	34-92	1-94
SBm+			1-44	0-87	17-93	
C.D. 5%			2-88	1-71	35-14	

Table 12. Performance of high yielding strains of *Panicum miliaceum* at C.A.Z.R.I., Jodhpur during the Kharif, 1974.

S.No.	Entries	Sources	Characters			Yield (q/ha)
			Dzys to 50% flowering (Average)	Days to maturity (Average)	Average yield (gms.)	
1.	PV-17	Coordinated Trial No. XI	50-8	81-3	69-15	3-84
2.	PV-27		50-8	82-3	66-50	3-69
3.	PV-38	"	53-0	80-3	77-47	4-30
4.	PV-196	"	49-3	80-0	30-32	1-68
5.	PV-1462	"	48-3	80-0	106-10	5-89
6.	PV-1685	"	45-5	80-0	63-60	3-53
7.	MS-4806/2	"	47-5	78-8	61-05	3-39
8.	MS-4872	"	46-0	76-5	208-37	11-57
9.	MS-4914	"	50-5	78-5	131-02	7-27
10.	CO-1	Check	51-3	81-5	87-50	4-86
11.	AZ PM-21	C.A.Z.R.I.	45-8	76-3	219-77	12-20
12.	AZ PM-31	C.A.Z.R.I.	46-0	77-0	251-62	13-97
SEm+			0-53	0-49	32-76	
C.D. 5%			1-08	0-99	66-83	

PASTURE IMPROVEMENT, SELECTION OF HIGH YIELDING GRASSES, THEIR SEEDING, DEVELOPMENT AND UTILISATION

R. B. Das*

INTRODUCTION

The important general considerations and principles of arid zone pasture that would be discussed here will be more understandable if we first define our concept of "pasture" as differentiated from "Rangeland". The term "pasture" as is used here refers to a fenced, relatively small acreage of planted, domesticated, grazeable grass or other forage crop which is intensively managed. Such management involves close control of grazing animals and frequent use of cultural treatments as tillage, fertilization, mowing, cutting, weed control and insect control. The term "pasture" as defined here also includes annual or perennial species growing on dryland or irrigated areas.

Intensive pasture production and management is done with the aim that, net profits from a farm in arid zone or ranch will be greater as a result of growing "pasture" than if the acreage were extensively utilised or managed even with best improved native vegetation which may be defined as "rangeland".

The purpose of differentiating between "pasture" and "range" is that "pasture concept" and "rangeland concept" are quite different, and a clear understanding of these differences is essential from the outset. A pasture operation involves periodic cultural re-establishment, intensive annual use of considerable labour, machinery and material, where as rangelands are established once and thereafter it is more or less a capital enterprise.

Drought causing unstable Ecological balance

Periodic drought, a principal factor causing variation in ecological balance not only produces diminishing effect on abundance of plant population, a reduction in general cover and a decrease in vigour of the plants but also significantly decreases in range primary production. Therefore, the livestock industry which is based on consumption of primary produce over the desert range pastures must build flexibility into operation in order to survive the effects of high variability in forage production from year to year. Further, the effect of drought

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upon primary production in desert ranges are frequently confounded with past grazing use by livestock, insect and rodent populations and in some cases, sand drift from adjacent cultivated farm lands or deteriorated rangelands.

The U.S. Weather Bureau has defined drought (1937) as a period when rainfall is but 30 per cent of average of 21 days or longer. Also, it is generally seen that drought conditions along with alternate periods of high precipitation appear rather regularly over time throughout the arid and semi-arid regions of the world causing significant fluctuations in primary and secondary productivity of the land under a given eco-system.

In western Rajasthan Desert, the precipitation data show that monthly and yearly moisture receipts vary widely from their means, and extended periods below normal are common so as to say as much as nearly 40 per cent. As a consequence, primary production (Forage yield) from arid zone range pastures varies from the best to the poorest years by as much as 4 times, reflecting directly and indirectly to a variation in secondary production (livestock production) between wet and dry years.

The ecological balance precariously hanging in desert eco-system is disturbed significantly influenced by drought causing variability in primary and secondary production. Thus, we see that drought is by far the most serious physical hazard for maintaining the ecological balance or so to say an eventual synchronization between primary and secondary productivity which range managers find it difficult to foresee for adjusting range resources utilization pattern by introducing flexibility in stock numbers.

Modern management decisions with respect to maintaining a balance between primary and the consumer population must recognize the fluctuations in herbage production resulting from varying climatic conditions in the eco-system.

Research has so far failed to present methods of predicting primary production from existing or pre-existing soil and climatic factors in a given ecosystem. However, with the aid of high speed computers and expert analysis it should not be too long in the future before, herbage yield in many areas can be determined with a high degree of accuracy by means of past weather features, climatic patterns, soil moisture along with other parameters related to plant growth which is responsible for primary production and hence, for secondary production as well. This may involve form of precipitation, distribution over certain periods, soil moisture to varying depth as the beginning of the growing season, atmospheric temperatures and evapo-transpiration-precipitation ratio responsible for ecological balance.

Necessity of Pasture Improvement and Development in Arid Zone

Approximately 5.56 thousand square kilometers of land in India is under arid and semi-arid conditions spread over Rajasthan, Gujarat, Haryana and Madhya Pradesh. The animal population in the region is 21.5 million of which, cattle, buffaloes, sheep, goats, camel and others comprise of 7.40, 6.55, 4.27, 0.65 and 0.27 millions respectively. In other words we may say 10.58 million adult animal units are in production in the regions.

Considering the fact of feed and fodder requirements of the above animal population for maintenance only 27.2 million tonnes of dry forage (7 kilo per adult animal unit per day) would be needed. However, available forage from existing sources including cultivable waste, fallow fields, grazing lands and the crop residue etc. is estimated to be 17.3 million tonnes of which crop residue forms nearly 60 per cent portion. Thus, there is an overall shortage of 36.2 per cent of feed in the region. Calculating on the basis of a productive nutritious ration the requirements fall short of availability and would be nearing 80 per cent. It would be sufficiently clear from the above that, there exists a significant gap between present feed resources and animal population in the arid zone resulting in low productivity directly influenced by insufficient and low nutrient feed.

It is an accepted fact that the main economic stay of the desert people is from livestock production seconded by agriculture practised on small land holdings where cropping of cereals is unpredictable under dry-farming on a land which receives between 100 to 300 mm of erratic and highly unreliable rainfall.

Again, continued improper land use has completely destroyed the original vegetation cover and majority of grazing lands are put under plough for cropping which is practised on all types of and classes of lands including shifting sand and dune slopes having as much as 30 to 40 per cent dip. In addition, heavy and continued grazing by all types and kinds of animals have caused and are causing wide spread soil erosion, dune formation, loss of soil fertility bringing in its trail misery and poverty to the already poor people who continually struggle to recover from one famine and loss of valuable livestock under prolonged drought to enter another famine of the same devastating nature, and thus, creating a vicious circle. This circle could be broken only by an effective programme of improvement and the development of pastures as explained above, utilising the land and water resources of the desert ecosystem.

Criterion for selection of high yielding pasture strains varieties

Comparative trials with numerous collection of strains of pasture species of grasses and legumes (approximately 1088 varieties) have been conducted during last 18 years by the Agrostology section of Central Arid Zone Research Institute at Jodhpur and Pali centres. These trials indicate that following species can usually be considered for improvement of pastures in Indian arid zone. The variety names listed are of proven value at Jodhpur on sandy soils, however, other varieties available at the Institute which may be equally productive at the other locations.

*Perennial species**Rainfed conditions (dryland).*

- (a) *Lasiurus indicus* (CAZRI 353, CAZRI 352, CAZRI 321, CAZRI 324, CAZRI 351).
- (b) *Cenchrus ciliaris* (CAZRI 277, CAZRI 392, CAZRI 214, CAZRI 362, CAZRI 326).
- (c) *C. setigerus* (CAZRI 417, CAZRI 418, CAZRI 1, CAZRI 411, CAZRI 413).
- (d) *Panicum antidotale* (CAZRI 331, CAZRI 333, CAZRI 379, CAZRI 347, CAZRI 332).
- (3) *Dolichos lablab* var. *lignosus*

On controlled irrigation sites

- (a) *Lasiurus indicus* (CAZRI 339, CAZRI 318, CAZRI 351, CAZRI 565, CAZRI 314).
- (b) *Cenchrus ciliaris* (CAZRI 587, CAZRI 392, CAZRI 277, CAZRI 505, CAZRI 75).
- (c) *C. setigerus* (CAZRI 296, CAZRI 76, CAZRI 1, CAZRI 418, CAZRI 175).
- (d) *P. antidotale* (CAZRI 638, CAZRI 621, CAZRI 626, CAZRI 237, CAZRI 330).
- (e) *Panicum coloratum* (Var. Meckerikeri-CAZRI 96).
- (f) *Panicum maximum* (Var. Giant).
- (g) *Chloris gayana* (Var. EC. 341).
- (h) *Medicago sativa* (Var. Sirsa-9).
- (i) *Pusha Giant Anjan* (Var. CAZRI 521).

Small grain or legume fodder species

- (a) *Pennisetum typhoideum*—(Fodder Bajra, Var. 117, R.91 Chadi and D-2291 Durgapura).
- (b) *Phaseolus aconitifolius*—(Moth, Var. T₁₈, T₁₆, T₂₄ Hissar).

- (c) *Cyamopsis tetragonolobus*—(Guar-fodder Var., No. B-191,55 Durgapura No. 128 Hissar, 119 Hissar, Durgapura and D.S.E.-25).
- (d) *Vigna sinensis* (cowpea)—(Var. R.S.9 Durgapura, CL-1 Ludhiana N.P. 3 IARI).
- (e) *Avena sativa* (oats)—Var. Kent).

Numerous factors ought to be taken into consideration for selecting a species for improving arid zone pasture in western Rajasthan.

Suitable characteristics of a pasture species are:—

- (i) It is a pasture plant and has:—
 - (a) Palatability.
 - (b) Nutritive value.
 - (c) Persistency (stability).
 - (d) Value as a drought feed.
 - (e) Season of use and flush growth period.
- (ii) Species should have hay production capability.
- (iii) Seed production capability.
- (iv) Adapted to soil and site conditions.
- (v) Availability of seed and its cost.
- (vi) Ease of establishment.
- (vii) Ability of go dormant and revive rapidly.
- (ix) Withstand grazing and trampling.
- (x) Drought resistance.
- (xi) Resistance to cold and frost.
- (xii) Resistance to hot strong winds.
- (xiii) Insect resistance.
- (xiv) Rodent resistance.
- (xv) Disease resistance.
- (xvi) Responsive to special treatment.
 - (a) Cultural operations.
 - (b) Fertilization.
 - (c) Weed control etc.
- (xvii) Special problems are:—
 - (a) Poisonous properties.
 - (b) Relative palatability.
 - (c) Compatability with other land usage.

Additional factors which should be considered before selecting and improving any pasture grass or legume for arid zone are:—Effect on

resale value of land, social aspects with neighbour farmer, prussic acid poisoning, and the fact that germinable seed passes through grazing animal and the grass can be seeded inadvertently over large areas with astonishing rapidity.

Establishment for improvement

While it is not intended to dwell long on establishment procedures, however several unique facts about establishment of improved pasture grasses and legumes in arid zone of western Rajasthan are emphasised briefly. These pertain only to *C. ciliaris*, *C. setigerus*, *Lasiurus syndicus*, *Panicum antidotale*, *Dolichos lab lab* and *Alyosia scarabaeoides*.

Control of Biotic Factors

It is of paramount importance that any operation for improvement of pastures need to be backed by steps to have most effective protection from all biotic activities. Productivity of such protected pasture lands have been worked out at the Institute centres which varied from 3.51 Q/ha. to 26.33 Q/ha. from the grass component alone (Chakravarty, 1968). Efficiency and cost of different types of fencing used in variously located pasture improvement areas has been worked out (Bhimaya *et. al.* 1966) and it has been determined that angle iron posts with four to five strands of barbed wire were the most efficacious and economic in the long run. Since, currently cost of fencing material has gone up significantly, it would be worthwhile considering planting of live-hedge fencing with *Prosopis juliflora* or with *Acacia tortilis* or *Euphorbia* species.

Seed bed preparation

The improved and highly productive species of grasses ought to be considered at par with any other crop as far as soil working and seed bed preparation is concerned. The studies carried out at Central Arid Zone Research Institute, Jodhpur has clearly demonstrated that seeding without cultural operations lead to failure where as complete soil working after removal of bushes and other undesirable scrub vegetation has resulted in increased establishment as it evidenced by 67% increase in subsequent pasture production (Chakravarty, 1968). Re-seeding without any cultural operation is a failure (Dabadghao, 1959).

Seed rate

The seed rate would vary from species to species and according to soil type, rainfall and the subsequent intended utilization. Whether

for pasture or for purely healthy seed production. The table 1 will give the seed rate for the respective purposes.

Table 1. Rate of seeding for pasture and seed production under dry as well as irrigated conditions.

Pasture species	Dryland condition		Semi irrigated condition	
	For pasture use kg/ha	For seed production kg/ha	For pasture use kg/ha	For seed production kg/ha
<i>Cenchrus ciliaris</i>	2	0.75	2.5	1
<i>C. Setigerus</i>	4	1.5	6	3
<i>Panicum antidotale</i>	1.5	0.75	2.5	1
<i>L. sindicus</i>	4	1.5	6	3
<i>Dolichos lablab</i> (var. <i>lignosus</i>)	20-25	10-12	25	15

The studies carried out also indicate higher seed rate for dryland conditions because during the season having fluctuations of rainfall pattern, seed may be required to be sown twice or thrice to achieve desirable establishment (Chakravarty *et. al.* 1966) and Shankarnarayan *et. al.* 1968).

The sowings are done in lines to have better establishment. Subsequent cultural operations are also facilitated when the establishment is in lines.

Technique of seeding

The soils of arid zone are usually subjected to period moisture stress even during monsoon period due to erratic nature of rainfall. The task of seeding and sowing operations are to be done within a very short period of time immediately after first effective rain. Studies were conducted at the Institute to compare different methods of sowing namely by mechanised seed drill, hand sowing etc. in combination with different spacing of furrows. The results are reproduced below (Chakravarty *et. al.* 1973).

Table 2. Plant population per metre in rows.

Treatment	No. of seedlings per metre
Spacing 30 cm	7.93
Spacing 60 cm	8.68
Spacing 90 cm	9.87
Spacing 120 cm	13.62

The results obtained were found to be statistically significant.

Time of seeding

The studies have shown that although monsoon sowings have resulted in maximum germination and establishment, however, sowing carried out during pre-monsoon period is equally comparable (Shankar-narayan *et. al.* 1968). In view of the fact that farmers are very busy with sowings of grain crop during monsoon, seeding of large areas of pasture land with high yielding selected species of pasture grasses and legumes are recommended during pre-monsoon period with pelleted seed containing some ant repellent.

Depth of sowing

Investigations carried out at this Institute revealed that it is not the depth of placement of the seed which is all important but, it is the column of soil which covers, that influences to a great extent the success or failure of seedling emergence from the sown seed. It was observed that '*Cenchrus ciliaris*, *C. setigerus* and *Panicum antidotale* covered to the depth of 1-2 cm. gave optimum germination' (Chakravarty *et. al.* 1968 b) while *Lasiurus indicus* can stand depth upto 4-5 cm. (French, 1968).

Weeding

Considering the effect of weeding it has been observed that two weedings carried out at an interval of 3 and 7 weeks after germination has resulted in an increased forage production of *Panicum antidotale*, *Lasiurus indicus* and *Cenchrus ciliaris* as compared to no weeding (Chakravarty, 1968 b).

Moisture conservation

It is a universally accepted fact that, on slopping areas contour bunding and contour furrowing help in conservation of soil moisture. These measures are, therefore, essential to increase forage production from improved pastures when limiting factor of moisture deficiency is eased by water conservation techniques. It has been observed that increased forage production to the extent of 700 per cent has been obtained with adoption of contour furrowing as compared with no contouring (Ahuja, 1964-65).

Improved pasture Varieties and their range of Production

The measures out line above when adopted in case of selected varieties and cultivars of high yielding pasture grasses the forage pro-

duction is enhanced by 200 to 300 per cent more in comparison to low producing cultivars. The results obtained under various trials under rainfed conditions as well as under semi-irrigated conditions for the varieties named above in the text are detailed below.

Under Rainfed conditions.

(a) <i>Cenchrus ciliaris</i>	Origin	Dry matter yield Q/ha.
Variety CAZRI 277	Australia	25.7
Variety CAZRI 392	Australia	17.5
Variety CAZRI 214	Australia	16.7
Variety CAZRI 362	Gadra Rd.	15.0
Variety CAZRI 326	Narhad (Raj)	13.3
(b) <i>Cenchrus setigerus</i>		
Var. CAZRI 417	Pali	8.2
Var. CAZRI 418	Pali	8.0
Var. CAZRI 1	Australia	7.7
Var. CAZRI 411	Beriganga	7.2
Var. CAZRI 416	Pali	6.7
(c) <i>Panicum antidotale</i>		
Var. CAZRI 331	Pali	10.2
Var. CAZRI 333	Pali	9.7
Var. CAZRI 379	Karnal	7.3
Var. CAZRI 347	Pali	7.0
Var. CAZRI 332	Pali	6.9
(d) <i>Lasiurus sindicus</i>		
Var. CAZRI 353	Mohangarh	81.4
Var. CAZRI 352	Jaisalmer	69.9
Var. CAZRI 321	Jaisalmer	69.9
Var. CAZRI 324	Jaisalmer	67.3
Var. CAZRI 351	Mohangarh (Jaisalmer)	64.9
(e) <i>Dolichos lablab</i> (legume)		
Var. Lignosus	I.A.R.I. (New Delhi)	25.2

Annual fodder—grain crops

(a) <i>Pennisetum typhoideum</i> (Bajra)		
Var. T.F. 23-4 x R117	Durgapura	77.41
Var. T. F. 23-A x R 91	-do-	73.71
Var. D. 2291	-do-	73.21
(b) <i>Phaseolus acutifolius</i> (moth)		
Var. CAZRI T18	Hissar	29.12
Var. CAZRI T16	-do-	29.11
Var. CAZRI T24	-do-	29.74
(c) <i>Cyamopsis tetragonolobus</i> (guar)		
Var. No. B-191-55	Durgapura	40.33
Var. No. 128	Hissar	34.02
Var. No. 119	Hissar	33.99
Var. No. D.S.E. -25	Durgapura	33.68
(d) <i>Vigna sinensis</i> (cowpea)		
Var. Rs-9	Durgapura	29.34
Var. CL-1	Ludhiana	27.91
Var. N.P.3	IARI (New Delhi)	23.12

Under Semi-irrigated conditions

(a) <i>Cenchrus ciliaris</i>		
Var. CAZRI 587	Chandan (Jaisalmer)	147.2
Var CAZRI 392	Australia	139.5
Var. CAZRI 277	Gayandah (Aust.)	127.4
Var. CAZRI 505	Biloela (Aust)	124.7
Var. CAZRI 75	Australia	118.7
(b) <i>Cenchrus setigerus</i>		
Var. CAZRI 296	Local	75.7
Var. CAZRI 76	Australia	74.5
Var. CAZRI 1	Australia	72.1
Var. CAZRI 418	Pali	63.1
Var. CAZRI 175	Beriganga	62.7
(c) <i>Panicum antidotale</i>		
Var. CAZRI 638	Udramsar (Bikaner)	90.2
Var. CAZRI 621	Lawan (Pokran)	65.8
Var. CAZRI 626	Chandan (Jaisalmer)	65.8
Var. CAZRI 237	Sholapur	63.8
Var. CAZRI 330	Sholapur	53.1
(d) <i>Lasiurus sindicus</i>		
Var. CAZRI 399	Jodhpur	185.9
Var. CAZRI 318	Jaisalmer	138.3
Var. CAZRI 351	Mohangarh	137.7
Var. CAZRI 568	Beriganga	132.8
Var. CAZRI 314	Jodhpur	128.9
(e) <i>Lucerne</i>		
Var. Sirsa 9	Hissar	73.20
(f) <i>Hybrid Napier</i>		
Var. Pusha giant	IARI	323.05
Var. E.B. -4	Ludhiana	310.70
Var. N.B. 5	do	267.84
Var. N.B. 17	do	215.69
Var. N.B. 21	do	284.37
(g) <i>Annual fodder grain</i>		
<i>Avena sativa</i> var. kent	U.K.	57.58

The selection and improvement of pasture grasses and other species has given a positive lead to enhance feed and fodder production in arid zone of western Rajasthan in order to increase livestock production and thus, improve the economic conditions of the common man.

Use of fertilizers for improvement of pastures

There are conflicting views expressed regarding the role of the fertilizers play in increasing forage production on a pasture land. Also, we are faced with the increasing cost and shortage of fertilizers even for cereal production programme. During such period when fertilizer was available in plenty and cost was also low some trials were conducted at

Jodhpur as well as at Pali which has revealed that, application of nitrogen (22.4 kg/ha) singly or in combination with phosphorous (22.4 kg/ha) significantly increased the pasture production in case of *L. indicus* (43 per cent), *Cenchrus ciliaris* (44 per cent), *C. setigerus* (48 per cent) over control (Dabadghao *et. al.* 1965). Although, forage yield was also increased (24 per cent) in case of *Panicum antidotale* but the increase was not statistically significant. Application of phosphorus or potash (22.4 kg/ha) did not show significant increase in forage yield. Constructing the over all picture from the economic angle, application of fertilizer was found to be uneconomical.

However, it was observed that with suitable fertilizer application there was a significant increase in the yield of crude protein in *C. setigerus*, *L. indicus*, *C. ciliaris* and *Panicum antidotale* to the tune of 108, 82, 58 and 26 per cent respectively over the control (Das *et. al.* 1964).

Application of farm yard manure (22.4 Nkg/ha) not only increased the forage production significantly during the year of application but also has shown significant response on its residual effect at Pali in case of *Cenchrus ciliaris* and *Dichanthium annulatum* (Chakravarty & Das, 1964-65).

Need for seed production

Any programme of improvement and development of pastures in arid zones need a strong backing with availability of seed of suitable variety of adapted species. The technique of planting for production of seed of pasture species is same as explained above for a pasture land except for variation seed rate given in Table 2.

After care of seed production block

The established plants may be kept free from weeds to reduce competition and to ensure purity of the stand. Inter-row cultivation with a pair of bullocks or using a tiller behind the tractor may be undertaken only in the second season after the plants have established well in lines and plants can be seen clearly from the tractor seat. Fields cultivated from the start and when necessary mowed to control weeds.

Fertilizer application for seed production block

Pasture species for seed production will respond favourably to the application of 50 kg each of N.P and K over an area of one hectare applied on a rainy day in the beginning of the season. The applica-

tion of farm yard manure and bone-meal mixed in equal quantities to supply 50 kg of nitrogen and 50 kg of phosphate per hectare will enhance the seed yield by nearly 36 per cent over the control.

Harvesting

Most of the grass seed are ready for harvesting in about 10-15 days after the commencement of flowering and steps may be taken to collect the seed crop as soon as possible. Delay may result in losing the seed crop.

According to flowering and maturity habits of the different species of grasses, seed collection methods are described below.

Hand-Harvesting

(a) *Panicum antidotale* can be rubbed, *Cenchrus ciliaris* and *C. setigerus* are stripped into receptacles carried by the person harvesting. *Lasiurus indicus* and *Dichanthium annulatum* are picked from the plant as they ripen. By this method high quality grass and high yield per hectare can be obtained from a few hectares of land.

(b) Cutting with a sickle and curing in heaps in the field for subsequent hand threshing is a slightly faster method than stripping into receptacle, but the danger of weather damage during curing in the field is quite serious.

(c) Collection with hand harvester has also yielded good results, but both ripe and unripe seeds get collected at the same time and hence viability and soundness of the seed is sacrificed for quantity.

Mechanical Harvesting

Mechanical harvesting is practical for grass species like *Cenchrus ciliaris*, and *Cenchrus setigerus* by fixing a mechanical seed harvester.

Yield of seed crop

The seed crop of different grass species varies greatly with soil, rainfall and method of collection. The yield range (in kg per hectare) in various species varied from 45 to 250 kg/h.

Storing and testing of seed

The seed is generally cured before cleaning. The seed should be stored dry in well-ventilated and insulated rooms where extreme heat

does not affect it. It has been observed that if the temperature is allowed to rise above 100°F, the viability is affected to a considerable extent. Freshly harvested seed of any grass species exhibits a profound dormancy. For best results seed should be used only after one year of good storage and cleaning.

Quality and quantity of grass seed depend upon proper planting, fertilizer and time and method of harvesting. A large quantity of good, sound, seed, more specially of *Cenchrus* species, can be collected by mechanical seed harvester as discussed above.

Pasture utilisation

The utilization of the grazing areas and developed pasture land is very intimately related to improvement and production from the areas to be utilised for grazing of the livestock. Because of erratic rainfall and deficiency of soil moisture the grasses of the area have only one growing season (in July-August when there is at least some precipitation). There may be second flush of growth in autumn or spring if there be any rain during the winter period, but that is very rare. Hence, the grazing capacity, of the pasture is estimated on the basis of summer growth of the grasses generally. The estimated grazing capacity of the different classes of pasture land is shown below.

<i>Pastures.</i>	<i>Range of carrying capacity per ha. (Sheep)</i>
1. Sown pastures of <i>Lasiurus indicus</i> and <i>C. ciliaris</i> in sandy soil at Jodhpur (Rainfall 300 mm)	3.0 to 5.0
2. Sown pasture of <i>C. ciliaris</i> and <i>Dichanthium annulatum</i> in sandy loam soil at Pali (Rainfall 500 mm)	4.0 to 7.3
3. Natural pasture under protection for 3 years in sandy loam soil at Pali	1.0 to 2.5
4. Natural pasture under protection for five years in sandy soil at Bikaner (Rainfall 250 mm)	0.5 to 2.0
5. Natural pasture under protection for five years in semi-rocky areas at Beriganga near Jodhpur (Rainfall 300 mm).	0.4 to 1.1
6. Natural pasture unprotected, near Jodhpur	0.2 to 0.6

The information furnished above indicates that there is a great scope of increasing the fodder resources, consequently the livestock production of the arid zone of Rajasthan by developing the sown pastures with high yielding perennial grasses and protecting the natural grasslands from unplanned use.

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ROLE OF FORESTRY IN SAND DUNE STABILIZATION

K. D. Muthana*

INTRODUCTION

Forest activities in arid regions are of great importance both for stabilizing the soil conditions as well as for meeting the growing demands of the increasing human and livestock populations for fuel, fodder and shade. It may not be possible to think of large-scale plantations to obtain timber from trees but small timbers for agricultural implements, hutments, fencing posts etc. can be easily obtained. Biotic interferences have been responsible for gradual disappearance of the vegetative cover thereby accentuating soil erosion which has been the greatest contributing factor in the process of desertization. This also brought an imbalance between human and animal population on the one hand and the plant, water and resources on the other. Forests, in fact, regulate the climatic factors like rainfall, temperature and humidity. Vegetation in arid zones is sparse with scattered thorny trees, shrubs and grasses ineffective from soil and water conservation points of view and is classified as *Tropical Thorn Forest* (Champion, 1946).

In India, Forest covers about 22% of the land area whereas for the prosperity and self sufficiency of any nation, forests should cover more than 33% of the land area. Rajasthan State has about 3,42,20,000 ha. of land area of which forest area is about 13,41,750 ha i.e., about 3.93% of the total area. The area of Western Rajasthan is about 2,13,68,853 ha. of which there is hardly 1% of the area under forests. The situation in this regard is much worse in the eleven desert districts of Western Rajasthan (Table 1).

Table 1. Dis-ribution of Forest area in the Eleven Desert Districts.

District	Total Geographical area in '000' ha	Forest in '000' ha
Barmer	2635	9
Bikaner	2720	10
Churu	1661	1
Ganganagar	2071	3
Jaisalmer	2871	19
Jalore	1273	4
Jhunjhunu	591	17
Jodhpur	2272	1
Nagaur	1783	—
Pali	1241	63
Sikar	784	9

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It has, therefore, been rightly emphasized by Planning Commission and Forestry Commission that wastelands, marginal lands and lands not fit for agricultural operations should be put under trees and grasses.

Before attempting afforestation of different habitats in arid zone, emphasis should be given on selection of species both indigenous and exotic, production of nursery seedlings, soil working techniques and cultural operations in view of the low and erratic rainfall, and protection from pests.

Selection of species: The adaptability trials on exotics from different iso-climatic regions of the world have been in progress at the Central Arid Zone Research Institute, Jodhpur. The details on the performance of these introduced species are summarised in Table 2.

Table 2. Performance of Exotic and Indigenous tree species

Species	Origin	Survival	Ht. in cm	
			Mean	Maximum
E—Eucalyptes.				
E. rostrata	Australia	90.0	614	1085
E. terminalis	Australia	45.5	1042	1260
E. camaldulensis	Australia	45.5	781	890
E. ochrophylla	Australia	72.7	811	950
E. melanophloia	Australia	100	992	1180
E. tessellaris	Australia	81.8	600	740
E. sideroxylon	Australia	72.7	640	940
E. coolabah	Australia	100	864	1040
E. hybrid	Madras	36.4	1272	1400
A—Acacia.				
A. tortilis	Israel	100	640	730
A. sieberiana	Sieberia	46.2	438	550
A. raddiana	Australia	100	570	715
A. salicina	Australia	84.6	444	615
A. karroo	F.R.I.	50.0	347	415
A. nilotica	Jodhpur	100	541	680
A. senegal	Jodhpur	100	254	320
Pro—Prosopis				
Pro. juliflora	Israel	92.3	688	860
Pro. alba	Israel	58.3	293	350
Pro. chineraria	Jodhpur	100	212	350
Colophospermum mopane	S. Rhodesia	91.7	328	420
Zizyphus spinachristii	Israel	100	321	435
Azadirachta indica	Jodhpur	100	467	560
Albizia lebbek	Jodhpur	84.8	402	450
Tecomella undulata	Jodhpur	92.3	353	450
Tamarix articulata	Jodhpur	61.5	198	280

The data presented in Table 2 show that the exotic species performed better under the arid conditions than the indigenous varieties.

The desertic areas under arid zone have been divided into six principal edaphic habitats. On the basis of work done at the Central

Arid Zone Research Institute, the following tree and shrub species have been recommended for these habitats:

(i) *Deep sandy soils*:—*Acacia tortilis* (Israeli babool), *Prosopis juliflora* (Vilayathi babool), *Albizia lebbek* (Siris), *Azadirachta indica* (Neem), *Prosopis cineraria* (Khejdi), *Tecomella undulata* (Rohida), *Eucalyptus melanophloia*, *E. camaldulensis*, *E. terminalis*, *E. hybrid* etc.

(ii) *Shallow alluvial soils*:—*Azadirachta indica*, *Prosopis juliflora*, *Albizia lebbek*, *Acacia nilotica* sub. sps. *indica* (babool), *Acacia tortilis*, *E. terminalis*, *E. camaldulensis*, *E. sideroxylon* etc.

(iii) *Sand stone rocky areas*:—*Acacia tortilis*, *Azadirachta indica*, *Prosopis juliflora*, *Acacia senegal*, *Anogeissus rotundifolia* (Indrok).

(iv) *Semi-rocky gravelly areas*:— -do.-

(v) *Shifting sand dunes*:—*Acacia tortilis*, *Prosopis juliflora*, *Calligonum polygonoides*, *Acacia senegal*, *Parkinsonia aculeata*, *Prosopis cineraria*, *Albizia lebbek* etc.

(vi) *Highly saline areas*:—*Acacia tortilis*, *Prosopis juliflora*, *Salvadora oleoides* (Kharajal), *Salvadora persica* (Pilujal), *Tamarix articulata* (Farash) etc.

Raising seedlings:

Proper arrangements of nursery for the production of seedlings for the afforestation programme must be made in a well drained deep sandy loam soil. The usual practice for allocating area for the preparation of nursery is to set apart 5% of the area earmarked for annual plantation. The nursery should be effectively fenced to keep out all animals and should have proper irrigation facilities. The C.A.Z.R.I. after trying various containers such as polythene bags, earthen pots, earthen tubes, Galvanised iron tubes etc. has found that Galvanised iron tubes are the best and most economical under desertic conditions. For stabilisation of sand dunes, sun dried earthen bricks have also proved very effective giving very high percentage establishment of plants.

Studies carried out on the economics of raising seedlings have shown that:—

(1) The best potting mixture consisted of sand, farm yard manure and clay in equal proportions.

(2) Cylindrical metallic containers of 3 varied sizes viz. 10.2 cm. diameter × 30.5 cm. long; 7 cm. diameter × 30.5 cm. long and 7 cm. diameter × 22.8 cm. long have been found to be the most ideal sizes for raising and transporting tree seedlings.

(3) The use of metallic containers not only gives an increased plant population and growth in height of seedlings but also effects economy in watering to the extent of 25% compared to earthen containers of similar dimensions.

(4) 9 litres of water, at a time per set of 50 containers have been found to be most economic dose of watering for successfully raising the seedlings.

(5) Overhead shade particularly during hot weather helps in reducing the water needs of seedlings by 9.6%.

(6) Seedlings raised in metallic containers and placed in cemented beds of under 9 litres of watering level required 29.8% less water as compared to those kept in earthen beds due to lesser number of root clippings in cemented beds.

(7) On long term basis, the metallic containers work out much cheaper than the other types of containers since containers have been used for over 12 years and still remain in good shape (Kaul and Ganguly, 1963).

(8) While transporting seedlings to far off places, it has been seen that seedlings raised in metallic containers could be transported safely without causing much damage to the plants and in larger quantities when compared to seedlings in earthen pots.

(9) The cost of production of 100 seedlings from sowing stage to transplanting stage, i.e. from October to July has worked out to Rs. 12 including cost of manure and clay.

(9) Sun dried earthen bricks should be made from a semi-solid paste having a mixture of equal proportions of clay, sand and farm yard manure. This is done by putting the paste in a wooden or steel mould which is then taken out and allowed to dry in the sun. These are 30 cm. high, 10 cm. and 15 cm. squares at the top and bottom respectively. Provision for a cavity of 2.5 cm. diameter and 10 cm. to 15 cm. deep at the top of the brick is made for dribbling seeds or for planting seedlings, cuttings or stumps. These bricks are embedded in sunken beds and taken care of till the planting season. At the time of planting in the field, after a good shower, these seedlings with the bricks are carefully removed from the beds and transported to the sites taking all precautions that the bricks remain intact. (Prakash M. and Pathak S.).

Besides, the bricks provide nutrition to the plants in the initial stage and also absorb and retain moisture for longer period. Species such as *Prosopis juliflora* (Vilayathi babool), *Prosopis cineraria* (Khejdi), *Acacia senegal* (Kumat), *Acacia tortilis* (Israeli babool), *Azadirachta indica* (Neem), *Albizia lebbek* (Siris), *Ailanthus excelsa* (Arudu), *Dalbergia sisso* (Shisham) etc. have been successfully raised in bricks

Sand dune stabilization techniques

Sand dunes are mostly barren stretches of land devoid of vegetation and most of them remain unexplored due to their inaccessibility. The means of drifting sand which engulfs the fertile agricultural fields, canals, wells, railway lines, roads, buildings etc. is the main problem in the Indian arid zone. To check the onslaught of these moving dunes and accumulation of sand dune on the adjoining fertile and cultivable land and to prevent the natural resources from over exploitations and to make the arid regions more productive with assured subsistence to the inhabitants, a viable programme of dune stabilization through vegetative cover hardly needs any emphasis.

The Western Rajasthan has an area of 2,13,68,853 ha. of which 1,28,02,872 ha. fall under moving and semi-stabilized sand dunes of different degree and extent (Raheja P. C. and Sen A. K.), the details of which are furnished in Table 3.

Table 3. Degree and extent of sand dunes in Western Rajasthan.

Extent of sand dunes	Area in sq. km.	% of total area
No dune	85,659.81	41.50
0 to 20% of the area affected	18,902.85	8.90
20 to 40% of the area affected	39,782.25	18.60
40 to 60% of the area affected	34,322.11	14.70
60 to 80% of the area affected	10,164.91	4.80
80 to 100% of the area affected	24,856.60	11.50
Total	213688.53	100.00

Judging from the mode of occurrence and physical features, the dunes of Western Rajasthan can be divided into five types namely, parabolic, longitudinal, transverse, barchan and sandy hummocks. These types of dunes are stated to indicate their orientation in relation of the prevailing wind. As the wind blows, the 2 flanks of the parabolic dunes extend towards the windward side, but in the case of barchan dunes the flanks extend towards the leeward side. The ridges of the longitudinal and transverse dunes run parallel but perpendicular to the wind direction. The sandy hummocks are formed near about and around the fence line, bushes and shrubs with no definite shape (Bimal Ghose, 1974).

The Central Arid Zone Research Institute has done a lot of stabilization work on different types of sand dunes at Jhunjhunu, Narhar, Churu, Sardarshar, Dungargarh, Sikar, Barmer, Bikaner etc. represent-

ing different agro-climatic regions of Western Rajasthan since 1953. On this basis a technology of dune stabilization has been evolved. This constitutes mainly of revegetating the affected areas with grasses, shrubs and trees (Bhimaya C. P. *et. al.*). The processes involved are:—

- (i) Protection of dunes against biotic interferences by fencing.
- (ii) Treating the affected dunes by fixing barriers in parallel strips or in chequer board design using locally available shrubs from the crest down to the heel to serve as micro windbreaks.
- (iii) Revegetating by direct seeding or transplanting seedlings of indigenous and exotic species raised in sundried earthen bricks or G.I. container.
- (iv) Planting of grass slips or sowing seeds of grasses and castor on the leeward side of the micro wind breaks.
- (v) Continuous and proper management of such dunes till the cost of input is recovered in about 10 to 15 years period.

Fencing

The sand dunes contemplated under stabilization programme should be earmarked a year in advance and fenced preferably with five strands of barbed wires fixed on angle iron posts spaced at 6 metres apart. If large quantities of thorny brushwood, such as *Zizyphus nummularia* (Jhar bori), is locally available near the site, fencing may be done by cutting and placing such thorny brushwoods. The only drawback in such types of thorn fencing is that it needs repairs and renovation whenever it is damaged or blown off. Regular watch and ward is essential in such type of fencing to prevent biotic interferences. In any case, fencing must be completed before the onset of rains.

Amongst the different types of fencing tried, angle iron post and barbed wire fencing proved to be the most effective and economical. Cost of such fencing worked out to Rs. 9 per running metre. Cost per hectare in blocks of 40, 80, 100, 200, 500 and 1,000 hectares worked out to Rs. 400, 275, 260, 180, 120 and 85 respectively (Muthana and Ahuja, 1973).

Brushwood barriers or erecting micro wind breaks

Locally available brush wood species such as *Crotolaria burhia* (Sinia), *Leptodenia spartium* (Khimpi), *Zizyphus nummularia* (Jhar bori), *Aerua psudotomentosa* (Bui), *Calligonum polygonoides* (Phog), *Panicum turgidum* (Murat), etc. are collected at site and buried vertically crown downwards in lines 2 to 5 m. apart to reduce the wind

velocity at the dunes surface. Closer spacing and cross barriers to form a checker board pattern may be adopted in localities subjected to high wind velocity or in places where disorderly local current frequently occur. The operation should be completed before the commencement of monsoon. Cost of such operations worked out to about Rs. 100 to Rs. 120 per ha.

Eatablishment of Vegetation Cover

Trees, shrubs and grass species recommended for sand dune stabilisation according to different rainfall zones are as follows:-

i) Rainfall zones of 30 cm to 15 cm.

Trees:- Prosopis juliflora, Acacia tortilis, Acacia senegal.

Shrubs:- Calligonum polygonoides and Zizyphus sps.

Grasses :- Lasiurus indicus.

ii) Rainfall zones of 30 to 40 cm.

Trees:- Acacia senegal, Prosopis cineraria, Prosopis juliflora, Tecomella undulata etc.

Shrubs:- Zizyphus sps. Calligonum polygonoides, Ricinus Communis etc.

Grasses:- Cenchrus ciliaris, Cenchrus setigerus, Lasiurus indicus, Saccharum munja.

iii) Rainfall zone of 40 cm and above:

Trees:- Prosopis cineraria (Khejri), Prosopis juliflora (Vilayathi babool), Acacia nilotica (Kikar), Acacia senegal (Kumat), Tecomella undulata (Rohida), Parkinsonia aculeata (Parkinsonia), Ailanthus excelsa (Ardu), Acacia tortilis (Israeli babool), Albizzia lebbek (Siris) etc.

Shrubs:- Cassia auriculata (Cassia), Ricinus communis (Irandi), Zizyphus sps. (Bordi).

Grasses:- Cenchrus ciliaris (Dhaman), Cenchrus setigerus (Kala dhaman), Panicum antidotale (Gramna), Saccharum munja (moonj) etc.

Seeds of grasses and leguminous creepers mixed with clay and sodium arsentate to protect them from gerbils may be sown during monsoon on the leeward sides of the micro wind breaks.

Well developed seedlings raised in sundried earthen bricks when planted in pits 45³ cm or 60³ cm proved very successful. Such deep planting facilitates the root system to get in contact with the moist zones at a lower depth which are generally met with at 50-60 cm. below the surface. Seedlings raised in G.I. containers and planted on the

dunes have also given excellent results. Presprouted branch cuttings of *Tamarix articulata* (Farash) nad *Calligonum polygonoides* (Phog) may be planted on the dunes with the onset of rains to give better establishment. Similarly, presprouted stumps of *Prosopis juliflora* (Vilayathi babool), *Albizzia lebbek* (Siris), and *Dalbergia sissoo* (Shisum) may also be planted on the dunes. After planting one or two weedings are essential during the 1st year.

In such afforested dune area, four years old *Acacia tortilis* plants attained a height of 3.3 to 4.7 cm. (mean height) and 10 year old *Prosopis juliflora* recorded a mean height of 5.0 m to 7.0 m. at different habitats. The mean growth in height of the important indigenous species at different dune habitats is presented in Table 4.

Table 4:- Performance of tree species on different dune habitats.

Species	Age	Churu	Jhunjhunu	Bikaner	Barmer
<i>Prosopis juliflora</i>	10	261 cm	500 cm	275 cm	705 cm
<i>Prosopis cineraria</i>	10	221	510	—	—
<i>Zizyphus jujuba</i>	14	332	450	—	—
<i>Tamarix articulata</i>	11	—	480	—	598
<i>Albizzia lebbek</i>	11	—	440	—	398
<i>Azadirachta indica</i>	11	—	390	—	502
<i>Parkinsonia aculeata</i>	11	—	570	—	567

From a preliminary study on the dynamics of soil moisture in sand dunes conducted at Osian 72 kg WNW of Jodhpur, it was observed that high moisture contents exceeding field capacity throughout the year below 1.5 m. depth in the shifting sand dunes was available. The moisture contents in the stabilized sand dunes were very low upto 7 metres. This evidently indicates better afforestation possibilities on the shifting dunes.

Experience at Central Arid Zone Research Institute has shown that while afforesting the sand dunes with exotic and indigenous tree species, it is desired that seedlings of exotic tree species may be restricted to half the height of the dunes from the crest downwards. The lower half and the interdunal areas may be planted with indigenous varieties of frost hardly trees, shrubs and grasses. This would save the tree species from being damaged and affected from frost.

After care:

Success of the sand dune stabilization work depends on the after care. No grazing should be allowed within the area. Cropping and

other biotic interferences should be stopped for at least 10 to 15 years. Grasses from the dunes may be harvested after 2 years onwards. The trees may be lopped for fodder and felled for fuel fixing the rotation period at 10 years onwards or so.

The ultimate success of sand dune stabilization depends on choosing the right species, planting sturdy stocks, planting in time and deep and timely replacement of casualties.

Cost-benefit ratio of sand dune stabilization:

The data on expenditure incurred and the returns by way of fuel, fodder, seeds, etc. for the dune stabilization areas at Bikaner and Jhunjhunu districts indicate that the technology of dune stabilization breaks even after over 14 years. Average cost per hectare including construction, major repairs and operational costs came to Rs. 551.61 for Udramsar, Rs. 753.76 for Shri Kolayatji, Rs. 1038.96 for Shivbari and Rs. 455.48 for Jhunjhunu areas. The average benefits per hectare composed of fuel, fodder, munja, grass, tree seeds etc. came to Rs. 1560/- for Udramsar, Rs. 615/- for Shri Kolayatji Rs. 637/- for Shivbari and Rs. 2086/- for Jhunjhunu areas. This gave rise to benefit cost ratio of 1.88, —0.18, —0.39 and 3.58 to 1 respectively for Udramsar, Sri Kolayatji, Shivbari and Jhunjhunu areas. Thus it can be safely said that besides being a technologically sound proposition, sand dune stabilization is an economically viable proposition as well as summarised in table 5.

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Table 5. Cost benefit ratio for sand dune stabilization for a block of 100 Ha.

Expenditure				Returns from 10th year onwards by adopting 10 years rotation on a 100 Ha. block.				Net Profit after 10th	
Sl. No.	Items of work	Rate	Amount	Sl. No.	Items of work	Rate	Amount	For 10 Ha.	Per Ha.
	Planting distance 5m x 5m. No. of plants required-40,000			1.	Fuel yield by adopting felling blocks of 10 Ha/ year 300 Quintals/Ha-3000 quintals.				
1.	Fencing with barbed wire and angle iron posts.	—	26,000	2.	Rate of fuel sold at site.	Rs. 3/- Qt.			
2.	Erecting micro-wind breaks-75,000 rft.	15 Rft/ Rupee	5,000	3.	Value of Fuel from 10 Ha.	Rs. 3/- Qt.	9,000/-		
3.	Digging pits 60 x 60 x 60 cm, refilling with fresh soil, mulching etc. 40,000 pits.	8 pits/ Rupee	5,000	4.	Fodder value from loppings	Rs. 4/- per Ha.	40/-		
4.	Cost of raising seedlings-50,000 Nos.	10 per rupee	5,000	5.	Value of thorny twigs at site.	Rs. 1/- per ha.	10/-		
5.	Cost of transporting the planting materials over a distance of 5 km. on tractor trolleys	10 Rupees per 200 plants.	2,000	6.	Grand total (3+4+5)		9,050/-		
6.	Cost of weeding-2 weeding a year.	—	2,000						
7.	Cost of planting and replacement.	100 plants per mandays	2,000						
8.	Watch and word-2 watchmen for 8 months.	Rs. 150/- per man per month.	2,400						
9.	One watchman for 9 years	Rs. 100/per month.	10,800						
10.	1 Pucca hut 1 Kachha hut	—	6,000						
11.	Unforeseen expenditure	—	800						
12.	Interest on fixed capital 11%	—	7,730						
13.	Depreciation on fixed Capital 5%	—	1,900						
	Grand Total		76,270/-						
	Less cost of permanent fencing (26,000/-)		50,270/-						
	Expenditure for a 10 Ha block	—	5,027/-		Returns from 10 Ha Block		9,050/-	4020 Say	402/- 400/-

ECONOMIC EVALUATION OF ARID LAND MANAGENEMT TECHNOLOGY

Jagdeesh C. Kalla . . .

INTRODUCTION

Concomitant with the maintenance of optimum eco-system, the main endeavour of Central Arid Zone Research Institute, since its inception has been to identify the problems and generate their solutions to mitigate the economic hardships faced by ever-increasing population inhabiting arid zone of India.

The main approach at this Institute for evolving package of practices resulting in proximity to ideal eco-system along with production levels has centered around land use. The technology as a result of various experimentations of arid zone mainly constitutes of putting different land forms into the orbit of active production activities. Process involving Sand Dune Stabilisation, creation of shelter belts, planning of fuel plantation crops, establishment and management of rangelands, planning irrigation for maximum benefits and viable cultivation of crops under dry conditions can be counted upon to be the major components of technology of arid land management systems.

This is only possible when farm families employed in agricultural pursuits are convinced of the assured returns incidental to the application of such technology. It has constantly been felt that before passing a technological innovation to the concerned population, its economic evaluation should be done. Thus the economic evaluation of technology generated for arid zone where uncertainties play a large role in establishing the production patterns, assumes an importance which hardly needs any emphasis.

In this paper it is proposed to present economic evaluation of technology developed for arid areas. An attempt has been made to evaluate economics of different technological projects by measuring costs incurred and benefits emanating out of each enterprise. In order to facilitate the understanding of methodology an example of economic evaluation of Sand Dune Stabilisation programme has been elucidated in details followed by sketchy details of other aspects of technology which are set out in table appended.

Concepts and methods

The word technology according to its dictionary meaning can be

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called as the means by which material things are produced. When production in agricultural sector is under consideration, it necessarily means the manner by which resource manipulation is done to achieve efficiency in production (Lave, 1966). Since arid zone and its resource endowments present basically a different set of circumstances under which the population inhabiting the arid zone have to attempt to maximise production activity for their continuing survival and economic welfare, the technology for augmented production is also different than normal situations.

Since its inception, C.A.Z.R.I. has been entrusted with the ominous task and onerous responsibility to generate new state of art which will generate either larger existing output from the given resource-base or will save the quantity of resource while maintaining the present production levels, so that posteriority does not draw a blank from the remaining resource base. Any technological finding thus imperatively has got to be tested through yard sticks of economic measurements. Thus the measurement of costs of the technology and consequently the returns accruable incidental to its employment, form a core of criteria which justifies the onward transmission of the technology to the ultimate production units. Besides, evaluation has to be discounted for the social costs and benefits also before a final decision of its implementation is arrived at (Luning and Sterkenburg, 1973).

In principle it seems rather straight forward to estimate the total resource cost before the intrusion of new knowledge and then estimate the resource costs, given an output level after the innovation with the difference representing the resource saving. Alternatively, an equilibrium output can be estimated and again afterwards with the incremental increase in output representing the gains and output made possible by the application of new technology. While this procedure seems innocently oversimplified, intrusion of new knowledge into economic system is a dynamic process where change is not an instantaneous transformation. As a matter of fact it is composed of a series of time—dimensional events and developments (Marglin 1967). This opens a Pandora's box leading to endless difficulties in measurement and classification of incurrence of costs and accrual of benefits.

The problem is further compounded by the fact that comparison between the production process with and without the application of technology cannot be done. For example, out of the total land about 51 per cent of the land in arid zone of Rajasthan fall under various categories of degenerated land form. The prehistoric use of such lands can hardly be put to any cardinal measurement to serve as a benchmark because if a technology is applied to put these lands under the orbit of commercialisation, the 'with and without' comparison will

inevitably lead to tremendously increased cost and relatively shy benefits. (Little and Miralees 1969).

Another factor causing the constant deterrant to the evaluator is the timing of the technology. It hardly needs any emphasis that longer the gestation period of the technology, greater will be the price changes resulting into the distortion in the monetary evaluation of cost and benefits. Although discounting methods to transform the costs and benefits of different time period are available, (Douglas and Lee 1971), nevertheless the nebulousity and arbitrariness reduce the meaning of such evaluations.

Despite all these lacunae the exercise of evaluations of technology is not all that sterile. This is principally so because for planning the resource-use (and especially so in arid zone), such broad outlines can be of immense utility for enabling the minimal wastage of precious resources.

Costs

Costs involving a decision to implement a technological innovation are classified into three categories (Eckstein 1958 Gittinger 1972) namely, fixed costs, recurring costs, and maintenance costs. Fixed costs here imply those costs items which will have to be incurred irrespective of production. For example in a sand dune stabilisation programme costs of fencing will be incurred and is chargeable to the total project even in a zero production year. Variable costs on the other hand are referred to the cost items which are composed of material and labour costs. These are exclusively incidental to the production activity. For example, in a sand dune stabilization programme watering, weeding, and plant protection will be zero with a zero production level in a particular year. Lastly, costs like watch and ward and contingency will be considered as annual costs. Since all these costs will involve a time period of more than an accounting year; these will hardly agree to the production on annual basis, their linear discounting is to be done by the following formulations suggested by Yang (1968).

$$(a) 'PWF'_c = P \left[\frac{r}{1 - (1+r)^{-n}} \right] + \frac{R}{(1+r)^n} \left[\frac{r}{1 - (1+t)^{-n}} \right] + \sum_{i=1}^n ci/n \quad \dots (i)$$

$$'PWP'_c = P \left[\frac{1 - (1+r)^{-n}}{r_n} \right] + R(1+r)^n \left[\frac{1 - (1+r)^{-n}}{r} \right] + \sum_{i=1}^n ci/n \quad \dots (ii)$$

$$(c) 'VC' = \left[\sum_{i=1}^n Pi + \sum_{i=1}^n Ri + \sum_{i=1}^n ci \right] n^{-1} \quad \dots (iii)$$

Where PWF, PWP and TC are total cost entailing present worth of future costs, present worth of past costs and total costs. Present fixed costs, R represent maintenance costs and C_i represent annual average variable costs.

Benefits

The value of the benefits emanating from any long range programme will have a built-in variability of the selling prices. In order to enable a compatible comparison benefits are also supposed to be discounted by following the following the identities suggested by yang (1968).

$$(a) PWF_b = \left[\frac{B}{(1+r)^n} \right] \quad \dots (iv)$$

$$(b) PWP_b = B(1+r)^n \quad \dots (v)$$

$$(c) TE = \sum_{i=1}^n B_i \cdot (n)^{-1} \quad \dots (vi)$$

Where PWF, PWP and TB are respectively present worth of future, Present cost of Past and total benefits and r the discount rate in both cost & benefit estimation. A comparison of the cost-benefit ratio will thus enable to rank the economic merits of each technological finding.

Results and Discussion

I Economic evaluation of sand dune stabilisation

One of the principal problems facing arid zone in western Rajasthan is the dreadful hazard of drifting sand and unstable dunes. Accentuated by climatic factors, drift of sand engulfs settlements, crop lands and already meagre infrastructural facilities.

Looking to the urgency of dealing with the problem, experiments on sand dune stabilisation were carried out at Jhunjhunu, Sardarshahar, Churu, Dungargarh, Bikaner and Barmer from 1953 onwards. The technology evolved out of the experimentation (Bhimaya *et. al.*, 1961, Kaul 1968) constitutes of the following five steps:

- i) Protection of dune infested areas against Biotic interferences by fencing.
- ii) Treatment of shifting sand dunes by fixing barriers in parallel strips or checker board designs using local shrub material

- starting from crest down to the heel of the dune to protect seedlings from burial or exposure.,
- iii) Afforestation of such treated dunes by direct seeding and transplanting of seedlings of indigenous and exotic species awaited in sun-dried-plant in bricks consisting of mixture of sand, clay and farmyard manure in ratio of 1: 1: 1 (Prakash *et. al.*, 1957).
 - iv) Direct planting of suitable grass species from leeward side, and finally., and,
 - v) Continuous management of treated dune.

Upon applying this technology costs and return for a period of 1953-70 were recorded for four locations namely Udairamsar, Sri Kolayatji, Shiv Bari & Jhunjhunu. The total and discounted costs of sand dune stabilization program are set out in table 1.

Table 1: Total and Discounted Costs (Rs.) of Sand Dune Stabilization program in Western Rajasthan (1953-70)

Item	Udairamsar	Shrikolayatji	Shivbari	Jhunjhunu
Total costs	16851.76	7115.59	10514.38	11701.21
PWF	1329.04	940.58	1161.28	1181.79
PWP	290323.49	51993.30	76467.45	101007.07
Per hac. costs	551.61	753.76	1038.97	455.48
PWF	43.50	99.64	114.75	46.00
PWP	9503.22	5507.77	9532.36	3931.77

It is evident from table 1 that even by following same technology costs vary from Rs. 7,115.59 in case of Sri Kolayatji to Rs. 16,851.76 in case of Udairamsar. This variation in total cost can be attributed to age of project, size of area and Geo-climatic conditions discounted to the future. The present worth of cost evaluated at the discounting rate of 9 per cent per annum came out to be highest (Rs. 114.75) for shiv bari followed by that in Sri Kolayatji (Rs. 99.64), Jhunjhunu (Rs. 46.00) and Udairamsar (Rs. 43.50). Almost similar situation was discernible when the present cost were discounted for past investments.

Benefits

Measurement of benefits was first accomplished by summing up the total available output in terms of fuel woods, timber, tree seeds, forage and grass seeds. The total and per hect. benefits emanating from the total span of 1953-70 are set out in table 2.

Table 2: Total and Discounted Benefits (Rs.) Emonrting from Sand Dune Stablization Program in Western Rajasthan (1953-70)

Items	LOCATIONS			
	Udramsar	Srikolayatji	Shivbari	Jhunjhunu
Benefits/ha	1560.00	616.00	637.00	2085.92
PWF	187.67	111.29	106.25	224.48
PWP	12967.66	3409.44	3818.42	19382.79

A perusal of table 2 reveals that highest total and per hectare benefit were accruable in Jhunjhunu area (Rs. 53,587.29 and Rs. 2,085.92 respectively) followed by Udairamsar area (Rs. 4,75,658.05 and Rs. 1,560.00 respectively), Shivabari area (Rs. 6,446.44 and Rs. 637.00 respectively) and Shri Kolayatji (Rs. 8,515.05 and Rs. 616.00 respectively). Judged from the variations in the magnitudes of PWF_b and PWP_b, it can be said that gestration period could be positively related to the stream of benefits accruable during the periods under consideration.

Benefit cost Ratios of sand dune Stabilisation technology

From the gross benefit total cost were deducted and the resultant net benefit were divided by the corresponding costs to arrive at benefit-cost ratios which are presented in Table 3 below:

Table : Benefit-cost ratios for sand dune stabilisation technology of different locations.

Particulars	LOCATIONS			
	Udramsar	Shrikolayatji	Shivbari	Jhunjhunu
<i>'B-C' Ratios</i>				
a) Total	1.83 : 1	— .15 : 1	— .39 : 1	3.58 : 1
b) PWF	3.55 : 1	— .14 : 1	— .51 : 1	4.51 : 1
c) PWP	0.35 : 1	— .43 : 1	— .60 : 1	3.72 : 1

It can be seen from the table above that return per rupee investment was highest (Rs. 3.58) in case of Jhunjhunu followed by Udairamsar (Rs. 1.83) and was negative (Rs. -.15 and Rs. .39 respectively) for Shri Kolayatji and Shivbari area. It can thus be concluded that, the dune stabilisation technology is an economically sound proposition provided it is followed judiciously.

II. Economic Evaluation of Wind Breaks and Shelterbelts

Wind breaks and shelterbelts are essentially created along road side, farm boundaries, dams and canal to confuse the winds which after at-

tainment of a certain velocity are prone to carry the precious top soil with them. Experimentation on the effects of wind breaks on yield of certain crops were carried out on Suratgarh Farm which showed a production increment of ranging from 20-50 per cent depending on crops.

III. Fuel Plantation Crops

Quality of land resources coupled with increase in population has created big shortage of fuel wood in rural and urban areas constituting arid zone. A 10-year plan of plantation to 87,000 sq. km. (suggested by National Commission of Agriculture) by trees like *Albizia lebbek*, *Azadirachta Indica*, *Prosopis Julliflora* and *Accacia Tortillis* will not only make the fuel economy self sustaining but will provide employment potential to 5 crores Man-days for 10 years, and will generate respectively 1.12:1, 0.99:1, 1.06:1 and 1.71:1. Benefit-cost ratios for the aforesaid varieties of trees.

IV. Range Management Technology

Resource endowment in desert area provide conducive situations for livestock industry. In order to have efficient livestock production, the existing poor status of range land has to be increased. The technology developed for establishing range lands by scientists, here will have cent percent increase in production of grasses and thus enhance the carrying capacity of the existing rangelands.

V. Crop Technology

In arid areas of Western Rajasthan only about 21.39 per cent of total geographical area is sown annually, out of which only about 8 per cent is irrigated. Water, where ever available, has a tremendous cost. Crop technology, therefore has a two-pronged approach of (i) putting irrigated area to the most economic use and (ii) putting rainfed area under dry farming methods in order to achieve stability in cropping sector of arid areas. Following dry farming practices, it is possible to strike benefit-cost ratios of 3.57, 3.09 and 6.82 per rupee of expenditure for crops like Wheat, Barley and Sunflowers.

Similarly individual technological innovations like wind strip cropping, stubble mulching, field bunding, run-off concentration are likely to have substantial yield increment possibility.

Finally, economics of irrigation justified investment on sprinkler and trickle irrigation systems.

It therefore, can be said that the application of technology for the maximisation of production *pari-pasu* the development and conservation of arid lands is not only technologically but also economically a sound proposition.

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ECONOMIC EVALUATION OF ARID ZONE TECHNOLOGY

S. No.	Particulars	Technology	Duration	Employment	Cost/ Unit	Benefit/ Unit	'B-C' ratio	Remarks
1	2	3	4	5	6	7	8	9
1.	<i>Sand Dune Stabilisation</i> (Gyan Chand et al. 1974)	Constitutes of Soil working, planting or transplanting of plant material suitable to with stand bio-stress and continuous management, and prevention from biotic interference.	15 years	1500 M.D./ Ha	Rs. 700-00 (Accrual basis)	1225-60	1.75:1	
2.	<i>Wind breaks/shelterbelts</i> (Bumaya et al. 1961)	Plantation of checker board pattern of trees across the boundary and along roads. Plants which proved suitable are <i>Dalbergia sisso</i> on avenue row, <i>Acacia Arabica</i> in 2nd row, <i>Zizphus jujuba</i> or numularia on 3rd row.	15 years	8000 M.L./ Ha	Rs. 530-00/ mile (1961-62 prices)	20-50% increase in crop yields	—	
3.	<i>Fuel Plantation Crops</i> (Kalla et al. 1974)	Constitutes of clearing plantation site, Alignment and digging of pits of 60 cm at 5 m distance, Trans-planting of <i>Altezzia lobek</i> , <i>Azadirachta-Indica</i> , <i>Prosopis Juliflora</i> and <i>Acacia Tortillis</i> by first in nursery for 7-12 months Weeding hoeing, management and prevention from biotic interferences.	10 years	5 crore M.D. on 58000 ha. (Accrual of sub- marginal land)	Rs. 211-45 (Accrual basis)	<i>Altezzia lobek</i> Rs. 237-20 <i>Azadirachta indica</i> Rs. 210-90 <i>Prosopis Juliflora</i> Rs. 223-90 <i>Acacia Tortillis</i> Rs. 362-00	1.12:1 0.99:1 1.06:1 1.71:1	

1	2	3	4	5	6	7	8	9
4.	<i>Range Management Technology</i>	Constitutes of Protection from biotic factors-Angle iron & Barbed wire fencing based on block of 1000 ha.	1 Year	Annually about 1800 MD/ha.	Rs. 125/ha	100% n-crease in yield of Forage with- in 2 years.	—	—
		<i>Reseeding</i> Sandy medium soils below 300 mm. rainfall for <i>Lesinus stidicus</i> For sandy and medium soils above 350 mm annual rain- fall cenchrus and dicanthium spare suitable.	3 years	1800MD/Ha	Rs. 250/ha	100% of increase in forage yield	—	—
		Shade tree plantation & water points	2 years	„	Rs. 300/ha	200% increase in forage yield	—	—
		Gerbi control	4-5 years	„	Rs. 200/ha	100% increase	—	—
			Every year		Rs. 5/ha	10% increase	—	—
5.	<i>Crop Technology</i> (S. D. Singh)							
5.1	<i>Wind strip cropping</i>	Constitutes of creating a perma- nent grass strip of Sevan 5m wide, across the wind direction in crop land to grass land ratio of 6:1 for Bajra, Moong and Month crops	10 years	„	Rs. 129-00/ ha	6% Yield in-crease in Bajra.	—	—
						12% Yield in-crease in Moong	—	—
						9% Yield in-crease in Moth	—	—

1	2	3	4	5	6	7	8	9
	<i>Irrigation Technology</i>	Sprinkler Irrigation	Annual basis	—	—	Yield increment at the rate of about 38% as compared to boarder strip and 2 percent from check basis	—	—
6.	<i>Dry Farming Technology</i> (R. P. Singh)	Constitutes of conservation of moisture, uses of fertilizer and improved seed along with judicious management.	Annual basis Wheat Barley Sunflower (Safflower)	— — — —	— — — —	Rs./Ha 49 4:12 2494.46 4797.22	3.57:1 3.09:1 6.82:1	—

GRASSLAND AND RANGE MANAGEMENT

L. D. Ahuja*

Abstract

Due to hostile agroclimatic conditions in arid regions, agriculture is unstable, grassland husbandry which sustains large livestock population occupies an important place in the local economy. As a result of heavy pressure for production of food for increasing human population, marginal and sub-marginal lands are put under plough. Therefore, the only recourse left is to develop existing grasslands most speedily for higher livestock production and improving local economy.

The paper deals with methods of improvements of different types of grasslands in arid zone. The methodology of development and improvement involves selection of site, protection from biotic factors, grubbing of unwanted bushes, propagation of top feed cum shade trees, soil conservation measures, stabilization of sand dunes, reseeding with appropriate grass species, fertilization, development of water resources, rodent control, maintenance and upkeep of grasslands and their proper utilisation etc.

INTRODUCTION

The climate in the North Western arid zone is characterised by extremes of temperatures ranging from below 0°C in winter to 45°C in summer with precarious and erratic rainfall ranging from 100 to 500 mm per year; about 80 to 90 per cent of which occurs from July to September. Mean aridity index in arid parts of States of Maharashtra, Mysore, Andhra Pradesh, Haryana, Punjab, Gujarat and Rajasthan is 68, 68, 68, 74, 75, 76 and 78 per cent respectively with maximum of 91 per cent in Jaisalmer district of Rajasthan. The aridity index in cold desert (Ladakh and Leh) is 88 per cent. Every third year is a famine year and alternate bad year is common saying for the arid regions.

Land forms in this region are very heterogenous comprising of barren rocky areas, shifting sand dunes, sandy plains, saline flats, alluvial flats, dead streams, barren gravelly stretches and undulating topography etc. Permanent streams are absent. Drinking water is scarce with sub-soil water level at 100 m and more below the ground level; with

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fairly high salt content. As a result of these hostile agroclimatic conditions agriculture is unstable; area put under cultivation is as low as five per cent in low rainfall zones like Jaisalmer district. It has been estimated that in drought years the agricultural production from crops falls to 10 per cent of normal while average livestock production yield falls only by 33 per cent. Marginal improvement in fodder production, rangeland development, and water availability is, therefore, likely to add considerably to the yield and stability of livestock farming and finally economy in the desertic areas.

Rangeland or grassland may be defined a land form where agriculture cannot be sustained on sound footings due to hostile agroclimatic conditions.

This region has proved to be the home land of best breed of cattle, sheep, goats, camels etc. of the country which are in great demand in other states of the country. Livestock in this tract are inherently hardy and possess high production capacities. Cows of Tharparker, Kankrej, Rathi, breed have the potentials to produce milk yield of 2000-2500 litres/lactation. Bullocks of Haryana, Nagauri, Kankrej are reputed for excellent draft capacities under hard conditions.

Livestock population in arid areas of the country, is 22.89 millions, of which cattle, buffaloes, sheep, goats, camels and other species comprises of 7.27, 2.67, 6.90, 5.14, 0.65 and 0.23 millions respectively. These when converted to adult cattle units, amount to 11.8 millions.

Available forage from farming, cultivable waste, fallows, pasture lands is about 63.3 per cent of the needs of existing livestock under normal years of rainfall. The production is very much lower during the years with sub-normal rainfall, leading to acute scarcity conditions and alarming problem. This entails transport of fodder from other states to keep the livestock living, and taxes the State and Centre exchequer very much (Ahuja and Muthana, 1969). In addition to that the livestock is forced to migrate to other states where they get crossed with local mongrels resulting in loss of breed entity, contacting of diseases which cause economic losses, reduction in livestock production potentials, reduced employment to local people, less availability of nutritive feeds like milk and meat to local population, and devolving of animal excrete to soils in this tracts etc.

Due to increase in human populations resulting in their needs for human food, there will be continuous encroachment on marginal and sub-marginal land for cereal and legume cultivations. Number of livestock in arid areas has and will continue to increase at a higher rate in comparison to that of other regions. Therefore, gross area for grazing per unit of livestock will shrink. In order to meet with the conditions so circumscribed, the only resource left is to improve existing grazing resources and increase their production (Mann, 1974).

Studies were, therefore, undertaken in the Range Management and Soil Conservation section and other sections of the Central Arid Zone Research Institute since late fifties on range land paddocks spread out in 10 districts of Western Rajasthan under different agro-climatic conditions. The results of the studies are summarised below.

(1) *Grassland covers in arid zone*

Grassland cover of north western parts of arid regions of India has been recognised as *Lasiurus - Cenchrus - Dichanthium* type (Dabaddhghao, 1960). In a reconnaissance survey of about 11,000 sq. km. in Luni basin of Western Rajasthan, Satyanarayan (1964) reported the following twelve pasture types within this cover:

(1) Short grass community of *Oropetium thomacum* - *Tragus biflorus* which occurs more as a regressive stage representing the most degraded grassland cover.

(2) *Sehima - Dichanthium* type with the highest percentage of perennial species. A few annual palatable legumes also occur within the community, raising its nutritive value.

(3) *Cenchrus setigerus* and (4) *Eleusine compressa* community, generally characteristic of loamy and sandy loam soils. Under a planned stocking rate and regulated grazing period, both these types can be transformed into "Good" and "Excellent" range condition class pastures.

(5) The *cypodon dactylo* community which has a limited distribution and prefers moist loamy soils. This community is a precursor to the *Dichanthium - Cenchrus* type.

(6) *Aristida* community occurring both as a pioneer or retrogressive stages.

(7) *Cymbopogon jawarancusa* type which is unpalatable.

(8) *Panicum antidotale* and (9) *Panicum turgidum* community grazed selectively but having association with fairly abundant top-feed.

Three other pasture communities are characteristic of saline flats and of limited distribution.

(10) *Haloxylon salicornicum* community.

(11) *Atriplex stocksii* community and

(12) *Suaeda fruticosa - aeluropus lagopoides* community.

Different species on Rangelands in Arid Zone

There are above 70 species of grasses and 60 species of legumes etc. in the arid regions. Different species have importance under different ecological conditions. Important grass species of the desert could be

classified as Annuls, low perennials, high perennials. These are given below:-

Annuls

1. *Oropetium thomacum* First coloniser on rocky, gravelly soils. Low set grass can be grazed upon by species like sheep, wild hares etc.
2. *Tragus biflorus* -do-
3. *Aristida species* Shallow rooted grass. Comes up in interspaces of high perennial grasses and in association with low perennial. In pure stand it occurs both as pioneer or retrogressive stage. It comes up under all agroclimatic conditions except on saline soils. It is palatable till middle August. Thereafter awns come up which make it unpalatable.
4. *Cenchrus biflorus* It needs higher rain (soil moisture) than *Aristida* species. It is palatable till middle August, thereafter burrs develop which render it unpalatable.
5. *Echinochloa colonum* Comes up on saline and water logged soils. Palatable at all stages. It also comes up in the interspaces of *Dichanthium annulatum*. Its Palatability rating is good.
6. *Chloris virgata* Comes up on saline soils. It also come up in association with *Dichanthium annulatum*. It is Palatable at all stages.
7. *Eragrostis species* Comes up on light to medium soils with annual rainfall above 300 mm. Palatable at all stages.

Low perennials

1. *Eleusine compressa* Prefers, shallow, gravelly soils. It also comes up well on loamy and sandy soils in association with all high perennial species. On sandy hummock in saline soils this species also comes up. It is palatable at all stages.

2. *Cymbopogon jawarancusa* It comes up in association with *Lasiurus indicus* in extremely arid areas. It can come up on rocky terrian to sandy soils. Its Palatability is rather poor.
3. *Cynodon dactylon* Prefers moist loamy soils. It is highly Palatable at all stages.
4. *Panicum turgidum* Good for areas with shifting sands. It is palatable becomes woody and unpalatable during preflowering stage. After that its roots bind the sands. But it is favourable for dune stabilisation.
5. *Eromopogon foveolatus* It comes up on medium to heavy soils and with annual rainfall above 380 mm and in association with *Dichanthium annulatum*. It gives good tonnage. Its palatability rating is "Good".
6. *Iseilema* sp. It comes up on heavy soils under rainfall above 400 mm annually and gives good tonnage. Its palatability rating is "Good".
7. *Brothrichloa pertusa* -do-
8. *Saccharum bengalense* Good for eroded soils-terrain with ravines. It binds soils—palatability rating is rather poor.
9. *Erianthus munja* Good for stabilisation of dunes. Roots bind the sand. In Haryana, Rajasthan it is found valuable for binding shifting sands.
10. *Sporobolus helvolus* In saline soils where, other edible grass species give poor performance, this species come up well. Yield upto 2 tonnes/ha have been recorded. Palatability is good.

High Perennials

1. *Sehima nervosum* Climax species for hilly terrain.
2. *Lasiurus indicus* King of desert grasses. Comes up on sandy soils, duney areas with low precipitation (rainfall 300 mm and below). Under well managed conditions it can

yield 3.5 tonnes dry forage per hectare during good years of rainfall. It is highly palatable for cattle and sheep upto flowering stage. After September-October it becomes woody when its palatability rating falls.

3. *Cenchrus ciliaris*

Comes up well on light soils with annual rainfall 250 mm and above. It can yield upto 3.5 tonnes of dry forage during good rainfall years. It is highly palatable at all stages by all kinds of farm animals.

4. *Cenchrus setigerus*

It gives high yields on medium soils with annual rainfall of 250 mm and above. Forage yield upto 4.5 tonnes per hectare have been recorded during good rainfall years. Palatability of this species is same that of *Cenchrus ciliaris*.—"Very Good".

5. *Panicum antidotale*

Although this species come up on sandy terrains; it gives very good performances on medium soils with annual rainfall above 250 mm. Upto pre-flowering to flowering stage it is relished by farm animals. Thereafter it becomes woody and hard. It suffers a set back due to moderate to heavy intensity of grazing stress. Forage yields upto 2.6 tonnes/ha have been recorded during good rainfall years.

6. *Dichanthium annulatum*

This species given encouraging performance on medium-heavy soils with annual rainfall above 380 mm. Forage yield upto 8.9 tonnes/ha have been recorded during good rainfall years. It is highly palatable upto flowering and seeding stage.

CLASSIFICATION OF DIFFERENT RANGEL AND TYPES

About eighty to ninety per cent of grasslands in arid regions are under 'Poor' to 'Very Poor' condition and are subject to sever crosion

hazards; while those under climax vegetative cover are not grazed due to water scarcity (Ahuja, 1969).

It is, therefore, necessary to understand the different condition classes of natural rangelands. There are five broad condition viz., (i) "Excellent", (ii) "Good", (iii) "Fair", (iv) "Poor" and (v) "Very Poor". Description of different condition classes of rangelands as given below (Bhimaya and Ahuja 1969).

Excellent condition class of rangeland

The grassland has the optimum density of high perennial grass species like *Dichanthium annulatum*, *Cenchrus setigerus*, *C. ciliaris* or *Lasiurus sindicus* depending upon the edaphic and rainfall conditions of the tract. High perennial species predominate over at least 50% of the total area, as evidenced through stock maps. The perennial species have a vigorous stand with well developed tussocks having abundant number of tillers and height of one metre and above. There is mulch layer in the interspaces between tufts of the plants. The linear transects based on Parker's loop method would record about 4 or 8 per cent hits of high perennial species under low and high rainfall zones respectively. Air dried forage production under normal rainfall year would be about $1\frac{1}{2}$ tonnes and above per hectare and about half of it would be contributed by high perennial grass species. The grazing capacity on year long basis of such rangelands is 25 to 30 adult cattle units per 100 hectares of rangeland.

"Good" condition class of rangeland

Along with predominance of high perennial species there is association of low perennials. High perennial species predominate over an area of about 25 per cent and above of the total land area, as established through stock maps. Low perennial species occupy an area of about 15 to 20 per cent. A few bare spots may occur. There is less mulch in between the tussocks. The linear transects based on Parker's loop method would record about 3 or 6 per cent hits of high perennial species under low and high rainfall zones respectively. Under normal years of rainfall, air dried forage production would be about 1.0 tonnes/hectare; about fifty per cent of which would be contributed by high perennial grasses. The grazing capacity on year-long basis of such rangeland is about 20 adult cattle units per block of 100 hectares of rangeland.

"Fair" condition class of rangeland

The cover consists of mostly early maturing, mid successional stage plants, "Low perennials" mixed with annual grasses. The population

and vigour of high perennial species is considerably reduced and most of them assume prostrate form and their reproduction from rhizomes is limited. The mulch on the surface soil is very much reduced and there are more barren spots with very clear signs of soil erosion. There is conspicuous presence of non-edible bushes like *Tephrosia purpurea*, *Mimosa hamata*, *Lycium barbarum* etc. The stock maps reveal that area occupied by low perennials is about 45 per cent. The linear transects based on Parker's loop method reveal presence of about 2 per cent hits of high perennials and 10 per cent of low perennials. Under normal years of rainfall forage production would be about 0.75 tonne per hectare of which high perennials and low perennials contribute about 20 and 40 per cent respectively. The grazing capacity on year long basis of such rangelands is about 17 adult cattle units per block of 100 hectares.

"Poor" condition class of rangeland

This condition is represented by predominant stand of annual grasses with scattered colonies or admixture of low perennials. In highly saline soils, definite colonies of *Cyperus* species and *Sporobolus halvolus* exist. On rocky and gravelly stretches *Eleusine compressa*, *Dactyloctenium indicus* and legumes like *Indigofera cordifolia* form associations with annuals like *Aristida* sp., *Cenchrus biflorus* and *Oropetium thomaeum* etc. The high perennials occur mainly under bushes and protected places. Their vigour is poor with few tillers and low reproducing capacity; barren spots (conspicuous signs of soil erosion) are markedly evident. The stock maps reveal that the area covered by annual grasses is maximum and it is above 60 per cent. The high perennials, and low perennials cover an area of about 5 and 20 per cent respectively. The linear transects based on Parker's loop method reveal presence of high perennial, low perennial and annual grasses forming 1, 9 and 15 per cent of the vegetative hits respectively. Under normal years of rainfall, the yield of air dried forage is about 0.5 tonne/hectare of which annuals contribute the maximum followed by low perennials. The grazing capacity on year-long basis of such grass and is about 13 adult cattle units on a block of 100 hectares.

"Very poor" condition class of rangeland

Highly denuded open grazing ground with predominant cover of annual grasses and thorny bushes not susceptible to proper assessment. Perennial grass species as a rule are very much denuded or absent. Mulch on the soil is totally absent and large barren spots are very con-

spicuous. Soils are badly eroded. Average air dried forage production is about 100 to 200 kg./hectare or even less.

2) *Technique for improvement, management and Utilisation of rangelands and pastures*

In order to reduce social and economical evils, it is essential to develop these rangeland and their techniques are given below:

2.1 *Selection of sites*

Lands falling under land capability class V to class VII are unfit for crop cultivation and those under Class IV are subject to wind and water erosion hazards. It will be desirable if long term grass crop rotation, is followed on class IV lands to reduce erosion hazards to improve soil fertility and vegetative production. It is advisable to take up pasture development work at sites with the easy accessibility and water facility so that local people can visit the places frequently and realise the value of such developmental work.

2.2. *Fencing*

In this part of the country no development project involving land can be successful without proper protection from biotic factor. Amongst various types of fencings tried and studied it has been found that angle iron posts spaced 6.1 m apart with five strands of barbed wire fencing is by far the most effective and economical in the long run (Bhimaya et al, 1966). As iron and steel material is not easily available trench and core wall fencing, corewall thorn fencing, live hedge fencing may be constructed on co-operative or "Sheramdan" basis by villagers, during forced idle periods or lean periods. Such types of fencings need regular care and repairs.

Presently cost of angle iron post and barbed wire fencing is about Rs. 9.00 per running metre. Cost per hectare is inversely proportional to the size of the block. The cost of fencing per hectare in blocks of 40, 100, 200, 500 and 1000 works out to Rs. 600, 400, 270, 170, 125 respectively (Ahuja, 1974).

2.3. *Grubbing of unwanted bushes*

Unwanted thorny bushes like *Lycium barbarum*, *Balanites aegyptiaca*, *Acacia leucophloea*, *Mimosa hemata* etc. which hinder the growth of grass species and are troublesome to grazing animals should be grubbed

out mechanically followed by application of herbicide 2-4-5-T (trichlorophenoxy acetic acid) immediately after cutting away aerial parts of bushes (Dabadghao, 1969). Even useful top feed species like *Zizyphus nummularia* should not have crown cover more than 14% on range. (Ganguley *et. al.* 1964).

2.4 Soil conservation

On lands with shallow soils and rolling topography with about 2 per cent slope, contour furrows with 929 cm. (1 sq. ft.) cross sections spaced 8 to 10 metres apart increase the forage yield six times (average of ten years, Ahuja, *et. al.* 1973). In case of lands at foot hills (Piedmont) flowing nalas should be harnessed with pucca masonry dam and earthen bunds, across the slope to serve as water spreading devices, and gulleys and nallas to be plugged. Cost of such soil conservation measures presently is about Rs. 150/per hectare and it can be recovered in 3-4 years time due to increase in forage yield. Response of forage production under different soil conservation measures in Range Management Sub-station Jadan is given in Appendix I.

2.5. Stabilisation of sand dunes and moving sands

In arid zone, shifting sands are very active, except during monsoons. They threaten the existence of nearby villages, towns communication lines like roads and fertile lands. If stabilised and managed properly they offer a potential productive site for afforestation and grassland development (Kaul, 1968). For stabilisation and rehabilitation of sand dunes, three distinct processes are involved, namely (a) protection against biotic influence, (b) treatment of shifting sand dunes by fixing barriers (mulching) from the crest down to the heel of the dune across the wind direction, (c) (i) afforestation by direct sowings and or plantings of suitable tree species and (ii) seeding or planting root slips of drought hardy perennial tussocky grass species. In such areas till dunes are stabilised grazing should be prohibited. Grass may be harvested manually. Cost of stabilising the dune presently works out to Rs. 600/- to Rs. 800/- per hectare. (Muthana and Ahuja, 1973).

2.6. Forage production

An efficient grassland management aims at maximum utilisation of forage without undue interference with the growth and vigour of the important fodder and useful species.

With adequate fencing and grazing the rangeland according to their carrying capacity (aiming at 70 per cent forage utilisation level), the

forage yield can be doubled within three years time (Ahuja and Mann, 1975).

Estimated air dried forage production of the protected and properly managed "Very poor", "Poor", "Fair", "Good" and "Excellent" grasslands in arid zone is 200, 500, 750, 1,000 and 1,500 kg. per hectare during normal years of rainfall (Bhimaya and Ahuja, 1969). The yields fluctuate with the rainfall.

2.7. *Reseeding the rangelands*

Natural succession of desired species (climax) species is a very slow process. Hence reseeding the natural grasslands with appropriate grass species suiting the agroclimatic sub-regions, is the only recourse if higher productivity is desired.

2.7.1. *Suitable species for reseeding in different sub-zones*

Rangelands should have maximum coverage of high perennial species in shortest time. *Dichanthium annulatum* gives high yields on heavy soils with annual rainfall above 380 mm, *Cenchrus ciliaris* and *Cenchrus setigerus* produce high forage on well drained soil under rainfall above 250 mm. *Lasiurus indicus* gives high forage yield on sandy soils with low precipitation (300 mm. and below). *Panicum antidotale* performs well on medium textured soils with annual rainfall of 250 mm., and above under protected conditions, while *Setaria nervosa* yields good forage on hilly terrain.

2.7.2. *Reseeding techniques*

This involves thorough soil working, grubbing of unwanted bushes, sowing of appropriate grass species and after care of the resultant cover. These operations should be completed by end of June. Due to erratic rainfall conditions, and poor germinations of seeds of *Lasiurus indicus* and *Dichanthium annulatum* (Ahuja and Bhimaya, 1967), sowing of mixture of seeds of *Cenchrus* species and *Lasiurus indicus*, *Cenchrus* species and *Dichanthium annulatum* are recommended for low and high rainfall tracts respectively (Ahuja and Bhimaya, 1966). The seed rate of different mixtures is about 5 kg. per hectare.

In order to have better results of reseeding, the grass seeds should be pelleted. (Chakravarty and Bhati, 1969). Pellets are prepared by mixing seeds of grasses, cow dung, tank silt or clay and sand in proportion (by volume) 1 : 1 : 3 : 1, using sufficient quantity of water and preparing round pellets (of the size of about 0.5 to 1.0 cm. diameter), each

pallet containing 2 to 3 spiklets, and then dried and stored. Cost of palletting of seeds is Rs. 3.00 to Rs. 3.50 per kg. The pallets should be sown in lines 60 to 75 cm. apart taking care that pallets are not placed more than 1 to 2 cm. deep in the soil. Sowing operations with palletted seeds should be carried out just before the expected first effective rainfall of monsoons.

In view of the fairly high cost involved and slow juvenile growth of high perennial grasses, it is advisable to resort to root slips planting of grasses like *Lasiurus indicus* and *Dichanthium annulatum* and nurseries established for the purpose (Ahuja and Bhimaya, 1967). Chakravarty and Verma (1969) found better establishment in *Lasiurus indicus* pasture by planting seedlings in comparison to rooted slips. But due to water scarcity conditions presently, the use of rooted slips is recommended.

Such reseeded grasslands need at least two weedings during their first year of establishment (Chakravarty and Verma, 1972).

In highly saline soils where other good species fail to come up a lower perennial grass like *Sorobolus helvolus* performs well. It is quite nutritive and has high forage production potentials (Ahuja and Bhimaya, 1966).

2.7.3. Fertilisations

Nutritive value of high perennial grass species is very high 6 to 12 per cent (Mondal and Chakravarty, 1968; Sen and Ray, 1964; Ahuja, 1973). It is, therefore, essential to provide adequate soil nutrients for optimum production from these grasses. Application of sulphate of Ammonia @ 113 kg/ha. (20 lb. Nitrogen per acre) has resulted in increased yields of forage by 50 to 70 per cent over their respective controls (Ahuja, 1973). The protein content of forage fertilized pasture was higher than in control plots, during years of normal rainfall.

2.7.4. The production capacity of these reseeded grasslands is very high. Yields of air dried forage from pastures of *Dichanthium annulatum*, *Cenchrus* species and *Lasiurus indicus* of 8.9, 4.7 and 3.6 tonnes per hectare respectively have been recorded under rainfed conditions. *Sporobolus helvolus* has recorded yield of 2.0 tonnes per hectare (Ahuja, 1969). Different intensities of grazing stress (T1 grazing on capacity, T2, T4 heavy intensity of grazing, T3, T5 moderate intensity of grazing) did not affect yield of *Lasiurus indicus* for a period of 5 years (Appendix II) and *Cenchrus setigerus* for a period of 3 years. Due to improvement of native grasslands, following above technique their carrying capacity will increase many fold (4-6 times) and provide highly nutritive fodder. It is further observed that more

land is available for pasture development in arid regions with mean annual rainfall below 300 mm. If the existing rangelands are improved upon the shortage of forage could be reduced from 39.3 per cent to 2.5 per cent (Appendix III) (Ahuja, 1973) while due to heavy pressure for cultivation in the sub-zones with mean annual rainfall above 300 mm., the available land (proportionately) for grassland improvement is very much less and the pressure of live-stock per unit area is more. Here the shortage of forage could be reduced is 19.4 per cent. In this region cultivation of the fodder crops in combination with legumes will have to be resorted to if proper livestock production is envisaged (Mann, 1974). As a result of pasture improvement the increase in carrying capacity is two to three fold (Appendix IV).

2.8. Maintenance of top feed cum shade trees on grasslands

On a "Good" grassland, there should be per hectare about 25 to 30 useful tree species like *Prosopis cineraria*, *Azadirachta indica*, *Salvadora* sp., *Albizzia lebbek*, *Acacia nilotica* etc. suiting different habitats to provide top feed, shade, during lean periods of the year, timber and fuel (Bhimaya and Ahuja, 1966). In areas under shifting and semi-shifting sand dunes, *Acacia tortilis* have given good performance. In saline areas, species like *Tamarix articulata*, *Prosopis juliflora*, *Acacia nilotica* have performed well. Protein content of leaves of top feed species is very high, i.e. 10 to 29 per cent (Ganguly *et. al.* 1964). These authors report palatability rating, of the top feed species as fairly good.

2.9. Rangelands with climax vegetation

Extensive areas in the low rainfall region of Jaisalmer, Bikaner and Barmer districts are covered by the high producing nutritive grasses like *Lasiurus indicus*. But these pastures are fast deteriorating due to indiscriminate over-grazings. Such vast areas cannot be protected in a short time. In order to upgrade these pastures, these areas may be brought under the purview of the *State Forest Act* or the *State Soil Conservation Act* then regulated grazing could be dividing the area into suitable blocks and practising rotational grazing.

2.10. Hilly areas

In hilly tracts and at the foot hills reseedling is generally not a practical proposition. Controlled grazing on the basis of the optimum grazing capacity is the best way of upgrading such grasslands.

2.11. Reclamation of eroded and ravine areas

Vast areas are eroded and regular gulleries and ravine formations have been formed. It is essential to carry out detailed integrated survey of such land forms and phased programme for development taken up. Broadly following work has to be taken up.

Construction of small check dams of random rubble masonry may be carried out in nallas and ravines. Existing trees and shrubs should not be uprooted immediately and more useful species may be planted in a phased manner. Tree species may be pruned upto the height of 2-3 metres so as to provide sufficient sun shine for grasses which grow underneath the trees. On the slopes and ridges etc. small thorny bushes may be got eradicated and in their places and in space in between trees, tussocky grass species like *Cenchrus* species, *Saccharum bengalense* etc. must be planted and encouraged. *Saccharum bengalense* must be encouraged on the bed of nallas and gulleys. On the slope planting of trees like *Prosopis cineraria*, *Acacia nilotica*, *Azadirachta indica*, *Acacia tortillis* may be carried out.

2.12. Legumes for improvement of soil fertility and rangeland production

As availability of fertilizers is problematic concern and their cost is rising, role of legumes on grassland production is under study. In limited trials legumes in combination with cultivated grasses, pasture have given higher forage yields with more protein content in the composite forage. Studies on compatibility and performance promising legumes like *Dolichos lab lab*, *Phaseolus atropurpureus*, *Clitoria ternata*, *Rhynchosia minima*, *Alysicarpus scaraboides*, *Cyamopsis tetragoloba*, *Phaseolus aureus*, *P. aconitifolius*, *Vigna sinensis* etc. on grasslands with different grass covers and under agroclimatic sub-regions are in progress. In areas like Bikaner District in pure stand of *Lasiurus sindicus* legumes like *Phaseolus aconitifolius* (Moth) are taken as in interspace crop. It adds to the resultant product.

2.13. Utilisation

It is advisable not to graze resseeded pastures during the first year of establishment. However, if the establishment is good, the grass may be manually harvested during November or so. In the second year of establishment the grazing should be so arranged that proper seed formation and shedding of the seeds takes place to guarantee satisfactory regeneration of these species and forage production is never allowed to decline and the pasture is kept in a progressively improved condition.

After the entire area of the rangeland is established with climax vegetation, as a result of reseeded, it is advisable to utilise it rationally which is discussed below.

Utilisation of forage from grasslands can be through (a) harvesting, preserving and then feeding to the livestock, (b) grazing.

(a) *Harvesting*: Due to very low forage yield from existing rangelands cost of harvesting is exorbitant. Harvesting time of agricultural crops and forage on the ranges coincide. (Ahuja, 1966).

In reseeded, established and fertilized pastures, forage yield are fairly high, it is best to reserve a portion (about 25%) of it to harvest during flowering stage and preserve it as hay for feeding down calves, milking stock, sucklings, sick animals, working bullocks and all stocks during adverse climatic conditions.

(b) *Grazing*: - Best way to utilise the native rangelands is through controlled grazing which is dependent upon carrying capacity. Carrying capacity (on yearlong basis) of pastures under five different condition classes in arid zones, during normal years of rainfall is as under:

Conditione class of Rangeland	Number of adult cattle units (300 kg. body weight) per 100 hect.
"Excellent"	25-30
"Gold"	20
"Fair"	17
"Poor"	13
"Very poor"	6 and less.

Grazing saves cost of harvesting of low set grasses and low yielding annual grass species. Livestock while grazing work up the soils through their hooves, break up the top crust of soil, thereby encouraging better porcolations of water for plant use and better rang production. Their excreta i.e., dung and urine add to the plant nutrient contents of soil and improve its fertility. (Ahuja, 1966).

It is best to not to carry out grazing in the grassland immediately after the onset of monsoons. Continuous grazing on grasslands is likely to result in depletion of desirable and climax species in the long run. Hence rotational grazing is suggested. Presently following grazing schedule is suggested.

For grazing grasslands with dominance of perennial grass species or reseeded grasslands, the area may be divided into four compartments

A, B, C & D and four years cycle of rotational grazing may be carried (based on carrying capacity) on the schedule given below:

Year of grazing	Grazing month of year and Compartments			Reserve Comptt.
	Aug., Nov., Feb., May	Sept., Dec., March, June	Oct., Jan., April	
1st year	A	B	C	D
2nd year	B	C	D	A
3rd year	C	D	A	B
4th year	D	A	B	C

The compartments should be demarcated by proper fencing. If fencing material is not available, fibre lines or katcha roads about 10 m wide should be drawn out mechanically and rotational grazing carried out with the help of graziers. Grass from reserve compartment may be used for animals during July and for stall feeding as and when needed as discussed above. Production potentials from different sub-stations under different soil and rainfall conditions in arid zone are

presented in Appendix V.

(c) *Suitable species of farm animals for different types of Rangelands*

Different species of farm animals utilise different plant species depending upon their chemical composition, growth, morphological, physiological and other characteristics. A rangeland infested with bushes, thorny vegetation could be used by goats. Low set species are well used by sheep. Tussocky grasses like *Lasiurus indicus*, *Dichanthium annulatum*, *Panicum antidotale* etc. are more fruitfully used by large animals like cattle. Hence the choice of introduction of farm animals on the range depends upon its botanical composition.

(d) *Palatability of different species and grazing behaviour of animals on the rangeland*

On rangeland various types of plant species come up whose growing habits, morphological and physiological characteristics differ considerably, and these affect their utilisation by different species of farm animals. Amongst all grasses, *Cenchrus ciliaris* and *Cenchrus setigirus* the perennial species are most palatable to all species of farm

animals during the entire year. Annual species like *Aristida funiculata*, *Cenchrus biflorus* cause severe discomfort to sheep from middle of August to beginning of November as their awns and burrs pierce through the mouth parts and skin of grazing animals. Such species are are troublesome to cattle also. During this period perennial species like *Dichanthium annulatum* and *Lasiurus indicus* are relished the most. From November onwards these perennial species become woody, therefore, are not liked by cattle and cause discomfort to sheep by injuring their mouth parts with sharp ends of stems; and therefore, annuals whose burrs and awns have shedded are relished. From March onwards when annual grasses get exhausted, high perennials get broken down, are eaten. Details have been discussed by Ahuja (1971). During hot weather, animals are crazy after greens. Cattle eat green shoots of *Calligonum polygonoides*, *Caparis aphyla* and flowers of *Aerua psudotomentosa* which are normally unacceptable to them. *Tribullus terrestris* is poisonous to cattle, while it is highly nutritive for sheep. *Fagonia cretica*, *Boerhavia diffusa* *Blepharis* sp. etc. sp. are palatable to sheep but are not palatable to cattle. Due to thorny nature of plants, species like *Lycium barbarum*, *Balanites aegyptiaca* and *Mimosa hamata* are harmful to cattle on the range, but their leaves are eaten up by mostly goats, and to some extent sheep. Tussooky grasses like *Dichanthium annulatum* and *Lasiurus indicus* during maturity, are unpalatable to sheep and goats, but are grazed upon by cattle, low set grasses like *Oropleium thomaeum* and species of *Enneapogon* can be only grazed upon by sheep. In order to have best utilisation of rangeland production, it is best that sheep and goats follow cattle. Goats will eat up thorny bushes which otherwise are troublesome to cattle (Ahuja, 1971).

2. 14. Livestock responses to different grazing systems

Amongst the various systems of grazing tried viz. deferred and deferment cum rotational grazing trials conducted, continuous controlled grazing on yearlong basis, has given the highest livestock returns (Ahuja, 1964). During monsoon seasons when the grass on the rangeland is green and highly nutritious, livestock production is highest irrespective of condition class of grasslands. During this period cows yielding 3 litres of milk per day did not need any concentrates.

Young growing stocks, in yearling heifers also exhibited highest gains under continuous controlled grazing system on yearlong basis. The gains in body weight of yearling heifers under "Poor" and "Fair" rangeland have been recorded as 64.6 and 67.9 kg. per year respectively. Total gains in body weight of yearling heifers on a unit area

of 100 hectares of "Good", "Fair" and "Poor" condition class of rangeland were 1897, 1656 and 1056 kg. respectively per year (Ahuja, 1964).

Irrespective of the type of pastoral treatment highest livestock production was recorded from July to October when the forage on the rangeland is mostly green. The increase in body weight of Kankrej and Tharparkar heifers has been found to be 10.5 and 12.5 kg per month per animal respectively during the above reported period (Ahuja *et al* 1968, 1969).

The gains in body weight of animals fell after the grass on the range gets weathered. By feeding concentrates to meet with D.C.P. and T.D.N. needs from January to July (lean periods of the year) the growth doubled in comparison to that under year long continuous controlled grazing (Ahuja *et al*, 1971; Ahuja *et al*, 1968).

Growth of yearling ram lambs, on yearlong basis was 15 to 26 kg. per animal per year depending upon the pasture type and breed. Wool production was about 2 kg. per animal per year (Ahuja *et al* 1967, 1970). On the whole growth of heifers was higher than that of sheep under continuous controlled grazing system (Appendix VI).

2. 15. Supplement feeding

About 90 per cent of the total rainfall, in this region occurs during July to 1st week of September (about 8 weeks) in a year. Even in rangeland, dominated by climax species like *Cenchrus species*, *Lasirus indicus*, *Dichanthium annulatum*, *Panicum antidotale* etc. grasses get weathered and nutritional level in grasses falls down from December onwards. It does not supply adequate nutrients to the grazing animals on the ranges. Studies at the sub-stations of the Central Arid Zone Research Institute, Jodhpur reveal that it is essential to provide supplemental feeding in concentrates to meet with D.C.P. and T.D.N. requirements of the productive stocks like growing stocks, working animals etc. By providing supplement feeding in concentrates, as mentioned above, growing heifers nearly doubled their growth in comparison to those under continuous controlled grazing on yearlong basis (Ahuja *et al* 1968, 1971). Cost of such concentrate feeding is about Rs. 1.40 per kilogram increase in body weight of growth. Such increase in body weight hastens maturity and finally livestock production the long run.

It is advisable to purchase concentrates for productive stocks, sick animals etc. during harvesting times when they are cheap and stored properly.

2. 15. *Waer requirements for drinking for different species of farm animals on the range, during different seasons have been determined.*

No range management programme will be successful unless adequate arrangements for drinking water for animals and workers are made. In the interior of the desert, water is one of the main limiting factor for proper livestock production. Vast stretches of grasslands under climax to sub-climax cover of *Lasiurus indicus* (Sewan) remain under utilised due to non-availability of drinking water. In some places the water of tube well sunk is brackish. Till some permanent arrangements for water supply is made, it will be advisable to provide under ground water, reservoirs (Tankas) for stock and human consumption on the range. A 'Tanka' with a capacity of 200 kilo litres costing about Rs. 16000/- is sufficient for 100 hectare of "Good" condition class pasture. But in areas with high scarcity of water, if only seasonal grazing on carrying capacity basis is practised, a "Tanka" having capacity of 200 kilo litres will suffice for 150-200 hectare of rangeland (Ahuja and Bhimaya, 1967, Prajapati et al 1973).

Drinking water requirement of farm animal on the range per day during different parts of the year are given below:—

Table : Drinking water consumed by farm animals of the range per animal per day (litres).

Kind of live stock	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
<i>Adult Stores</i>												
i) Cows dry	—	—	—	—	—	—	10.3	26.5	28.6	32.8	35.0	41.3
ii) Sheep	—	—	—	—	—	—	2.1	2.1	2.7	3.2	3.8	4.5
iii) Growing stock (Yearling)												
Heifers	10.6	11.1	12.6	12.9	11.3	9.0	10.2	12.1	13.5	15.0	15.9	17.0
iv) Ram lambs	2.4	2.4	2.1	1.9	2.1	1.6	1.8	2.2	2.5	3.2	3.8	4.0

The intake of water during monsoons (July-October, when grass on the range is succulent) and autumn and winter (November-February, when temperatures are low), is reduced; while it increased during hot weather months. Adults take more water than yearling ones (Ahuja, 1964).

Due to scarcity of water, it has been possible to keep sheep living properly on water supply reduced by 25 per cent of normal needs, even during hot weather, for restricted periods (Purohit *et. al.* 1973).

Animals can tolerate higher salt content in water than plants. The intake of water and physiological functioning of sheep given normal water and water with 1 per cent salt for about a fortnight did not differ significantly. But animals lost their body weight and intake of water was reduced if the concentration of salt in water was raised beyond that to 1.3 per cent and this is considered unfit for sheep (Ram Ratan, 1970).

2.16. *Rodent control*

Some vertebrate pests viz. rodents like gerbils cause heavy damage to pastures by gnawing the stems and eating away the rhizomes.

No pasture development programme will be successful unless gerbils control measures are adopted. Amongst the various poisons to kill these rodents pests tried, baiting with zinc phosphide and compound 1080 have proved to be most efficacy and economical in the long run (Prakash, 1969).

2.17. *Livestock management on rangelands*

Animal Health: Due to inadequate communications in the interior of the desert and high cost of treatment of animals, it is advisable to adopt prophylactic measures to ward off the attack of diseases as far as possible. It is very essential to carry out periodic preventive inoculation and vaccinations against contagious and deadly diseases like Rinder Pest, Haemorrhagic Septicimia, Black Quarters etc. In case of sheep it is essential to carry out periodic deworming. External parasites like ticks, lice, etc. should be controlled by dipping or spraying periodically. In the arid regions, mineral deficiencies in livestock are very common. It is advantageous to provide mineral mixture in feeds and mineral salt licks. After taking these precautions and providing necessary timely veterinary aid, not only cost of feeding goes down, but the mortality is reduced and the returns from livestock increase (Ahuja and Bhatia, 1969).

3. *Housing livestock*

In arid zone, provision for adequate housing for livestock has not received any attention so far. Housing of livestock could be (a) for migratory stocks which should be movable and (b) for stocks reared and managed in situ.

Due to recurrent, famines, migration of livestock during lean periods, from arid regions to states where grazing is available, is a common

feature. For protection of animals from vagaries of climate, wild animals and theft and safety during migration, movable or collapsible livestock housing, equipment, light in weight and easily manageable is needed. For protection, angle iron posts and woven wire will serve the purpose. In case of sudden drop in temperature small chholdari (tent) type material with tarpaulin (water proof material) roofing erected on bamboo poles to protect the livestock from rain and wind will serve the purpose.

For livestock kept on rangelands, the site for animal houses should be on well drained soils, preferably at elevated site, adjoining a shelter belt on wind break. A well protected cattle shed, sheep pan, goat pan with high roofs is essential to protect animals against vagaries of weather viz. high temperatures during day, low temperatures in winter and rainy period. Young stock, pregnant dams, lactating and nursing animals, draught animals, sick animals and studs need special care in this respect. Prajapati *et al* (1969) suggested an animal house opening towards east or south-east (to save animals from scorching sun during afternoon, hot and sandy storms and cold winds). For 20 yearling heifers it should have a gross area of 21.3×9.1 m. protect by angle iron post and woven wire fencing with covered shade of 2.9 m. breadth 12.2 m. length and 2.4 m. to 2.8 m. height. This provides covered area of about 1.8 sq.m. supplemented with about 7.4 to 9.3 sq.m. loafing yard with watering, feeding and mineral salt arrangements per animal. Thatching of roofs with tattas made of thorns of *Zizyphus nummularia* or *Aerva pseudolomentosa* etc. insulates the material and provides adequate protection against regours of cold and heat. Cost of such shade works out to about Rs. 2,000/- for 20 yearling heifers or 10 cows or 100 sheep.

4. Assessment of performance of animals (cattle)

For periodical assessment of changes in body weight for growth rate and requirements of feeds, it is essential to know the body weights of animals. Small animals like sheep and goats could be weighed with the help of spring balances etc. but heavier animals like cattle need weighing machines which are difficult to maintain and handle in the interior of desertic areas. Therefore, regression equations have been evolved (Ahuja *et al* 1964, Ahuja, 1965) to estimate body weight of cattle with the help of heart girth and these are given below:—

Adult cows	$Y = 5.1180 \times - 479.7$
Male calves	$C = 3.053 \times - 220.9763$
Heifers	$Y = 2.8798 \times - 204.3452$

Where Y is the estimates body weight in kg. and X is heart girth in cm.

Thus for proper livestock production for improving economy in the arid regions, it is essential to use the pastures rationally. This will also speed up supplies of better quality livestock from arid regions to other areas for increasing their animal production.

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APPENDIX I
ABOVE GROUND PHYTOMASS PRODUCTION (AIR DRIED FORAGE YIELD KG/HA) UNDER DIFFERENT
SOIL CONSERVATION MEASURES

Year	Contour furrowing				Contour bunding				Contour trenching				Rain-fall in mm
	Treated	Control	Difference	Percentage increase	Treated	Control	Difference	Percentage increase	Treated	Control	Difference	Percentage increase	
1961	796.2	257.0	539.2	230.2	3220.5	83.2	2237.3	2533.0	724.2	257.7	466.6	181.0	544.9
1962	2297.0	212.0	2085.0	963.4	2183.2	413.1	1770.1	410.6	1467.9	274.5	1193.4	434.7	297.9
1963	647.6	65.5	582.1	833.4	1545.7	233.3	1253.4	435.4	864.2	184.2	630.0	359.1	250.4
1964	1951.0	110.0	1841.0	1673.6	1967.4	437.4	1470.0	295.51	1838.7	593.3	1204.4	207.3	394.0
1965	2293.3	234.3	2059.0	878.7	1716.4	1053.2	643.2	60.6	1549.5	905.2	643.3	70.9	477.8
1966	2328.1	255.3	2072.8	811.9	1635.2	1462.6	222.6	15.2	1791.2	908.0	883.2	97.2	446.2
1967	1741.0	434.4	1306.7	350.8	1033.8	822.2	277.6	33.7	1265.4	866.8	418.6	49.2	789.0
1968	371.8	27.6	354.2	2012.5	63.9	20.8	43.1	207.2	74.0	19.4	54.6	281.4	126.2
1970	1669.8	328.4	1341.4	403.4	11195.5	763.5	1227.0	159.6	2235.4	471.6	1823.8	386.7	586.0
Mean	1566.2	212.7	1353.3	633.7	1619.8	632.7	1017.1	163.8	1321.1	498.5	822.6	165.0	
SEm	183.2	183.2			196.6	196.6				177.7			
F Test	Highly significant				Highly significant				Highly significant				
C.D. 5%	547.6	547.6			567.6	567.6			531.2	531.2			
1%	754.5	754.5			809.7	809.7			731.9	731.9			

(Source Aluja, *et. al.* 1973)

APPENDIX II

Above ground Phytomass production (air dried kg/ha) from *Lasiurus sindicus* under different intensities of grazing stress in different years.

Treatment	Years					Mean	F. Test	CD level	
	1965-66	1966-67	1967-68	1968-69	1970-71			5%	1%
Rainfall mm	134	167	227	70	258				
T-1	252	344	372	16	124	242			
T-2	259	208	153	10	143	155			
T-3	303	241	224	13	93	175	25.1	Not Sig.	
T-4	325	172	155	18	125	159			
T-5	282	316	214	18	178	202			
Mean	304	256	224	15	133	187			
San			25.1						
C. D. at 5%			69.56						
1%			91.42						
Years	304	256	224	133	15				
	(1965-66)	(1966-67)	(1967-68)	(1968-69)	(1970-71)				

APPENDIX III

Land, Livestock and Forage Production after Pasture Development in Arid Zone
(Western Rajasthan)

Particulars	Annual aver. rainfall 300 mm & below.	Annual aver rain fall 300 mm & above	Total
1. Total land for pasture development ('000' hectares)	5488	1607	7095
2. Expected production of dry forage after improvement (m. tonnes per yr)	3.8416	1.9234	5.7700
3. Forage from cultivated crops (m. tonnes/yr.)	2.7470	4.9040	7.6510
4. Total forage (m. tonnes) (2-3)	6.6186	6.8324	13.4210
5. Total livestock population (m. acu)	2.653	3.769	6.422
6. Forage needs/yr. (M. tonnes)	6.759	9.611	16.370
7. Shortage (m. tonnes) (6-4)	0.1406	2.7786	2.9590
8. Percentage shortage (%)	2.5	28.9	18.1
9. Present shortage (%)	39.3	36.2	37.5
10. Shortage met with due to pasture development	36.8	7.3	19.4

APPENDIX IV

Carrying Capacity-Adult Cattle Units (A.C.U.) Per 100 Hectares/Year

Particulars	Annual aver. rainfall 300 mm & below.	Annual aver. rainfall 300 mm & above
1. Present carrying capacity (A.C.U.)	4-8	12-20
2. Carrying capacity after protection (A.C.U.)	8-20	24-30
3. Carrying capacity after soil conservation reseeding (A.C.U.)	20-30	40-48
4. Increase in carrying capacity due to improvement practices (3-1)	16-22	26-28
5. Increased yield of forage tonnes (2.5 tonnes/A.C.U.)	40-55	65-70
6. Value of increased forage (Rs.)	4000-5500	6500-7000

APPENDIX V

AIR DRIED FORAGE YIELD IN DIFFERENT RANGELANDS UNDER DIFFERENT AGROCLIMATIC REGIONS IN ARID WESTERN RAJASTHAN

Name of the RM & SC Area	Average annual rainfall	Soils	Perennial grasses suitable	In resceded area		Remarks
				Average yield of (kg/ha)	Maximum yield obtained (Kg/ha)	
1. Jaisalmer	189	Sandy rocky	Lasiurus sindicus	500	1600	
2. Chandan	149	Sandy	-do-	500	2300	
3. Khetolai	216	Gravelly shallow	Eleusine compressa	300	—	Range does not respond to reseeding
4. Lawan	171	-do-	-do-	300	—	
5. Beechwal	215	Sandy	Lasiurus sindicus	500	1000	
6. Bhopalgarh	304	Gravelly	Dichanthium annulatum & Cenchrus setigerus	600	1200	
7. Borunda	366	Rocky-sandy loam	Cenchrus setigerus	1400	3300	
8. Samdari	340	Sandy	Cenchrus sp. & L. sindicus	1000	2000	
9. Jadan	347	Shallow-heavy saline	Cenchrus setigerus & Dichanthium annulatum	1500	2500	Repeated reseeding is essential
10. Jaswantgarh	410	Heavy-saline	Sporobolus helvolus	1000	2500	Reseeding not practical
11. Palsana	541	Loamy-sand	Cenchrus ciliaris & G. setigerus	900	2000	only naturally succeeding <i>Sporobolus helvolus</i> to will perform well
12. Bisalpur	553	Shallow-heavy	Dichanthium annulatum	1600	3000	
13. Bilawas	450	Loamy to clay loam	Dichanthium annulatum	2000	5000	
					9000	

APPENDIX VI

Comparative Gains (Kg.) In Body Weights of heifers and Ram Lambs per 100 Hectares in Pastoral Treatment Continuous Controlled Grazing.

Condition class in rangeland	Heifers	Ram lambs
Poor	1055.8	585.0
Fair	1656.1	751.9
Good	1891.7	—

TERMITE ECOLOGY IN THE INDIAN DESERT ECOSYSTEM: A REVIEW OF RECENT WORK

M. L. Roonwal*

ABSTRACT

1. Faunal composition: Of the 32 termite species now known from Rajasthan (Western India), 27 occur in—the desert portion. 2. Six ecological groupings of these species are recognised, depending on the zones which they inhabit, viz., arid, semi-arid, wet, versatile, wood-inhabiting and canal-irrigated. 3. Soil preferences are discussed. 4. Swarming is now known in eleven desert species. It occurs only once a year and is confined to a few weeks (mostly mid-June to mid-August) in the monsoon. Its occurrence is conditioned largely by the immediately preceding rainfall. When rains fail, no swarming occurs. 5. Some desert termites have been bred in a recently evolved cement breeding cage which is briefly described. 6 A complete bibliography of termites of the Indian Desert is given.

INTRODUCTION

Rajasthan covers an area of 3,42,274 sq. km. of which the desert portion, which forms a part of the Great Indian Desert, occupies about 1,96,150 sq. km. A great deal is known about its physiography and climate, and a repetition of this information is superfluous.

Much work on Rajasthan termites (Insecta : Isopetra), especially of the desert area, has been done in the last 20 years. The faunal composition is now known to consist of 32 species. Although considerable information has also been gathered on ecology and biology, a great deal still remains to be known. The results so far obtained in a few fields are briefly discussed here. These studies have been circumscribed by the limited efforts which my students and I have been able to make, and I hope others also will now come forward and take part in this effort.

FAUNAL COMPOSITION

The first essential for an ecological study is accurate taxonomy—the faunal composition. The first serious collection of Rajasthan ter-

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mites was made by me in 1952 when I was at the Forest Research Institute, Dehra Dun; several districts were surveyed. In the years which followed, many headquarters parties of the Zoological Survey of India, Calcutta, made annual surveys, especially in the western desert districts. The abundant material so collected was studied at Calcutta and resulted in the publication, from 1960 onward, of a number of papers by Roonwal and Bose describing new species, culminating in 1964 in a faunistic monograph entitled "Termite fauna of Rajasthan, India", published in *Zoologica*, Stuttgart, 40 (3) (Heft 113). Here 19 species and subspecies, including some new ones, were recognised.

In the next ten years two of my students (S. C. Verma and N. S. Rathore) and I, as well parties of the Desert Regional Station of the Zoological Survey of India, Jodhpur, have continued to collect, and as a result we now know 32 species (some of them new) in Rajasthan, belonging to four families and 14 genera; of these 27 species occur in the desert region. Ecological studies were also made by us during this period.

The morphology of the various castes of the Harvester Termite, *Anacanthotermes macrocephalus*, a desert species, has been studied by my former student, Dr. S. D. Gupta (1962 *a, b*). Another former student, Professor K. S. Kushwaha (1960-61) has studied the pest aspects of termites in southern Rajasthan.

DISTRIBUTION IN RELATION TO RAINFALL AND VEGETATION

Regarding rainfall and vegetation we may divide Rajasthan into three zones:

Arid Zone: Annual rainfall below 30 cm. Low bushes, few trees; largely sandy. Two gerbils, *Meriones hurrianæ* and *Tatera indica*, abound and make underground tunnels. No cultivation. (Western region.)

Semi-arid Zone: Annual rainfall 30-60 cm. Open scrub. Some cultivation. (Central region.)

West Zone: Annual rainfall above 60 cm. Fairly well-wooded. Cultivation. (Eastern and south-eastern region.)

The 32 Rajasthan species can be grouped into six main ecological categories as follows (some species overlap):—

Arid Zone species: 17 species (5 exclusively).

Semi-arid Zone species: 20 species (2 exclusively).

Wet Zone species: 20 species (5 exclusively).

Versatile species: 10 species. Occur in all areas.

Wood-inhabiting species. 4 species.

Species of canal-irrigated areas: Little is known yet. A mixture is expected here.

RELATIONSHIP WITH SOIL, ETC.

Except the exclusively wood-inhabiting kalotermitid, the recently discovered *Incisitermes didwanaensis* Roonwal and Verma, all others dwell underground and come out to forage above ground under earthen shelter tubes made by workers. The Harvester Termite, *Anacanthotermes macrocephalus*, is an exception and forages in the open without shelter tubes. Desert species build no mounds, even though in moister areas elsewhere some of them are habitual mound-builders (e.g., *Odontotermes obesus*).

Some species show marked soil preferences. The Rajasthan Sand Termite, *Psammotermes rajasthanicus*, is confined to the sandy areas of the western desert, and just reaches east to Jodhpur. The Harvester Termite, *Anacanthotermes macrocephalus*, occupies both sandy and gravelly soils, and reaches east to the Jodhpur District. Some species, specially *Eremotermes* spp. and *Microtermes* spp., attack roots; in the hot summer months they go deep down to tap moisture from the roots of desert bushes.

SWARMING (TABLE 1)

The swarming of hundreds of thousands of winged termites (primary reproductives) in the desert region is an annual phenomenon of

Table 1.—Termite swarming in the Indian Desert

Species	Period of swarming	Time of swarming	Remarks
1. <i>Anacanthotermes macrocephalus</i>	First 3 weeks August	Night (8-11 PM)	Swarm also in a drizzle
2. <i>Heterotermes indicola</i>	2nd week July to 3rd week August	Night (8-8-30 PM)	—
3. <i>Coptotermes heimi</i>	End—May to early August	Night (8-9 PM)	—
4. <i>Eremotermes paradoxalis</i>	Mid-August	Evening (4-45-7-45 PM)	—
5. <i>Microcerotermes raja</i>	End-June to late August	Day (10 AM-3-15 PM)	—
6. <i>Angulitermes jodhpurensis</i>	Mid-August	Afternoon (2-15-4 PM)	Swarm even in heavy rain
7. <i>Odonotermes distans</i>	Mid-August	Evening (6-30 PM)	—
8. <i>Odontotermes obesus</i>	Early July to 3rd week August	Night (8-9 PM)	—
9. <i>Microtermes mycophagus</i>	3rd week June to 3rd week August	Night (8-9 PM)	—
10. <i>Microtermes obesi</i>	„	Day (10-30 AM-1-30 PM)	—
11. <i>Microtermes unicolor</i>	Early July to 3rd week August	(Night 8-15 PM) fl	—

great biological and economic significance. Biologically, this permits wide dispersal of the species. Economically, this dispersal increases the area of attack on crops and buildings. So far we have swarming records of eleven desert species (Table I) from whose study the following are the more important conclusions arrived at:—(i) Swarming occurs only once a year during a short period of at the most 9 to 10 weeks, in the monsoon, mostly from mid-June to mid-August. (ii) Each species has its own characteristic hour of swarming. Some swarm in the day in bright sunshine (*Microcerotermes raja*, *Microtermes obesi*), others in the evening or at night. Even in the same genus, one species, *Microtermes obesi*, swarms in the day, and another, *M. mycophagus*, at night (8-9 p.m.). (iii) Rainfall is the immediate stimulus for the initiation of swarming which generally occurs either immediately after the receipt of rainfall or within a few hours of it. (iv) Fully developed winged imagoes may remain in the nest for as long as a month or more before swarming out on receipt of rainfall. When the rains fail, no swarming occurs.

BREEDING DESERT TERMITES

Breeding

In recent years we have bred four desert species in Jodhpur, viz., *Anacanthotermes macrocephalus*, *Microcerotermes raja*, *Microtermes mycophagus* and *M. obesi*, and obtained information on egg-laying, brood-care, incubation period, hatching, etc. These are the first breeding records of termites of the Indian Desert. The first eggs, usually a few, are laid a few days after swarming, and this initiates an active egg-laying period of a month or so which is followed by a long rest period of several weeks before more eggs are laid.

A cement breeding cage

For those who may wish to breed termites, I would make mention of a cement breeding cage which we have used in recent years (for design and method of construction, vide Roonwal, 1973b). The dimensions, etc. of the cage are: Outer 50 × 40 × 10 cm. (excluding stone base). Inner: 42 × 32 × 5 cm. Weight: 30 kg. (including stone base and glass top). The main components of the cage are: A stone slab as base; a square or rectangular cement trough with grooved flooring (the cage proper) cast on the slab surface; ventilation tubes and water supply tubes (with cotton wicks) fixed in the cage walls; a grooved rubber lining on the top of walls; a glass top resting on the

rubber lining; and finally, a thick black cloth cover over the glass top. The floor is sprinkled with moist sterilised soil, and termites are released there. They can be observed through the glass top. Precautions against predators, especially ants, are necessary.

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ECOLOGY OF INSECT PESTS

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INTRODUCTION

The term 'arid zones' that is, regions deficient in rainfall, being characterised by extremely high temperatures strong wind, low humidity and excessive evaporation. Under such extreme adverse conditions the survival of the plant and animal life would seem very intriguing and yet the whole complex of life exist there. The number of insects living permanently in arid zones is quite large as compared to the higher animals. The main emphasis in the present article has been laid on the specialized adaptations of insects to life under arid conditions rather than results on the studies on the physical and biotic ecology of insects of the region.

Studies conducted on the adaptations suggests an interesting fact, that the organisation of insect anatomy and life economy is on the whole quite well suited to cope up the problem of aridity, the evolution of the class-insects having obviously been accompanied by specialisation, necessary for a change from aquatic to terrestrial and then to aerial life, i.e. for a change from moist to dry surroundings. Generally speaking, therefore, very drastic modifications do not appear to have been necessitated for life in the arid conditions. Only such of the existing structural and behavioural peculiarities of insects as are likely to be useful in arid regions have been fully modified during the evolution.

Adaptations to life under arid conditions may be classified broadly into three categories:

- A. Morphological adaptations.
- B. Physiological adaptations.
- C. Behavioural adaptations.

MORPHOLOGICAL ADAPTATIONS

(1) *Body colour*: Adaptive colouration in animals has been interpreted as serving mainly three purposes: (a) concealment; (b) advertisement and (c) disguise. The biological function of these elusive attractive or deceptive devices varies widely according to circumstances

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but there is little doubt that nature has exploited this principal both in arid and non-arid zones, probably more in former, where conditions of life are harder. With few exceptions the colour of desert insects is generally buff, brown, sandy grey, having a few pattern of dark brown, black and white. There are four probable uses of desert colouration.

- (1) Cryptic adaptation for protection against enemies.
- (2) Aposematic adaptation for advertising their distasteful or harmful nature.
- (3) Adaptation for reflecting back the rays of the sun.
- (4) Adaptation for absorbing actinic rays from the sun and transforming that energy into locomotor activity.*

(Black colour, apart from absorbing heat energy, also favours absorption of blue violet or ultra-violet rays, which stimulate metabolic activity. The black colour of majority of beetle inhabiting the hot deserts may thus prove to be a physiological response to the actinic rays in sunlight. The physiological effects of which are advantageously transformed into locomotor activity).

(2) *Protective body wall*: Majority of desert insect fauna which include colcopterans and orthopterans are provided with well developed hard integument. This enables them to prevent the excessive evaporation of water and body fluids which are physiologically necessary for the maintenance of life in the desert. The chitinous exoskeleton is almost fused segmentally in such insects as tenebrionids, curculionids, carabids and cicindelids. In them evaporation of body fluid is prevented due to absence of soft intersegmental membrane.

(3) *Policy*: A number of bombilids and asilids are highly pilose and are thus saved from intense heat by the reflective nature of hairs and scales.

(4) *Wingless fused elytra*: Numerous orthopterans and beetles in the arid zone are wingless. This morphological character saves them from strong winds.

(5) *Long legs*: Many Tenebrionids, cicindellids and carabids have developed elongated legs enable the insect to break contact with the hot sand surface and at the same time allow them to walk swiftly on sifting sand.

(6) *Oval or compressed body*: Several species of Tenebrionids and carabidae have developed smooth, slippery, hard oval and compact

* The most widely distributed pigments in insects—brownish to blackish or black tint are due to O-dioxybenzol, melanin and its derivatives,

body which enable these beetles to wriggle along over the sand with astounding rapidity.

(7) *Organs for digging into sand:* In certain species fore-legs are modified into fossorial form which help insects to dig soil to find out the safer place.

(8) *Adaptation of internal anatomy for conservation of body water:* Malpighian tubules have undergone modification for more efficient conservation of water in the case of certain insects (e.g. Mcloid beetles, several species of which are xeric) by a process of reassociation of malpighian tubules with the hind portion of the gut. Rectal glands development or tracheal system and mechanism of spiracles are all directed to more efficient economy of water.

PHYSIOLOGICAL ADAPTATIONS

Besides structural modifications and behavioural adaptations there is a form of physiological acclimatization of certain insects to the hostile conditions of arid regions.

(1) *Capacity to withstand heat:* Many insects are able to live on the surface of the soil at mid-day, even during the hottest season. Temperature upto 172°F (88°C) has been recorded on the surface of sand dunes in Sahara. A small shining black beetle (Tenebrionidae) *Zophoris punctata* Brull, was common at all times of the day during May, June and July near Jerusalem and it moved on bare soil when it was as hot as 60-62°C. In general, insects which live on the dunes during the heat of the day have their minimum and maximum effective temperature located at higher points on the scale than others. The carabid beetle *Geopinus*, which is active on the dune at nights, has the lowest minimum effective temperature.

(2) *Capacity to live without water for long periods:* Stratiomyid fly (*Hermetia chrysophila*) the larvae are able to endure at least fifteen months without food or water, and eat decayed cactus joints whenever moisture is present. There are several species of insects which are dependent on only metabolic water.

(3) *Adaptations in developmental processes and stages:* Insect life history in general is basically well designed to cope with fairly wide fluctuations in weather conditions and we are concerned with those further modifications which appear to have taken place specially in response to extremes of temperature or humidity which are characteristics of arid region. Many insect species of arid regions make good use of their capacity to remain in a state of suspended animation for long periods. Thus a great majority of insects of the Great Palaearctic

desert pass the nine dry months of the year in the state of dormancy and are active for a very short period which coincides with the presence of annual vegetation. Similarly high temperature and hot winds necessitate a period of dormancy in the insect life. In case of Phadka grasshopper (*Chrotogonus* sp.) in central India, even if there is rainfall at the proper time, all eggs may not hatch out and some may remain dormant for second or third summer. The potential utility of this sort of partial awakening from diapause is likely to be that, if the environmental conditions in any one season do not allow the nymphs to reach the adult stage and lay a fresh crop of eggs, some eggs may still remain to hatch out during the next favourable season to ensure the continuance of the species. The diapause has a great survival value as it raises resistance of insects to unfavourable environment and its many of them into their local environmental rhythm, and almost always leads to a synchronization of the optimal conditions of food, climate, etc. and the active period of the insect concerned. It is a paramount factor in the maintenance of the species within an environment which is not continuously favourable.

BEHAVIOURAL ADAPTATION

Behaviour adaptations for ensuring security against inhospitable environment

(a) *Variability in environment*: The most characteristic feature of arid regions is the wide fluctuation in the nature of environment both in time and space. The recorded absolute range of temperature fluctuation has been as high at 88°C (150°F) at Kasalinsk in Turkistan and 57°C (102°F) at Ghardaia in Algeria in one year, and 28 to 29°C in summer and 20 to 22°C in winter in one day in Salah and Wargale in Algeria Sahara. The fluctuations at times are extremely rapid. (The maximum surface temperature recorded from western Rajasthan was 70°C. Much fluctuations have been noted in the temperatures when recorded on surface, 5 cm. below surface and 10 cm. above the ground at 3 a.m. in the month of June at Bikaner it was found 57.5, 48.2, 38.9 respectively. Fluctuations in humidity were recorded 15 to 66 per cent in one day). Fluctuations in relative rapid, a Wadi Digla, Egypt show that humidity at times can drop from about 95 per cent to about 15 per cent within few hours. As regards fluctuations in space, it has been reported that in Palestine where surface of the bare earth reaches 55-62°C at about mid-day in summer, the shade temperature remains around 32-38°C. On a sand dune in Minnesota it was noted that there may be a drop of 10°C within an inch above or below the sand surface when the temperature

is high. The relative humidity 3 inches below the surface was found to be 98 per cent when that of the air was only 15 per cent.

(b) *Site preference*: In arid region wide variation in the environment always exist, and the insects have in a constant environment. The site preference by the varied and large number of animal fauna is actually the secret of their existence as these animals avoid the extremes of desert climate by choice of suitable climates for their seasonal or diurnal resting places. A large number of insects have adopted underground existence at one or other stage of their life. As soil or sand affords more suitable environment and a better protection against harsh conditions above ground, a permanent or temporary underground existence is very common among insects in the arid zones. For e.g. ants, which are the most numerous xerophilous insects both specifically and individually are invariably underground dwellers. There are number of insects found hiding under stones, scooping out holes in the sand to prevent them from heat. Certain ants in Australian desert have successfully overcome climatic difficulties and many of them come up from their subterranean nests in the morning and late evening.

To avoid high temperature during mid-day hours insects move to favourable environment. Usually insects leave the soil surface when its temperature nears 50°C. Ants unlike other insects move their eggs, larvae and pupae freely in suitable stations. The army ant (*Eciton* sp.) colonies generally manage to remain in the vicinity of favourable zones such as ravines, withdrawing into moist and dark recess and underground places of the surface terrain in dry and going up into the hollows of standing trees during rains.

The most biological significance of insects' construction of egg-pods larval cages, pupal cocoons and nests etc. is the security against the adverse climatic conditions as well as from naturally occurring enemies. In arid regions larvae of numerous species of Tinidae and Psychidae have adopted a method for protecting their bodies against enemies, insolation and high temperature by constructing various types of larvae cages. Examples are the peculiarly flattened larval cases, composed of silk and admixture of sand, silk dead leaves and sticks of Psychids larvae. Pupal cocoons of many Lasiocampid moths are often very hard, horny or even calcareous. The nests made by several families of Hymenoptera also are often very hard, are impervious and afford effective protection against weather in arid regions.

(c) *Behavioural adaption for securing sustenance*: Environment of arid zones is equally adverse to plant life as it is of animal life. Most of the insect life is closely related to the plant for the availability of food for its survival. Except during very short and irregular periods

shortage of food is endemic. The insects specialised for arid zone existence have found different solutions to this perpetual menace.

A considerable section of the characteristic insect fauna of desert areas has become carnivorous, and specialisation for predatory existence has led to the evolution of (a) lochetic species, whose habit is to wait till their prey comes within striking distance and then suddenly seize it with their specially enlarged raptorial forelegs or (b) of swift hunters, or (c) of a habit of collecting victims during periods of abundance and storing them for their progeny.

The majority of the non-predatory insect fauna of the desert region which largely depend on the plant food has developed highly specialised phytophagous habits, (a) some of them have thoroughly adjusted their life history to the sporadic and irregular appearance of their food plants that active feeding stage coincides with the availability of the food plant in proper stage, (b) other species have developed habit of collecting their food and storing it against period of scarcity and (c) others again have developed polyphagous habits.

(d) *Behavioural adaptation for avoiding enemies*: Insects have developed many ways to protect them from their enemies. Few among them are (a) reflex bleeding—Genus *Anthia* squirt out a fine jet of liquid which is very irritating and smarting to the eyes. *Brachinus* emit a thick fog like cloud on being touched or disturbed, (b) Threatening response—Mantis *Eremiaphila braueri* of desert sp. from Baluchistan when molested suddenly unfolds its wings and stand up on its hind legs like a performing bear, (c) Dodging response, (d) Death feigning and (e) Mimicry are different methods adopted by the insects for evading as well as deceiving their predators.

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ROLE OF CONSUMERS IN THE FUNCTIONING OF DESERT ECOSYSTEM

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The role of consumers including man in the functioning of the desert ecosystem demands a more thorough consideration than it has received in the earlier discussions. Their role in the ecosystem can be understood only by studying in detail the functioning of the ecosystem. The term, 'ecosystem' here needs to be defined in an ecological perspective. The best definition for this purpose is that of Odum (1971) who defined ecosystem, as, "any unit that includes all the organisms (i.e., community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycles (i.e., exchange of material between living and nonliving parts) within the ecosystem". The free interaction of climate, physiography and biotic communities may through succession produce ultimately a more or less stable ecosystem if it is not disturbed by drastic interference by man, geological upheavals and catastrophic abiotic factors. The natural ecosystem, as for example, a climax forest is self perpetuating. It needs only sun energy from outside. Such an ecosystem is least affected by variations in weather. It has a diverse vegetation, although one of the species may dominate. The animal life of consumers and decomposers attains a state of balance with the producers and with each other seldom allowing any species to assume pest status.

On the other hand the man oriented agroecosystem in the arid zone or elsewhere are artificial where man himself along with his livestock usually assume a pest status. This holds true in the arid zone of India. These agroecosystems lack diversity and usually have introduced monocultures which often suffer from outbreak of pests and diseases. They are not self perpetuating and lack ecological balance and are prone to damage by calamities such as weather variations, pests, etc. Nevertheless the agroecosystems are most important for meeting the ever increasing food requirements of India. Their productivity is much higher than any other ecosystem, contributing 42 per cent to GNP but due to disequilibrium created in them a sustained yield from them is doubtful.

The main causes of disequilibrium are (i) soil degeneration (ii) disruption of water balance (iii) salinization (iv) deterioration in

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the geochemical cycle (v) changes in biotic relations. The overexploitation of material resources without understanding the ecological principles responsible for balance of nature, has created a number of new problems. The problems of soil and water conservations crop protection from pests, environmental pollution have assumed serious proportions. The ultimate drawbacks in man's efforts to produce more food or other commodities using modern technology and short-term measures without visualizing the long-range effects on the ecosystems need reorientation. It is high time to realize that the biological productivity of the ecosystems including the desert ecosystem is regulated in such a way that the total potentiality is not affected adversely.

The natural ecological balance in agricultural lands have been distributed in a number of ways. In India, the forest climax was destroyed over large areas replacing them by agricultural lands, grasslands, scrub, savavana, swamps and deserts. To indicate as to how animal life and their balance are affected a few examples are given:

(1) The habitats of carnivores (birds, snakes, wild cat, etc.) have been destroyed in the agricultural lands which replaced the forests. The carnivore birds particularly hawks, eagles, falcons which live in woodlands affording concealment preyed predominantly on rats and mice. Of the 250 species of snakes in the country about 80 per cent are predators of rodents. With the removal of forests the population of birds, snakes, wild cats, decreased and consequently the population of rodents has risen enormously. They take a heavy toll of food crops all over India including arid zone. It has been estimated that the field rats destroy 5.8-11.9 per cent of wheat and barley, 4-25.8 per cent of groundnut and 2.2 per cent of sugarcane (Anonymous, 1970).

(2) The population of insectivorous birds like the Indian grey-tit, the various species of wood peckers, the white stroke, etc. was also reduced due to removal of forests over large areas. The habitats of these birds are in the woodlands adjoining to the cultivated fields, where they feed on insects. The change in their habitat discouraged their breeding and consequently the phytophagous insects and other invertebrates got encouraged. Efforts in controlling these crop pests with the use of pesticides have created further imbalances in the animal complex and posed the problem of toxic residues injurious to human health and environmental pollution.

(3) Not only the habitats of wild life in the forest were destroyed but man has been indiscriminately killing the wild life for his recreation and pleasure. This has already done lot of damage to the balance of nature. The importance of wild life conservation is yet not fully realised by public at large. It is high time that whatever fauna of wild life has been left, is protected and allowed to play its role in maintaining balance of nature.

The role of animals in the functioning of ecosystem is very important. The consumption by phytophages and decomposition by decomposers accelerate the flow of energy and circulation of matter. But for their presence in the food chains more and more nutrients would go on getting trapped into organic matter and would not be available to the primary producers, the plants. The predators of phytophages, through food chains and food webs keep the population of primary consumers in check and help in maintaining natural balance in the system. It is not possible here to go into details of the numerous useful and harmful actions of the animals which affect the ecosystem one way or other. But there should be no doubt that the study of the role of animals in any ecosystem cannot be neglected, if it is desired to restore natural balance.

Although the original balance of nature cannot be restored immediately it is necessary to rehabilitate the relationship between soil, vegetation and animal life as far as possible. This can be done by three methods (i) afforestation over large areas (ii) improvement of grasslands (iii) and improvement of agroecosystem of the desert zone.

Afforestation

In the desert zone the over-exploitation of the available vegetation by man and his cattle has few parallels. Only 3.93 per cent of the total area in the arid zone of India is under forests as against 33 per cent required under the national policy for maintaining the ecological balance. The first and the foremost step to improve the desert ecosystem therefore, should be afforestation over all the available land in this region. Of the 40 per cent area under agriculture a substantial part is under subsistence agriculture depending much on vagaries of weather and there is little scope for improvement of agriculture in the marginal lands in near future. It is advisable to divert such areas also to forestry in the overall interest of the ecosystem. This has been done in several European countries. Researches carried out at this Institute have made the needed technology available for stabilising even the moving sand dunes. There is no reason why vegetation, particularly forests cannot be restored on other types of soil. There is great need to set aside as large areas as possible for natural regeneration of forests. Such areas would have to be protected from grazing by cattle sheep and goat. In the early stages the succession in these forests can be facilitated by man's efforts but ultimately these forests may be allowed to attain climax. The wild animal life in these forests should not be disturbed. The study of food chains, food webs and the interactions between populations in the community in such climax forests in this region would give clues for effective

management of the disturbed ecosystems for bringing about natural balance.

The need for increasing area under man-made forests in India is evident from the fact that only less than 2 per cent of the total forest area is under plantations whereas it is as high 71.2 per cent in U.K., 28 per cent in Japan, 13.9 per cent in Italy and 9.4 per cent in France. We can learn a lesson from Israel and use some quick growing exotic trees for putting up a green mantle over the arid zone. When Israel was born in 1948 its land was desert and wilderness; much of the rest was gaunt grey stone and eroded hills that looked beyond all redemption but today it wears a green mantle of new trees. The extension in forest area is all the more needed in India where the wood requirements for paper industry, timber, fuel, etc. is one the increase with the staggering increase in population and improving standards, but the per capita forest area in the country is the lowest (0.14 ha) in the world excepting some European countries (Table 1). The percentage of plantations to total forest area in India is as low as 1.7 which indicate a meagre effort as compared to several other countries. Plantations in the arid zones can contribute a lot to India's forestry besides improving the desert ecosystem. The extension of forests in this area would have ameliorating effect on the climate. This will also benefit the adjoining grasslands and agro-ecosystems and improve the balance of nature.

Table 1

Forest area in different countries
(FAO year book of Forest products 1969)

Country	Forest area (percent of total)	Forest area (ha. per capita)	Percentage of plantation to total forest area
U.S.A.	43.0	1.59	3.4
U.K.	7.0	0.03	71.2
France	19.0	0.24	9.4
Italy	20.5	0.12	13.9
Japan	63.0	0.26	28.0
Indonesia	6.4	1.17	1.6
India (1965)	—	0.15	1.4
India (1969)	22.7	0.14	1.7
U.S.S.R.	51.0	13.00	—

Improvement of grasslands

Grasslands sustain large livestock population and the rangelands have been deteriorating under the heavy pressure of grazing. There is need to grow pastures and regulate grazing according to the carry

ing capacity in different climatic regions of the arid zone. The animal population in the arid zone is as high as 21.5 millions. The available forage from existing sources including cultivable waste, fallow fields, grazing lands and crop residues is short by 36 per cent on the basis of maintenance ration and by 80 per cent on the basis of productive ration. The gap between food resources and animal population would not lay any improvement in the productivity of grassland unless a big effort is made to develop pastures by making use of the management practices evolved at the Arid Zone Research Institute.

Improvement of the Agroecosystem in the desert zone

The increasing pressure of human population creates need for increased food production. In the desert zone the limit to increase in the production is set by conditions of water stress, harshness of climate and salinity in soil. Researches to evolve techniques for improving crop yield under dry farming condition have already made a headway and can contribute a lot to enable man to harvest higher yields. But the main objective of improving the desert ecosystem is getting lost in efforts for short range benefits. The functioning of the agroecosystem in desert zone, therefore, need a thorough study on the changes that are taking place particularly due to increasing pressure of the consumers particularly man and his livestock. Some efforts must be made to minimise their rate of growth in this region.

The study of energy flow and material cycling under variable conditions in the region is an urgent need. If the role of animals, as consumers, predators in the ecosystem is known, their populations can be manipulated to the advantage of the ecosystem and consequently the man himself. The study of agroecosystems can be taken up on the basis of subsystems. As for example the soil subsystem can be studied independently. Such studies should not be confined to physical aspect only but the biotic aspects, the role of consumers as decomposers will have to be studied. It has now come to light that decomposition is not carried out by bacteria and fungi only but a complex of invertebrate fauna is involved. The role of decomposers which is very important in the functioning of the ecosystem, may be interfered with harmful chemicals used on the foliage or soil itself for pest and weed control. We must also see that the soil receives back whatever is taken away in harvest in the form of grains, fibre, fodder, etc. by man.

Similarly the life-systems of the important crop pest species can be studied as a subsystem. Such studies can give a clue of the natural mortality factors (abiotic or biotic) that regulate the pest population and can be invoked for its control. The management of pests based on integrated control evolved through ecological studies would make it possible to avoid the use of pesticides.

The studies of various subsystems can then be integrated for understanding the overall functioning of the ecosystem. The effect of different cropping patterns on the ecosystem will have to be studied on long-range basis. The main objective should be management of the system for benefit of man without deteriorating its potentiality for sustained yields. It is already known that raising of shelter belts around horticultural crops and increasing the tree plantation in the agroecosystem helps to improve the system. The trees like *Prosopis cineraria* aid in crop production in the arid zone. The *Eucalyptus* grown around the wheat fields do not deteriorate the yield under increased irrigation practices. The extension of farm forestry in the agricultural lands will not only help to improve vegetation, but will also provide badly needed timber and fuel wood. The availability of fuel wood will divert the cattle dung to the soil.

Most of the food-chains in the forests, grasslands and agroecosystems are similar in that they start from a plant base, go from a smaller to larger animal including vertebrates and are completed by scavengers. The mobility of animals result in a number of interactions between the various ecosystems which contribute to bring balance in natural populations. There is great need to study such interactions so that beneficial ones can be encouraged and inimical one's ameliorated. The interference into functioning of ecosystems should be made after gaining an understanding of the overall repercussions on the system. The role of consumers including man himself needs to be always kept in view in any effort for correcting the imbalances for an overall improvement of the desert ecosystem.

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POPULATION DYNAMICS OF RODENTS AND THEIR CONTROL

Ishwar Prakash*

ABSTRACT

Seventeen species of rodents are found in the desert biome of Rajasthan. Some of these rodent species exhibit a habitat specificity and others are distributed all over the desert. The rodents constitute the largest mammalian group in the Indian desert, both in total number and in the number of species. Due to their plasticity in behavioural patterns, their role in the intensification of desertic conditions is all too prominent. Because of their marked abundance, they exert a severe pressure on the desert vegetation, grasslands and cause severe soil erosion.

Extensive ecological studies and intensive laboratory experiments made at the Central Arid Zone Research Institute on desert rodents have provided the bases for the formulation of the following control measures of confirmed efficacy.

1. In the first method, three days of pre-baiting (*bajra* flour 97 parts; groundnut oil 3 parts) is followed by a day of poison baiting (*bajra* flour 95 parts; groundnut oil 3 parts; zinc phosphide 2 parts). The baits are placed a little inside active burrow openings.

2. The second method consists of soaking 1 kg. of dried berries of ber (*Zizyphus nummularia*) for 24 hours in 3:1 of a 0.1% solution of sodium mono-fluoroacetate (Compound 1080) and placing one such treated berry along with four untreated berries inside every active burrow opening. This is an economical and very efficient method of desert rodent control.

A third method of rodent control is mostly applicable to irrigated fields. It consists of fumigating the burrow with aluminium phosphide tablets, keeping the burrow openings closed in order to ensure the poisonous phosphine gas released inside does not escape.

The best time for launching rodent control operation would depend on the extent of infestation and on the area to be covered. Any time will be suitable for small scale operations. For large scale operations, however, summer is the most suitable period as in this season (a) breeding activity is at a minimum, (b) the rodent readily accept poisoned baits, no other feed being readily available in nature

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and (c) the farmers are relatively more free to attend to control operations.

INTRODUCTION

Rodents constitute one of the largest mammalian groups in the Rajasthan desert, India, both in total number and in the number of species represented. They exhibit a great plasticity in respect of their choice of a wide spectrum of desert habitats and their impact on the desert eco-systems is all too prominent. The rodents' role in the intensification of desertic conditions may be comprehended from the fact that a single species, viz. *Meriones hurrianae*, is able to excavate about 61,500 kg. of stabilised soil per km² per day during summer and deposit it outside its burrow openings in a loose formation (Prakash, 1973). This dug-up soil is easily blown away by the strong desert winds. The rodents, thus, are a prime biotic factor for soil erosion. Their impact on the desert vegetation as a result of their gnawing, debarking, cutting and feeding propensities is easily discernible throughout the tract (Prakash, 1963). In the desert region, orchards, crop fields and rangelands cannot attain their optimum productivity without a rodent control programme. The rodents are, therefore, regarded to be the most potent enemies of man in the desert in his endeavours for maximising output from this inhospitable terrains.

POPULATION DYNAMICS OF RODENTS

Habitat Selection

From the data recorded so far it may be seen that some rodents occur exclusively in a particular habitat such as *G. n. indus* from the sandy habitat, *R. c. cutchicus* and *Mus cervicolor* in rocky habitat and *M. musculus* and *M. booduga* in the ruderal habitat are some of the examples which occupy only one habitat (Table 1). Other rodents, however, occur in more than one habitat. Some are found in the sandy and gravel habitat while others in rocky and ruderal habitat. For example, *F. pennanti* is the most common (50% frequency) in ruderal habitat, though it occurs on sandy (14.2%), and rocky (35.8%) habitats also (Prakash *et al.*, 1971). Due to its higher occurrence in the ruderal habitat, it may be treated as a ruderal element. Similarly *G. gleadowi*, *M. hurrianae* and *R. gleadowi* prefer sandy habitat, and likewise *T. indica indica*, *R. m. pallidior* and *Golunda ellioti* prefer the ruderal habitat and *M. p. sadhu* prefers the rocky habitat (Table 2).

This observation is further confirmed by the number of rodents collected from each habitat. In all the districts 168 rodents were col-

lected from sandy habitat, 164 from the ruderal habitat, 81 from the rocky habitat and 36 from the gravel plains. The trap index data also show similar trend.

There are some reasons for this type of preference. The northern palm squirrel is arboreal and constructs nests of cloth pieces, grass leaves, etc. It, therefore, prefers a habitat where there are some trees which are relatively common in the village complex and on hillocks. As such, majority of the squirrels were collected from the trees in all the habitats. In the sandy habitat *M. hurrianæ* and *T. indica indica* occur on comparatively stabilised sandy plains but species of *Gerbillus* dig their shallow burrows even on mobile sand. Their burrow openings being completely buried under the drifting sand have been observed during the field study but they are able to venture out during the night. *R. mottada pallidior* has been hitherto reported from crop fields but in Jhunjhunu, Nagaur and Sirohi districts it was collected from sandy plains supporting a dense grass cover. On the rocky habitat rodents were collected from two situations viz. (1) *R. c. cutchicus* from crevices of the rock and small caves whereas. (2) *M. c. phillipsi* and *M. p. sadhu* from clumps of undershrubs like *Euphorbia caducifolia* where some soil has developed in situ. The former species was almost always associated with *Euphorbia caducifolia* clumps. Curiously enough *T. indica indica* were also collected from Pali district from a hillock under *Euphorbia* bushes though this species has not previously been reported from this habitat (Prakash *et al.*, 1971).

Rodent Abundance

We have so far recorded 17 species of rodents from the desert of Rajasthan. Some of these rodent species exhibit a habitat specificity and others are distributed all over the desert. *Nesokia indica* is found only in the irrigated fields in Sri Ganganagar district, whereas, *Golunda ellioti* and *Mus booduga* are found in irrigated fields in the south-eastern desert, on the foot hills of Aravalli ranges—a higher rainfall zone. *Rattus cutchicus* and *Mus cervicolor phillipsi* inhabit only the rocky habitat, whereas *Gerbillus gleadowi* is more numerous in the extreme arid sand dune country in the west. On the other hand, *Tatera indica* and *Meriones hurrianæ* the two gerbils, are found all over the desert in the fields; and *Rattus rattus rufescens* and *Mus musculus bactrianus* live inside buildings and are distributed throughout the desert. The species specificity and diversity of desert rodents in relation to various habitat types makes the problem more complex for the control operator since no one method can be applied to all the rodent species in a similar pattern over all the habitat types.

The species divergence is an important factor in the desert but still

more significant from the devastation point of view is their abundance and prolific breeding propensity. The population density of field rodents in the desert is thickest in India. In certain habitats and localities as many as 800 rodents/hectare have been estimated but at other places they are less abundant. During normal rainfall year, most of the rodents breed all the year round and the litter size varies from 1 to 10 at every birth. The youngs attain sexual maturity within 3-4 months and start taking part in the increase of population (Prakash, *et al.*, 1971).

Rodent Biomass

On an average of all the districts in various habitats, highest biomass was recorded at Churu and Jhunjhunu districts (Table 3). These values are even greater than those at Ganganagar where productivity of the land in terms of phytomass is relatively much higher than other districts due to the presence of irrigated crops taken with canal water irrigation. The lowest rodent biomass was recorded at Jaisalmer and Bikaner districts having the minimum rainfall in the region of study. It is rather interesting to record that rodent biomass in Barmer district is much higher as compared to that in Jalore district which lies in a better situation as far as the rainfall and soil characteristics are concerned (Prakash *et al.*, 1971).

Distribution of rodent biomass in ruderal habitat was recorded to be maximum as compared to sandy habitat and was lowest in the rocky habitat. Shortage of food in the ruderal habitat is less expected since the rodents inhabit the village complex where something is always available as human waste products, fodder for livestock in addition to other food such as the higher number of insects present due to cowdung. It may, therefore, be expected that the rodents of ruderal habitat maintain a higher body weight as compared to other habitats studied which are exposed to hazards of low and high air temperatures, scarcity of water, food and presence of predation. Both in sandy and ruderal habitat the highest biomass was observed at Jhunjhunu and Churu districts while the minimum in the sandy habitat at Jodhpur and Jalore districts and in ruderal habitat at Bikaner and Nagaur districts and rocky habitat at Jaisalmer and Sirohi districts.

As normally expected a good ground cover of vegetation should exhibit relatively a better rodent biomass. But the situation does not entirely fit in the above conjecture. As can be seen from the Tables 3 and 4 that in the sandy habitat at Jaisalmer though the total basal cover occupied by grasses in an enclosed area is good, about 6.9 per cent, the rodent biomass is very low i.e., 271 gms/hect. while on the other hand at Churu and Jhunjhunu where the basal cover of vege-

tation is low 1.26 and 1.00 percent respectively, the rodent biomass is fairly high, 2160 and 2580 gms per hectare. At Jodhpur and Jalore the basal cover of the vegetation as well as the rodent biomass are at a low level while at Nagaur and Pali both the figures support the above. It may, therefore, appear that rodent biomass may not be directly dependent on the vegetation cover and it may be the internal physiologic adaptation of the animals to withstand the various stresses of the xeric environment, the availability of the shelter, food and soil conditions which may also play an important role in the maintenance of rodent biomass in the desert (Prakash, 1974).

RODENT CONTROL

Our studies on the ecology and ethology of desert rodents have yielded information regarding the distances between bait stations (on the basis of home range data), the optimum season for control operations (on the basis of observed population fluxes and breeding cycles) and the effective ways of bait placement (on the basis of habitat types). We have also established the minimum lethal dosages in respect of a large number of rodenticides and proprietary products. The bait preferences (Prakash, Fitzwater and Jain, 1969) and bait shyness (Prakash & Jain, 1971; Prakash, Rana & Jain, 1974) in respect of seven species of rodents have also been worked out.

On the basis of these studies, two methods for the control of field rodents have been standardised.

The first method is an improvement of the old one in vogue. Experiments at the Institute revealed that mixing of 1.5 to 2 per cent zinc phosphide in carrier, was sufficient for rodent control, as against 5 per cent practised in the past. This decrease in the poison concentration not only increases the palatability of the poison-baits but also reduces the chances of secondary hazards and pollution of environment. The other improvement made is replacement of *gur* (Jaggery) by 3 to 5 per cent groundnut oil. The third change found advantageous is poison-baiting after three days of pre-baiting which brings about significantly higher mortality of field rodents. The fourth improvement is poison baiting should be done only on one day. If it is continued for more than a day, not only the consumption of the poison-bait is so low as to be wasteful of labour and material but the rodents develop bait shyness (Prakash, 1973).

The modified method is to pre-bait the active burrow openings in field for three days at the rate of 6 gms per rodent per day. Pre-baiting is to be done with: Bajra flour 97 parts; Groundnut oil 3 parts. On the fourth day the burrow openings should be poison-baited at the same rate with: Bajra flour 95 parts; Groundnut oil 3 parts; Zinc phosphide 2 parts.

The second method is based on three principles. The foodgrains should be saved for human consumption instead of using them for baiting rodents, the pre-baiting and poison-baiting should be done together and thirdly the method should be fairly cheap. Having studied the food habits of desert rodents, it was found that *ber* (*Jhadberi*, dried berries of *Zizyphus nummularia*) is preferred by them over seeds of most of the desert vegetation. These are usually collected by farmers when they prune the bushes for 'pala' (leaves of *ber*, an excellent concentrate for goats, and the thorns are used for fencing). *Ber* grows in the desert in abundance. Even if bought, the dried berries are cheap, 0.50 paise per kg. In addition to high palatability, the air-dried berries, possess sufficient soaking capacity. This 'non-foodgrain' material is therefore used as a carrier of poison for rodent control. The air-dried berries are soaked in a solution of compound 1080 (Sodium monofluoroacetate) having a dosage of 3 mg/kg. After soaking for 24 hours each berry is impregnated with a lethal dose for rodents weighing upto 100 g. One lethal berry and four ordinary are pushed inside burrow openings. This one-shot baiting technique is fairly economical. Including the cost of labour, *ber* and poison, a farmer will spend 30 to 45 paise per hectare for effective rodent control. If, however, he collects *ber* from wild and does the job himself, the method will cost him 0.5 to 1 paisa per hectare as compared to Rs. 3 to 15 per hectare by conventional methods.

The third method which has proved of some worth, at least in irrigated fields, is the fumigation of burrows with aluminium phosphide tablets. This method has not, however, proved effective as well as economical for burrow fumigation in dry soils as the moisture content in the soil is not usually sufficient to liberate phosphine gas from the mixture.

The time of Control

For a rodent infestation in a localised area or to save the crops from a sporadic attack, control operations can be taken up at any time of the year. But when a massive rodent control operation is to be taken up in the fields or a district, its timing has to be properly fixed to achieve best results at a relatively lower cost. Studies on the habits and behaviour of field rodents have helped in arriving at a decision about this important aspect of rodent control which has not been hitherto thought over in our country. It has been found that the breeding rats of a most of field rodents is minimum during summer months and in the month of December. Studies on their population dynamics indicated that lowest numbers occur during May and June. Analysis of their food habits pointed out that acceptability of baits

was maximum during summer months when there was paucity of natural food. These results led us to postulate that summer is the most appropriate season when large scale rodent control should be taken up effectively. Incidentally, the farmer, is also comparatively free during the hot months to take up this work (Prakash, 1973). If the job done precisely, the need for follow up programme will arise only during the next summer as studies at the Institute have shown that the rate of reinfestation by rodents is slow. But it will always depend upon the area in which the rodent control operation has been taken up. If rodents are controlled on a district level, i.e., in a large area, the reinfestation will be slow but if it is carried out only in one hectare or so, naturally the immigration of rodents from the surrounding areas will make reinfestation quick.

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Table 1. Percent distribution of rodents in various habitats in the desert biome of Rajasthan (after Prakash *et al.*, 1971)

Rodent species	Sandy	Gravel	Rocky	Ruderal
<i>F. pennanti</i>	14.2	—	35.8	50.0
<i>G. n. indus</i>	100.0	—	—	—
<i>G. gleadowi</i>	56.0	—	—	44.0
<i>T. i. indica</i>	28.8	10.0	3.6	47.6
<i>M. hurriane</i>	60.0	17.0	—	23.0
<i>R. c. cutchicus</i>	—	—	100.0	—
<i>R. meltaida pallidior</i>	37.0	1.6	5.1	56.0
<i>R. gleadowi</i>	66.6	33.3	—	—
<i>M. musculus</i>	—	—	—	100.0
<i>M. b. booduga</i>	—	—	—	100.0
<i>M. cervicolor</i> sbsp.	—	—	100.0	—
<i>M. c. phillipsi</i>	—	—	100.0	—
<i>M. p. sadhu</i>	28.0	13.3	53.3	13.3
<i>G. e. gujerati</i>	25.0	12.5	—	62.5

Table 2. Habitat preference of various rodents of desert biome of Rajasthan (after Prakash *et al.*, 1971)

Sandy	Gravel	Rocky	Ruderal
* <i>G. n. indus</i>	—	* <i>R. cutchicus</i>	<i>F. pennanti</i>
<i>G. gleadowi</i>		* <i>M. c. phillipsi</i>	<i>T. i. indica</i>
<i>M. hurrianæ</i>		* <i>M. c. sbsp.</i>	<i>R. m. pallidior</i>
<i>R. gleadowi</i>		<i>M. p. sadhu</i>	* <i>M. musculus</i>
			* <i>M. b. booduga</i>
			<i>Golunda ellioti</i>

* Occurs exclusively in the habitat.

Rattus rattus rufescens also occurs inside the houses in the habitat.

Table 3. Rodent biomass per hectare in the desert biome

Administrative districts	Biomass (g) per hectare				
	Sandy	Rocky	Ruderal	Average	
Barmer	811	955	1266	1011	
Jaisalmer	271	222	610	435	
Bikaner	460	—	490	475	
Jhunjhunu	2580	933	2930	2147	
Churu	2160	—	3122	2641	
Jodhpur	182	805	1652	880	
Nagaur	2555	—	333	1422	
Pali	1100	1142	1423	1222	
Jalore	233	1093	1644	990	
Sirohi	1350	433	2522	1434	
	Grain field	Cotton— Wheat field	Sugarcane field	Date palm field	Average
Sri Ganganagar	1889	1111	2600	2711	2052

Table 4. Basal cover of vegetation in sandy and rocky habitats at various districts of desert biome of Rajasthan

Administrative districts	Percent basal cover of vegetation	
	Sandy habitat	Rocky habitat
Barmer	0.1	0.1
Jaisalmer	6.9	4.7
Bikaner	3.2	—
Jhunjhunu	1.0	—
Churu	1.3	—
Jodhpur	1.0	1.2
Nagaur	9.0	—
Pali	6.2	1.5
Jalore	0.8	0.7
Sirohi	7.8	1.1

ROLE OF SHEEP IN THE DESERT ECO-SYSTEM & DROUGHT PROOFING THROUGH IMPROVED SHEEP PRODUCTION

R. M. Acharya and B. C. Patnaik*

INTRODUCTION

India has about 3.2 lac square kilometres of hot desert land located in parts of Rajasthan, Haryana and Gujarat, besides small areas in the Southern Peninsular region. In addition, an area of 70,000 square kilometres of cold desert in Ladakh presents entirely different agro-climatic conditions as compared to the hot desert. The desert districts of Rajasthan include Bikaner, Jaisalmer, Barmer, Jodhpur, Nagaur, Churu, Jalore, Pali, Ganganagar, Jhunjhunu and Sikar, out of which the first eight districts form the core of the desert. Parts of Mahasana and Banaskantha districts of Gujarat and the Bhiwani, Hissar and parts of Rohtak districts of Haryana have similar conditions (2).

The desertic conditions in North-Western region are believed to have developed as a result of meteorological, geological and hydrological changes over the centuries. But the process has been accentuated by the activities of man inhabiting these areas. Crop farming, over exploitation of trees for fodder and fuel purposes and indiscriminate and over grazing of the grazing land by the livestock, have been the key biotic factors accentuating the formation of desert. Over-grazing without any attempt at rehabilitation and proper management of the grazing land has resulted in wide spread degradation of these lands. Due to unsuitability of the land for crop farming and the latter being a gamble on the desert land, its inhabitants had to resort to animal farming. The rise in human population has led to an increase in livestock population resulting in an increased pressure on the already depleted natural vegetation. Eventually, due to the lack of natural vegetation for livestock grazing and scarcity of drinking water for the humans and livestock, the livestock raisers had to resort to migration to distant places in search of food and water. This had led to a nomadic system of livestock management.

Sheep as a biotic factor resulting in desertic conditions:

Sheep as a species is most suited for arid areas because of its close grazing habit and adaptability to the arid conditions. It is able to utilize the sparse and low-set vegetation available in the arid areas.

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It has also the ability to survive prolonged period of drought and semi-starvation and is less prone to extreme weather conditions. Because of its hardiness and adaptability to dry conditions, the north western region of the country has a large concentration of sheep. The state of Rajasthan has 8.5 million sheep which constitute 21% of the total sheep population in the country. The sheep population and its density in different desert districts of Rajasthan are given in Table 1 and the breeds of sheep found in different districts are shown in Table 2.

The high density of sheep population has not only resulted in depletion in natural vegetation in their home tracts but also on their migratory routes. Depletion of vegetation cover and disturbance of the soil during migration exposes it for wind erosion. Also, when grass cover is scanty, sheep scrap the soil by means of their hard hooves and eat away the grass roots, which further loosens the soil and helps erosion.

There are two types of migratory flocks found in arid areas: (i) the truly nomadic flocks which have no fixed centres but follow seasonal migratory routes to grazing areas largely governed by the availability of foraging and drinking water resources and (ii) flocks maintained for most part of the year on a system of free range grazing including stubble grazing on the crop land, but following definite migratory routes to the seasonal pastures and returning to their permanent abodes during certain seasons.

In Rajasthan, more than 0.5 million sheep are in permanent migration and these flocks are not brought to their home tract at any time of the year. About one million sheep migrate for 6-9 months (3). These flocks start migrating from October and return to their home tract by July immediately before the onset of Monsoon season. About 0.2 million sheep migrate for only 3-4 months. They start migrating during March and graze on crop stubbles in Rajasthan canal area from April to June. Quite often during migration, the sheep graze on stubbles in harvested fields and in forest areas on payment of fees.

Because of their close and selective grazing nature and their ability to utilize many weeds, bushes and to travel long distances in search of forage and water, sheep have often been incriminated as the creators of the desertic conditions. In reality, it is not the sheep but the man who owns the sheep is to be blamed for mismanagement of the grazing land which has resulted in the desertic conditions. Controlled and judicious grazing practices on the desert land could prevent soil from erosion and the droppings collected on the infertile land over the years could eventually convert it to fertile land suitable for crop production.

Sheep as a source of food, fibre and employment in desert areas:

Sheep is an important source of livelihood to a large population in desert districts and provides it with food and fibre. The total wool production in the desert districts is about 7.23 million kg. Considering that 28% of the sheep population is available for slaughter and the average carcass yield is 9 kg the total meat production in the desert districts would be about 13 million kg. In addition to providing wool, meat and milk, sheep provide employment to a large section of the population in these districts in the form of self-employment of persons tending their own flocks or those hired for tending flocks during migration. Besides grazing and management, many people are engaged in the work of sheep shearing and in wool and skin based industry. A survey conducted by C.S.W.R.I., Avikanagar on economics of sheep rearing in Chokla and Nali region in Rajasthan (4) has shown that the average income from a flock of 100 breedable ewes and attendant rams and followers was Rs. 3,881/- per year for Chokla and Rs. 5,642/- for Nali per annum. The relevant data including mortality, lambing percentage etc. are presented in Table 3.

Drought proofing through improved sheep production:

Erratic rainfall and uncertain weather conditions in the hot arid areas are so frequent and make the crop farming so uncertain that when there is drought, people in these areas virtually sit idle without any employment or migrate to cities and other distant places for employment. Some remunerative employment should be ensured for such people so that large scale exodus to the cities in search of employment is prevented. Animal farming, more particularly of sheep and goat farming seems to be a logical resource to such a situation. This will suitably fit into the desert development programmes being envisaged while providing self-employment to the people inhabiting the area and protecting them from the vagaries of drought and famine. The main emphasis in desert development should be on the improvement of range lands through regeneration of natural vegetation, reseeding, coupled with other soil conservation practices and afforestation. *The pastoral-silvicultural system of development of desert areas would result in the availability of sufficient grazing resources which can be judiciously utilised to maintain a large sheep and goat population.*

There is little scope for poultry and swine production in the desert areas because of the non-availability of sufficient cereals. Dairy production would be possible only in canal command areas and other areas where irrigation resources are available and it is possible to include fodder production in the crop rotation systems. Also, it is not

possible to maintain high producing dairy cattle under range conditions especially in low rainfall areas. Sheep and goat would perhaps be the best to fit into a pastoral-silvicultural system. Sheep being chiefly a foraging animal and goat being a browsing animal, they complement each other for utilisation of range lands (through foraging and browsing) and of top feeds. *The main emphasis after the range lands have been improved and sufficient vegetation is available, should be on improvement of sheep and goat production in a manner that the population of these species can be reduced to the numbers that can be maintained without any serious threat of deterioration to the range lands.* It will also be necessary to resort to certain amount of restraint on goats, so that they will not browse on young plantations. The loppings should also be done in a manner that is not detrimental to the growth of trees.

If the economic potential of a flock of 100 breedable ewes and their followers, 100 breedable does and their followers and an equivalent number of cows and their followers (one sheep/goat=0.15 cow) is considered, it appears that goat raising on the properly developed range land would be much more profitable as compared to that of sheep raising or cattle raising; whereas sheep raising show a marginal superiority in the income as compared to the cattle (Table -4). Theoretical calculations for the yearwise income have been made on the basis of assumptions given under the table. The initial investment and net available asset at the end of 6 years have not been taken into consideration.

As the development of all the desert areas through range improvement will require a tremendous financial and human resources and will take a long time, it may not be possible to sedentarise whole of the sheep population on such improved range lands in the near future. It may be necessary to continue migration of a large percentage of sheep population for search of grazing and drinking water. The improvement programmes for increasing sheep productivity will, therefore, aim differently for the sedentarised and the migratory populations.

Sheep improvement programme for sedentarised flocks: In areas where sufficient revenue/forest land is available in addition to the common grazing land, and there is sufficient concentration of sheep population, a communal model for sheep farming is suggested (5). At present the sheep improvement programmes in Rajasthan are being carried out by the State Department of Sheep and Wool which also, to some extent, is engaged in wool marketing. *It is proposed that the work on sheep improvement be done in an integrated manner involving three different state agencies i.e. the first concerned with input programmes for sheep improvement, the second for pastoral-silviculture*

and the third for organizing marketing and wool based industry. These three agencies may also advise the sheep farmers on formation of sheep farmers' cooperatives which in the initial stage may only manage the pasture land but later may take up the greater part of the input programme for sheep improvement and also further development of pasture on the common grazing land, wool and live animal marketing and development of small scale wool based industry.

Sheep improvement programmes for migratory flocks: In case of the nomadic flocks, the three state agencies mentioned earlier will cooperate in providing necessary facilities on the migratory routes, i.e. improved grazing areas, availability of some conserved fodder, necessary inputs for sheep improvement like prophylactic vaccination and drenching, superior pure breeding rams, sheep shearing and wool and live animal marketing facilities. These centres will also have sufficient drinking water resources for humans and animals. They may provide credit and banking facilities to the nomadic sheep farmers. The migration will be controlled by these centres through communication among different centres. The staff located at these centres will direct the migrating flocks to areas where sufficient vegetation resources are available so that the vegetation resources available are not over exploited.

Breeding for improvement in wool production: In the desert districts the sheep improvement would have to be mainly for wool production as it will not be possible under the prevailing vegetation resources to improve upon their meat production potential. The average wool yield and its quality of different native breeds in desert districts are given in Table 5.

Fine wool production: The breeding programme should be formulated in a manner that in areas where Nali and Chokla breeds are present, they will be improved for fine wool production through introduction of exotic fine wool inheritance. For this purpose, it is proposed to crossbreed Nali and Chokla with Rambouillet and Merino. The halfbreeds will be interbred for stabilising the exotic inheritance at 50% level. The results of crossbreeding some of the native carpet wool breeds with exotic fine wool breed available so far are presented in Tables 6 & 7. It can be seen that the halfbreeds produce around $2\frac{1}{2}$ -3 kg of 58-64s wool. There is also an increase in live weight in crosses over the native parent (Table 8). There is hardly any improvement in the wool production of the higher crosses, but there is a definite improvement in the wool quality. The higher cross also have problems with regard to their management as they are more sus-

ceptible to diseases and require better care and nutrition. The present experience is that it will not be desirable to introduce exotic inheritance beyond 50% and this level will provide the desired animal producing about 2.5 kg wool of 58s-64s count per annum.

Carpet wool production: Majority of sheep under migration belong to Marwari and Jaisalmeri breeds which are good carpet wool breeds. It may be desirable to improve them for carpet wool production. There is also need to improve the wool quality for manufacturing superior carpets. Although wool produced in North-Western region of India are known to be excellent carpet wools, they lack in lustre and uniformity and have excessive medullation, specially of kenty type. In the international market the Indian carpets fetch only 20-25% of the price paid for Persian, Afghan and Chinese carpets. The distribution of stud breeding rams selected for their greasy fleece weight and against medullation percentage will bring about improvement both in the quantity and quality of the carpet wool from the native sheep.

Modification of breeding season: The native breeds of sheep are known to breed throughout the year although majority of them are bred during July-August immediately after the onset of monsoon season when plenty of natural grazing is available. Some breeding is also done during the months of March and April when the flocks are put in stubble grazing or on top feeding. The results available indicate that the lambs born in the months of July and August have higher survivability and better growth than those born during winter. March-April breeding may, therefore, be more desirable as the lactating ewes and young lambs will have better nutrition and thus will produce heavier market animals.

Management of exotic rams and organisation of breeding programmes under crossbreeding: Because of the problems of the non-availability of requisite number of exotic rams and difficulties in maintaining their libido and semen quality under natural management conditions especially during summer and rainy seasons, it will be necessary to maintain the exotic rams protected from solar radiation and atmospheric heat, provide them with artificially cooled shelters and resort to artificial breeding. Protection from high temperature and solar radiation can be provided through grazing them during cooler parts of the day preferably late evening hours and also providing them with supplementary feed and fodder during late evening hours of early night hours to avoid excessive heat of increment when ambient temperature is high. The semen collection should be made in the early

morning hours and the semen after evaluation be diluted in sterilized cow/ewe milk or egg yolk citrate in 1:3 ratio. Since the fertility of the preserved ram semen declines rapidly, it must be used within 6-8 hours for ensuring good fertility.

In areas where it is not possible to organise artificial insemination for introducing exotic inheritance, it will be desirable to distribute halfbred rams followed subsequently by $\frac{3}{4}$ bred rams. This will allow the introduction of exotic inheritance in two steps. There is no problem of libido or semen quality in halfbreds even under prevailing management practices. The halfbreds and $\frac{3}{4}$ bred rams can be produced on state sheep breeding farms (this has already been envisaged) and also in areas where artificial insemination with exotic ram semen is being practised in farmers flocks.

Nutritional aspects of sheep improvement: Under the existing conditions of cost and availability of grains and other conventional animal feeds, it will perhaps be not possible to resort to intensive feeding practices for sheep production. Sheep in India will have to depend upon largely the grassland and forages, top feeds and some by-product feeds to meet their nutritional requirements. Since the main emphasis in desert development programme is on range land improvement which will provide better grazing conditions, it may be possible to exploit the genetic potential of our native sheep and it may further be possible to sustain more productive animals. The approximate requirement for different nutrients to maintain body weight of an adult sheep weighing about 35 kg is given in Table 9. Although the nutrient intake by the animal through grazing would depend upon the quality of pasture and the grazing density; under the existing conditions of our range lands, the intake is often less than the maintenance requirements especially during the months from January to June (6, 7). Unless resorted to supplementary feeding on conserved fodders, top feeds and/or cereals, the animals lose weight during this period. Because of the seasonality of availability of good grass cover which may not be utilised by the limited number of animals maintained over the whole year, it may be desirable to harvest the excess grass in middle of September and conserve it as hay. This will not only avoid wastage of grass through maturity and reduction in its nutritive value but will allow some regrowth which may increase the grazing period. This seasonality in availability of natural grazing does not seriously affect the wool production per unit weight from the animals, but the total wool production per animal is reduced because the animals maintain their body weight at a low level. This is because much of the energy and protein intake during the monsoon season are utilised to compensate the loss during the scarcity period rather than

promoting additional body weight gains. This points out to the necessity of the conserved fodders and top feed during the period of scarcity of grazing so that body weight loss is prevented during lean periods and susceptibility to disease and mortality can be reduced.

Pasture development: About 80-90 percent of the native range lands in arid and semi-arid areas are under poor to very poor conditions and those under climax vegetative cover are not fully utilised due to water scarcity. The main grass cover is of *Lasiurus*, *Cenchrus* and *Dicanthium* species. Natural regeneration of range lands should be done through proper protection from the biotic factor and/or re-seeding them with appropriate grass species where natural grasses are of poor quality or regeneration is not possible. Perennial grasses like *Cenchrus ciliaris*, *Cenchrus setigerus*, *Lasiurus indicus*, *Dicanthium annulatum*, *Panicum antidotale*, *Setaria nervosum* are highly nutritious and can be propagated in the arid and semi-arid areas depending upon the rain-fall and nature of the soil. Since the grasses are low in protein except during their early stages of growth, it will be essential that some perennial legumes like *Dolichos lab-lab* and *Phaseolus atropurpureus* are incorporated in the regenerated or reseeded range lands. In addition to the perennial species of grasses and legumes used for development of permanent pastures, certain annual fodders can be grown under dry-land conditions and conserved for use during scarcity period of the year. The common kharif legumes are Cowpea, Guar and Moth. These fodders can be grown alongwith Bajra, Jowar and also with perennial grasses. The average proximate composition and nutritive value of different grasses and legumes of the arid regions is given in Table 10.

Silviculture: It is very essential that suitable fodder trees and shrubs are planted in the range lands, to shade and top feed to the animals. The fodder trees that can be propagated may include *Prosopis cineraria* (Khejri), *Gymnosporia spinosa* (Kankera), *Acacia* species (Babul), *Ailanthus excelsa* (Ardu), *Azadirachta indica* (neem), *Albizia lebbek* (Sirish), *Tamarix articulata* (Farash) etc. The chemical composition and nutritive value of different top feeds available in the dry areas are given in Table 11. These fodder trees in addition to increasing the carrying capacity of the pasture land could also provide employment to the rural people through large scale collection of tree leaves which can be preserved as dry leaves or in meal form for using them in the supplementary feed during lean periods.

Carrying capacity: The information available at present indicates that grazing is available only in the months of July to October after

which the pastures start deteriorating and the animals would be able to maintain themselves on those pastures at the most upto January.

Researchers from C.A.Z.R.I., Jodhpur have recommended 2.47 weathers per hectare for the maintenance of animals on the year long basis (8). However, the carrying capacity of the developed grassland in terms of total ewe productivity over longer periods have not yet been determined. It is necessary to undertake experimental work by taking small flocks of ewes (50 to 100 heads) and maintain them on prescribed areas of natural range lands and also on developed pastures with fodder trees, alongwith fodder conservation practices within the allotted areas. Overall flock performance in terms of onset of oestrus, conception rate, lambing rate, lamb growth and survival, wool yield etc. should be studied over a period of atleast 3 years and the detailed economics of such management practices should be calculated.

Considering approximately seven sheep equivalent to one cattle, sheep constitute only one tenth of the livestock population converted into cattle units in the arid areas of Rajasthan (1966 census). Allowing one tenth of the total grazing area for sheep, there are 9.86 lac hectares of land which may be developed for sheep pastures. The cost of developing pastures carrying perennial grasses and legumes including fencing will be about 120 crores (total cost per hectare is around Rs. 1,320/- and comprise Rs. 80/- for preparation of soil which comprises of Rs. 35/- for reseeding Rs. 45/- for seed, Rs. 105/- for fertilizer and Rs. 1,000/- for barbed wire iron pole fence at the rate of Rs. 2.50 per running metre). This land development into pasture will be able to carry 29.6 lac sheep @ 3 improved sheep per hectare which is approximately 50% of the current population of sheep in the area. These sheep will be stationary and need not migrate for the lack of grazing and will produce almost the same quantity of wool as the present number (9).

Health aspects of sheep improvement: Maintenance of proper health is very important for the improvement of total productivity. Due to flocking nature of sheep, out break of contagious disease causes heavy mortality. Prophylaxis against common sheep diseases is more important than treatment of individual cases which is not possible and economical. Enterotoxaemia, Pneumonia, Sheep-pox and Gastro-intestinal parasitism are important diseases resulting in serious mortality and morbidity in sheep. Vaccination against enterotoxaemia and drenching against gastro-intestinal parasites immediately prior to rains will help in cutting down the mortality and morbidity due to these diseases. Sheep-pox generally occurs during dry months immediately after winter and vaccination against sheep-pox should be done some time in the month of March. Pneumonia can be reduced by providing

protection to young lambs against extreme weather conditions and increasing their resistance to disease through better nutrition, specially during rainy season and winter.

Management practices for sheep improvement: Proper management practices like care of advanced pregnant ewes through providing them some supplementary feed and proper care of young lambs during first few days of birth are to be followed so that mis-mothering is avoided and artificial feeding of lambs on sheep/goat milk can be restored to, in cases where mothers have poor milk production or lamb is orphaned. It will be advantageous to provide some supplementary leguminous green fodder/hay to young lambs to ensure better growth and health. The surplus ram lambs may be castrated at an early age to improve their growth, carcass yield and quality. They should be marketed at an early age but not later than 12 months. Ewes above $1\frac{1}{2}$ years of age which do not breed in two subsequent breeding seasons and ewes beyond 5 years of age should be culled. These management practices will help in raising the overall flock productivity.

Canary colouration of wool: Canary colouration or non-scourable yellowing of wool in north-western region during hot humid months is a serious economic problem that results in 15-25% reduction in price of the wool. It is now apparent that the canary colouration results as a consequence of adaptive mechanism in Indian sheep pertaining to thermo-regulation through cutaneous evaporation (10). Shearing of animals in later part of June and protecting them for about a fortnight from solar radiation by maintaining these under shade and by grazing them during cooler parts of the day may help in reducing the incidence of canary colouration and may further be helpful to the animal against stress of hot and humid climatic conditions.

Development of marketing facilities, wool, skin and meat based industries: Although the importance of development of marketing facilities for wool and live animals and development of small scale wool based industry has been stressed earlier, it is further emphasised that such facilities must be organized both for the sedentarised and migratory flocks by the Government or the Cooperative Agencies as this will avoid profiteering by a number of intermediary agencies dealing with the marketing of live animals and wool. Further, the development of wool based industry in the rural areas will help in providing remunerative employment throughout the year to the farming families. Establishment of large-scale slaughter and meat processing plants and plants for processing slaughter by-products in areas where large number of animals for slaughter are available may be helpful in

reducing expenditure on transportation and losses due to shrinkage and death. This will also help in more appropriate utilisation of slaughter house by-products and in the establishment of large industries, which may employ a large number of rural people.

Summary and conclusions: Sheep have often been incriminated as one of the important biotic factors in the formation of the desert because of their density of population, grazing habits and large scale migration resulting from unfavourable foraging and drinking water conditions in the arid areas. In reality, it is not the sheep but the man owing the sheep has to be blamed for causing the desertic conditions because of our exploitation of grazing land through much higher number of sheep and little concern on their rehabilitation and proper management. Sheep rearing would best fit into a system of pastoral-silviculture which would be the main approach for desert development. Sheep in turn would help convert the infertile desert land into a fertile one through their droppings during grazing over the years.

Since sheep serves as an important source of food, fibre and employment for a large section of the population in desert areas, it is very necessary to undertake sheep improvement programmes to improve the economic status of the sheep raisers and to provide protection to the farmer from being continuous victims of drought and famine.

Sheep improvement programmes should be taken up differently for sedentarised flocks and for migratory flocks in providing facilities for proper breeding, feeding, management including health cover and marketing.

Crossbreeding of the native fine carpet/apparel wool breeds (Chokla and Nali) with the exotic fine wool breeds (Rambouillet and Merino) should be undertaken to provide half-breds with improved wool production and quality. The exotic inheritance should be stabilized at 50% and further improvement be brought through selection of sires on six monthly greasy fleece weight and fibre fineness. Distribution of stud rams of native breeds, selected for heavier fleeces and against medullation should be made to improve the quantity and quality of the carpet wool from the other native carpet wool breeds.

Due to lack of sufficient number of exotic rams, artificial breeding should be resorted to for large scale crossbreeding programme. For this purpose special centres should be organised for maintenance of exotic rams under housing conditions which will prevent the rams from exposure to solar radiation and high atmospheric temperature. The centre should have facility for collection, dilution and preservation of semen so that proper libido and fertility of semen can be main-

tained and inseminations can be carried out within 6-8 hours of collection of semen.

In order to provide adequate grazing/supplementary fodder and top feeding, large scale range improvement programme through protection, reseeding with more hardy and nutritive perennial grass and legumes soil conservation and plantation of fodder trees should be undertaken. Fodder conservation both through harvesting of grass and legumes in middle of September and from tree lopping should be undertaken to provide supplementary fodder during scarcity periods of the year and for pregnant, lactating ewes and lambs. The improved range lands and reseeded pastures may be managed through communal system of farming by sheep farmers' cooperatives.

Prophylactic vaccinations and drenching should be done against common sheep diseases for both the sedentarised and migratory flocks. Farmers should be educated on the better management of pregnant and lactating ewes, lambs and also on the shearing and management practices to be adopted for checking yellowing of wool.

Development of marketing facilities and creation of sheep and wool based industries and provision of credit and banking facilities for the sheep farmers would be very essential to ensure economic return to them.

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Table 1. Sheep population and density in the desert districts of Rajasthan

S. No.	Districts	Area (sq. km.)	Sheep population*	Density (sheep/ sq. km.)
1.	Barmer	28,172	3,67,656	13.05
2.	Bikaner	27,369	4,01,701	14.67
3.	Ganganagar	20,638	2,83,825	13.75
4.	Jodhpur	22,644	6,82,636	30.14
5.	Jaisalmer	38,834	3,13,163	8.08
6.	Jalore	10,564	4,53,178	42.89
7.	Jhunjhunu	5,923	2,11,593	35.72
8.	Nagaur	17,644	8,02,055	45.45
9.	Pali	12,224	6,27,042	51.29
10.	Sikar	7,749	3,96,596	51.18
11.	Churu	16,860	4,26,060	25.27
Total		208,626	51,65,505	24.75

*1971 Census, Directorate of Sheep & Wool, Rajasthan.

Table 2. Location of sheep breeds in arid areas of Rajasthan

S. No.	Breed	Location
1.	Chokla	Churu, Jhunjhunu and Sikar districts, also found at common boundaries of Bikaner, Jaipur and Jodhpur common boundaries of Bikaner, Jaipur and Jodhpur Divisions and Nagaur District.
2.	Magra	Along borders of Jaisalmer, Nagaur and Bikaner districts, also extending all over Bikaner District.
3.	Pugal	Pugal area in western Bikaner district and extending upto borders of Pakistan in the west and northern parts of Jaisalmer district.
4.	Nali	North, north-eastern part of Bikaner Division extending into Punjab state.
5.	Jaisalmeri	North-western parts of Jodhpur and Jaisalmer districts.
6.	Marwari	Jodhpur Division and adjoining areas of Ajmer and Jaipur divisions.

Source : Reference No. 11

Table 3. Results of survey conducted by C.S.W.R.I. to study economics of sheep rearing in arid areas of Rajasthan

	Chokla	Nali
Number of villages involved in the survey	17	2
Number of flocks	57	78
Average flock size	115.2	281.4
Average wool yield/animal (Kg)	1.22	1.50
Average price/cwe sold (Rs)	31.01	30.77
Average price/lamb sold (Rs)	38.55	35.40
Percent breeders getting income from sheep folding	21.05	14.10
Average price/Kg wool (Rs)	6.67	6.48
Average income/sheep folded/year (Rs)	0.70	0.49
Average No. of lambs born per 100 ewes	60	67
Average No. of rams/100 ewes	31	23
Percent mortality (i) Adults	4.78	5.62
(ii) Lambs	31.25	16.78

Table 5. Average wool yield and quality (based on six month clip) of some native breeds of sheep in arid areas of Rajasthan

S.No.	Breeds	Wool yield (kg)	Av.Staple length (cm)	Av.Fibre Diameter (micron)	Av.Medullation percentage
1.	Chokla	1.308	4.90	27.57	17.03
2.	Nali	1.580	7.53	37.61	36.77
3.	Magra	1.360	7.81	37.20	56.83
4.	Jaisalmeri	1.530	8.76	33.08	44.85
5.	Marweri	1.130	9.47	38.76	49.80
6.	Pugal	1.117	6.00	34.46	61.52

Table 4. Relative income from Sheep, Goat and Cattle rearing under free range grazing

Species	1st year	2nd year	3rd year	4th year	5th year	6th year	Total
Cattle	300/-	4,040/-	4,495/-	2,290/-	2,550/-	3,835/-	17,510/-
Sheep	1,900/-	2,854/-	3,501/-	2,876/-	3,767/-	3,928/-	18,826/-
Goats	2,200/-	4,150/-	7,340/-	8,210/-	9,550/-	9,700/-	41,150/-

Assumptions :—

A. *Sheep*

1. Yearly lambing rate—70%
2. Lamb mortality upto one year of age 20%
3. Adult mortality 5%
4. Wool yield six monthly clip — Adult—0-600 kg
Lamb—0-400 kg
5. Sale value of wool per kg. Rs. 10/-
6. Sale value of sheep folding per animal per year Re. 1/-
7. Age at first lambing—2 year
8. Sex ratio—1:1
9. Sale value of male yearling lamb Rs. 40-00 each
10. Sale value of culled ewe—Rs. 40-00 each

B. *Goat*

- 1) Yearly kidding rate—105% (70 goats providing 1-5 kids per kidding)
- 2) Milk production 250 ml per day for 120 days
- 3) Sale value of milk per lit—Rs. 1/-
- 4) Kid mortality up to 1 year of age 20%
- 5) Adult mortality—5%
- 6) Sale value of yearling male Rs 50-00
- 7) Sale value of culled doe kid Rs. 100-00
- 8) Return from goat folding per goat—Rs 1/- per year.
- 9) Sex ratio—1:1

C. *Cattle*

1. Age at first calving—3 years
2. Inter-calving period—1 years
3. Milk production 2 lit. per day over a period of 300 days.
4. Calf mortality—10%
5. Sale value of manure —Adult — Rs 20/-
young—Rs 5/-
6. Income from culled/dead animal—Rs 50-00 per animal
7. Sale value of yearling male—Rs 400/-
8. Sale value of milk Rs. 1/- per lit.
9. Cost of supplementary feeding/day/cow Rs 0-50 during location only.

Table 6. Fleece characteristics of Rambouillet, Jaisalmari, Malpura and their crosses at 6 month/yearling age

S.No. Breed/ crosses	Grease Fleece wt (Kg)		Staple length (cm.)		Medullation % Av. fibre diameter (u)			
	6 month	Yearling	6 month	Yearling	6 month	Yearling	6 month	Yearling
1. Rambouillet	0.88 (38)	0.06 (24)	2.20 (33)	3.41 (24)	0.75 (33)	1.24 (24)	16.41 (33)	15.940.72 (24)
2. Chokla	1.25 (28)	1.14 (43)	3.76 (23)	4.76 (43)	29.40 (28)	1.36 (28)	27.18 (28)	26.90 (43)
3. RC (F ₁)	1.62 (33)	1.42 (23)	4.41 (83)	4.10 (23)	15.50 (82)	0.76 (82)	24.86 (83)	22.96 (23)
4. RC (F ₂)	1.22 (67)	1.29 (26)	4.00 (60)	4.14 (26)	7.80 (60)	1.20 (60)	23.19 (60)	22.30 (26)
5. RC (5/8)	1.26 (33)	1.27 (13)	3.40 (33)	3.37 (13)	10.40 (33)	1.60 (33)	21.19 (38)	16.04 (13)
6. RC (3/4)	1.34 (26)	1.21 (15)	3.27 (26)	2.25 (15)	5.80 (26)	2.02 (26)	19.54 (26)	18.26 (15)
7. RJ (F ₁)	1.45 (39)	—	3.91 (39)	—	24.20 (31)	1.82 (31)	25.50 (39)	—
8. RJ (3/4)	1.05 (14)	—	2.84 (14)	—	15.00 (14)	0.76 (14)	22.84 (14)	—
9. Malpura	0.67 (98)	0.52 (71)	3.55 (98)	6.67 (71)	78.90 (98)	0.64 (98)	36.52 (98)	39.00 (71)
10. RM (F ₁)	1.28 (120)	1.20 (30)	4.36 (120)	4.31 (30)	35.0 (120)	0.28 (120)	26.96 (120)	28.87 (30)
11. RM (F ₂)	1.02 (50)	1.11 (22)	3.96 (51)	3.99 (22)	19.0 (51)	1.26 (51)	23.95 (51)	58.58 (22)
12. RM (5/8)	1.15 (48)	1.25 (15)	3.27 (48)	3.63 (15)	14.70 (48)	1.29 (48)	43.43 (48)	21.46 (15)
13. RM (3/4)	1.11 (41)	1.14 (17)	2.87 (41)	2.82 (17)	10.50 (14)	0.96 (14)	20.64 (41)	19.86 (17)

 1. The values are mean $\pm$ SEM. 2. Figures in parenthesis indicate number of animals. Sources: Reference No. 12

Table 7. First six monthly fibre attributes of Rambouillet, Merino, Nali, Chokla and their crosses

S. No.	Breed/breed-crosses	Grease fleece wt (kg)	Staple length (cm)	Medullation%	Fibre diameter
1.	Rambouillet	0.98 0.06 (39)	2.71 0.10 (19)	2.61 0.49 (16)	12.98 0.17 (19)
2.	Merino (M)	1.17 0.03 (90)	3.30 0.06 (100)	4.57 0.42 (91)	16.61 0.21 (100)
3.	Nali (N)	1.02 0.18 (66)	6.15 0.22 (50)	63.5 (50)	41.7 0.22 (50)
4.	Chokla (C)	0.95 0.03 (107)	5.13 0.10 (78)	43.4 0.08 (78)	26.2 0.64 (78)
5.	R x C	1.06 0.20 (92)	4.46 0.08 (47)	23.79 1.62 (48)	19.43 0.33 (48)
6.	M x C	0.98 0.05 (43)	4.46 0.08 (32)	22.67 1.83 (31)	20.19 0.40 (31)
7.	R x N	1.11 0.03 (133)	4.55 0.08 (72)	32.64 1.50 (73)	22.63 0.30 (73)
8.	M x N	1.16 0.36 (81)	5.19 0.08 (104)	23.30 0.99 (104)	22.32 0.30 (104)

1. Value are mean SEM
2. Figures in parenthesis indicate number of animals.

Table 8. Body weight and survivability of some crossbred sheep.

S. No.	Breed/Breed-cross	Body weight (Kg) 9 month age	Survivability (%)					
			0—1 wk.		1 wk.—3 Mo.		3 Mo.—1 yr.	
1.	Rambouillet	28.00 1.08 (38)	86.21 3.23 (116)	91.84 2.79 (98)	64.41 6.34 (59)			
2.	Chokla	14.68 0.35 (72)	90.08 1.89 (252)	79.46 2.71 (284)	57.14 5.05 (298)			
3.	Malpura	18.66 0.34 (107)	91.97 1.08 (635)	89.33 1.28 (581)	62.18 3.16 (238)			
4.	R x C (F)	18.86 0.65 (50)	89.83 1.76 (295)	72.52 2.77 (262)	70.00 4.22 (20)			
5.	R x C (F)	21.43 0.63 (76)	95.97 1.78 (124)	94.96 2.02 (119)	81.93 4.27 (83)			
6.	R x C (5/8)	23.31 0.78 (40)	96.55 2.44 (58)	96.43 2.52 (56)	92.68 4.17 (41)			
7.	R x C (3/4)	21.06 0.90 (38)	98.52 1.05 (73)	95.45 1.83 (70)	95.24 2.35 (39)			
8.	R x M (F)	23.23 0.75 (54)	99.04 0.97 (135)	92.50 2.98 (132)	83.02 5.26 (84)			
9.	R x M (F)	23.74 0.75 (57)	99.04 0.97 (104)	97.09 1.67 (103)	78.79 5.11 (66)			
10.	R x M (5/8)	24.19 0.78 (50)	93.02 2.77 (86)	92.50 2.98 (80)	83.02 5.26 (53)			
11.	R x M (3/4)	21.87 0.87 (38)	95.89 2.35 (73)	92.36 3.12 (70)	89.74 4.98 (39)			
12.	R x J (F)	21.38 0.68 (34)	99.07 0.99 (108)	85.05 3.48 (107)	90.91 3.95 (55)			
13.	R x J (F)	16.03 1.12 (7)	100.00 0.00 (18)	83.33 9.30 (18)	54.54 16.51 (11)			
14.	R x J (3/4)	20.36 1.21 (14)	90.32 5.49 (31)	96.43 3.64 (28)	73.33 12.23 (15)			

1. Values are means SEM.

2. Figures in parenthesis indicate number of animals.

Table 9. Requirements for different nutrients for maintenance of an adult sheep weighing 35 Kg.

S. No.	Nutrient	required/day
1.	Total feed*	900 g.
2.	T.D.N.	450 g.
3.	D.C.P.	45 g.
4.	Calcium	2.4 g.
5.	Phosphorus	2.0 g.
6.	Magnesium	1.2 g.
7.	Common salt	3.0 g.
8.	Potassium	4.5 g.
9.	Sulfur	1.5 g.
10.	Copper	8.0 mg.
11.	Cobalt	0.2 mg.
12.	Zinc	75 mg.
13.	Iron	60 mg.
14.	Manganese	30 mg.
15.	Iodine	0.1 mg.
16.	Molybdenum	1.5 mg.
17.	Selenium	0.15 mg.
18.	Carotene	1.5 mg.
19.	Vitamin A	750 Iu.
20.	Vitamin D	200 Iu.

* Air dry basis

Table 10. Percentage proximate composition and nutritive value of some grasses and legumes found in arid and semi-arid zones.

S. No.	Botanical name	Common name	Crude protein	Crude fibre	Nitro- gen free extract	Ether extract	Total ash	Calcium	Phos- phorus	DM in- take/ 100 Kg body wt.	D.C.P.	T.D.N.
<i>Grasses</i>												
1.	<i>Aristida funiculata</i>	Lampla	2.39	33.20	53.81	1.11	9.49	0.80	0.27	1.55	—	—
2.	<i>Cenchrus ciliaris</i>	Anjan	5.50	33.90	50.70	1.20	8.79	1.00	0.15	3.00	2.2	40.00
3.	<i>Dicanthium annulatum</i>	Karad	2.40	35.77	49.84	2.01	7.63	0.28	0.14	—	—	—
4.	<i>Eleusine flagellifera</i>	Tantia	5.55	29.18	51.40	1.73	12.01	0.54	0.14	—	—	—
5.	<i>Lasiurus indicus</i>	Sevan	5.98	38.03	44.72	—	0.32	0.32	1.03	—	3.02	41.38
6.	<i>Panicum antidotale</i>	Blue panic	7.26	40.47	43.11	1.19	7.97	0.39	0.09	2.80	2.65	45.04
7.	<i>Cynodon dactylon</i>	Doob	5.00	32.90	51.60	1.13	9.36	0.52	0.37	—	—	—
8.	<i>Brachiaria ramosa</i>	Kuri	9.43	28.53	43.92	0.78	17.34	0.45	0.35	—	—	—
9.	<i>Schima nervosum</i>	—	8.55	29.21	33.44	—	0.81	—	—	—	—	—
10.	<i>Eragrostis chloromelas</i>	Boar Love	6.78	37.00	48.37	1.44	6.44	0.38	0.29	—	—	—
<i>Legumes</i>												
11.	<i>Dolichos lab lab</i>	Rawan	14.19	28.08	39.43	3.50	14.80	1.98	0.26	—	18.3	61.4
12.	<i>Phaseolus atropurpureus</i>	Sirat	23.0	30.4	29.70	6.6	10.20	1.18	0.28	2.34	19.12	53.43
13.	(pod stage)	Bekaria	14.8	25.6	46.4	2.0	11.3	3.4	0.17	4.4	10.7	55.5
14.	<i>Indigofera enneaphylla</i>	-do-	12.2	26.0	47.5	1.6	12.7	5.1	0.15	3.9	7.8	57.5
15.	<i>Indigofera cordifolia</i>	Gokhru	12.1	27.8	40.8	2.6	16.7	4.2	0.24	3.4	9.1	55.6

Table 11. Percentage proximate composition and nutritive value of some tree leaves and shrubs of arid and semi-arid regions.

S. No.	Botanical name	Common name	Crude protein	Crude fibre	Nitor- gen free extract	Ether extract	Total ash	Calcium	Phos- phorus	DM in Kg body weight	D.C.P.	T.D.N.
1.	<i>Acacia arabica</i>	Babul	7.04	33.32	51.16	2.56	5.92	1.24	0.11	—	—	—
2.	<i>Acacia catechu</i>	Khair	13.30	22.55	50.96	4.55	9.80	2.72	0.17	—	1.16	18.50
3.	<i>Azadiracta indica</i>	Neem	16.12	20.69	52.60	2.40	7.73	1.39	0.24	—	3.35	21.3
4.	<i>Prosopis cineraria</i>	Khajri	15.29	17.52	54.09	4.52	5.11	1.61	0.30	—	—	—
5.	<i>Gymnosporia spinosa</i>	Kankera	9.42	15.33	58.63	4.00	12.62	5.49	0.13	3.7	6.1	62.8
6.	<i>Zizyphus nummularia</i>	Pala	14.20	15.70	57.1	4.30	8.60	2.4	0.14	2.3	5.7	58.0
7.	<i>Ailanthus excelsa</i>	Ardu	16.25	21.85	47.48	3.00	11.43	1.43	0.17	4.26	13.00	64.00
8.	<i>Dalbergia sissoo</i>	Shisham	16.20	24.63	46.19	4.20	9.21	2.27	0.21	—	3.66	20.90
9.	<i>Albizia lebbek</i>	Siras	16.81	31.52	36.16	3.57	11.54	2.57	0.15	—	4.64	19.70

AN INTRODUCTION TO SHEEP AND CATTLE ECOLOGY

Brahma Chowdhary*

INTRODUCTION

Ecology has been defined as that branch of biology which deals with the relations of living organisms to their environments, their habits and their mode of life.

Domestic animals also include their relationship to human society, and economy, and in particular their productivity. On this earth out of the total domesticated animals only 30 are of economic importance to man.

2 Insects: Honey bee and silkworm.

9 Birds: Turkey, Duck, Goose, Swan, Guinea Fowl, Pea fowl, Pigeon and Ostrich.

3 Small mammals of very limited utility: Dog, Cat and Rabbit.

16 Mammals: They constitute the most important classes of domesticated livestock.

Equidae: Horse and Ass.

Camelidae: Arabian and Bactrian Camels, Llama and Alpaca.

Bovidae: European and Zebu (Indian humped) Cattle, Buffalo, Yak, Gayal, Banteng, Sheep and Goat.

Cervidae: Reindeer.

Suidae: Pig.

The credit of domesticating the first group of farm animals falls to peoples living at the end of the Mesolithic (middle stone age) period (Ryder and Stephenson, 1968).

The domesticated breeds of cattle, sheep, goat, pigs and horses originated from the older civilization of Asia that is in the Indus civilization of "Harappa", Mohan-jo-dhara, Pilibanga and Kalibanga (Ganganagar) respectively.

ORIGIN AND DISTRIBUTION OF SHEEP

According to Crawford, the oldest evidence of wool comes from Asia Minor, from Tell Asmar, the great hill or mound. The data set for this mound is 4200 B.C. or 6000 years ago. From Central Asia, the

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cradle of civilization, the sheep gradually were introduced into new locations until today they are found over the entire globe.

Thus, the domesticated sheep of today are believed to have originated from the following places: (i) Tibet; Argali (ii) Punjab: Urial; (iii) Afghanistan; Mouflon (Chowdhary; 1973).

Present day sheep's natural habitat is dry, hot in summer and cold in winter such as North India, Afghanistan and Tibet. Thus, sheep was not adopted to humid climate. Temperature and rainfall must be expected to exert the greatest influence on its distribution. High temperature has been responsible to produce a woolly sheep such as Chokla while high rainfall with high humidity has produced a hairy sheep such as Nellore (Chowdhary, 1973).

Distribution of sheep is due to 3 reasons:

(a) Geographical; (b) Historical; (c) Commercial.

Sheep raising:

(i) In arid and semi-arid regions where feed is not sufficient, the maintenance of flocks for production of the finer grades of wool, with lamb raising as secondary consideration.

(ii) A second type of sheep raising in semi-arid and sub-humid areas where lamb raising and wool production both.

(iii) The third type of sheep raising is in humid areas with more emphasis on lamb production for mutton purposes.

Mean temperature zones:

(a) At equator and in the tropics lies 80°-85°F (Tropical).

(b) Warm temperature or sub-tropical regions: 60°-70°F.

(c) Cool temperate regions: 50°F.

(d) Extreme arctic and antarctic: Below 40°F.

Most of the sheep are in tropical and temperate regions. 3000 B.C. sheep was domesticated for milk, meat, wool and skin in Indus valley civilization from where it has gone to different parts of this world and the environmental factors produced different breed of sheep such as (i) Low nutrition, high tropical temperature in summer and too cold in winter-evolved a sheep with fat tail (weighing 30 kg. able to supply food for 75 days at the 1 lb D.O.M.=0.4 lb fat) as food reserve needed during scarcity periods. Small body size with fine, medium and coarse wool such as in hot dry climate: Chokla, Magra, Marwari, Jaisalmeri, Pugal and Nali; in hot humid climate Nellore (hairy); Malpura and Sonadi (coarse); in temperate: Poonch and Karnah in Kashmir with medium fine quality wool.

(ii) Some of these animals have gone to Spain via middle east in the beginning of Christian era where on better pasture it flourished

well and from Spain they were raised in S. Africa (tropical) and England (temperature) and now they are being raised in Australia by better breeding and feeding management.

Different breeds in Arid Zone:

Rajasthan has 8 breeds of sheep. Sheep population and wool production (1966) is as under:

Breed	Population (lakh)	Wool in lakh kg	Wool in kg/sheep
Chokla	7.37	15.39	2.07
Jaisalmeri	5.90	14.75	2.50
Magra	4.90	8.91	1.80
Marwari	35.76	48.71	1.36
Pugal	1.33	2.42	1.82
Nali	5.15	10.52	1.80
Malpura	14.72	15.03	1.01
Sonadi	12.88	13.16	1.02
	88.01	124.89	1.42

In arid zone the Jaisalmeri sheep produced (2.50 kg) maximum while Marwari (1.36 kg) minimum but the Marwari breed of sheep provides 48.71 lakh kg of wool, out of the total 124.89 lakh kg* wool production in Rajasthan*. One of *(Chowdhary; 1972) the reason of low production in Marwari sheep is the severe competition for nutrition. The areas of her habitat is mostly cultivable while for Jaisalmeri sheep there is plenty of availability of pastures. Thus, the limiting factor is range land for grazing.

Marwari sheep is the hardiest sheep we have and it is a very good traveller, has comparatively long legs.

Wool and Lamb production:

In our breeds production of wool per sheep per year is very low and also lambing percentage is low. The main reason is lack of nutrition. They have to compete with other animals. Hence, to increase production from our sheep availability of good pasture and forage land is a must.

Since 1951 to 1971 sheep number and wool production in India has increased from 3.9 crores to 4.4 crores and 2.7 crores kg to 3.9 crores kg. Thus our sheep population varies between 4 to 5 crores. When famine, sheep dies and in good years number increases.

FINE WOOL PRODUCTION

It is possible to produce fine wool with exotic breeds, like Merino, Rambouillet and Corriedale provided before importing we consider

the ecological condition that is sheep from tropical area should be brought to Arid Zone and from temperate to temperate zone of India. This is first and foremost consideration. But the improvement of pasture and range land is equally important with availability of good water. If we achieve these two objectives we have a great potential to produce fine wool required by our growing wool industry.

	Rajasthan	Western Arid Zone of Rajasthan
People	25.8 million	8.3 million
Cattle	12.46 million	3.47 million
Buffaloes	4.69 million	1.12 million
Sheep	8.56 million	5.11 million
Goats	12.15 million	5.82 million
Camels	0.74 million	0.62 million

Cattle breeds:

This arid zone has the best milch animals such as Rathi, Tharparkar and draft breeds Nagauri.

These animals are very well adapted in this environment. Their ability to produce milk can be increased, the only limiting factor is lack of nutrition.

The night grazing is an answer during the hot summer but for efficient production availability of grass and water is a must now.

Grazing habit

Animals in arid zone normally decrease their intake during summer. However, in general they follow the night grazing pattern during hot summer season.

Livestock sector

In Rajasthan it has been estimated that the livestock sector of agriculture accounts for about 12% of the total income of the state. The total livestock population (1972 census) in the State is 39.09 million as under:

Cattle	12.46 million
Buffaloes	4.69 "
Sheep	8.56 "
Goats	12.15 "
Camels	0.74 "

It has been estimated that the total quantity of wool produced annually in the State is around 14 million kg. which constitutes about 40 per cent of the total wool production in the whole country. Even though, the bulk of the wool produced is of carpet quality, nearly one million kg. of fine wool is also produced in this State of Rajasthan.

The main source of earning in the western arid zone of Rajasthan which comprises of 11 districts covering 60.9% of total area of Rajasthan State (that is 208, 626 sq. km). In these districts only 38% of the total population of Rajasthan lives (3).

The population of livestock in these districts is as under:—

Cattle	3.47	million	41.6% of whole state
Buffaloes	1.12	"	27.8
Sheep	5.11	"	23.9
Goats	5.82	"	59.6
Camels	0.62	"	83.7
	16.3	million	

A fairly large percentage of sheep in Rajasthan is maintained on migratory basis (5). About 30% of the sheep population in Rajasthan is migratory and the average flock size of migratory sheep is around 70 against the average size of 40 in stationary flocks. According to an estimate about 1.5 million sheep migrate from State every year and that out of this about 0.6 million sheep are on permanent migration.

Sheep migration is a regular practice with the sheep breeders from the western arid districts of Jaisalmer, Barmer, Jodhpur, Pali, Jalore, Nagaur and Bikaner. A comparison of the livestock population and land use statistics shows that in the arid districts, grazing area available are 1.1 hectare and 0.38 hectare respectively as against the corresponding figures of 0.47 and 0.22 hectare for the whole state. The number of cattle and buffaloes for every thousand hectares of net cultivated area in the arid zone is 657 as against 939.5 for the state.

Grasses and shrubs

Certain species of grasses such as Sewan (*Lasiurus indicus*), Anjan (*Cenchrus ciliaris*), Dhaman (*Cenchrus setigerus*) known for high nutritive value are able to grow during rainy season and supply nutrition from June to December. From January to May is the lean period of the year during which the dry fodder and Bajra-Kuttar, Sewan-Kutter and Pala is used for valuable livestock in this area of Rajasthan. Also the Fog supplies nutrition from March to May in the form of Ghintal and Lasu* Siniya, Khimp, Bantka, Ker, Hinguni, Bui, Murali, Kumta, Dachhab and dab provide nutrition to sheep and

other livestock during this period of the year. During famine the above mentioned grasses and shrubs fail to provide nutrition hence sheep migrate to another areas such as Punjab, Haryana and Delhi.

The pressure of livestock in this area has been increasingly growing since somewhat earlier than the last two decades. The increase in cattle 45.6%, Buffaloes 42.1%, Sheep 67.2% and goat 94.2% between 1951 and 1966. The corresponding increase in the rest of State is only 11.5%, 37.0%, 57.0% and 78.6% (4). To provide better economical aid to the farmers of this area it is very essential now to establish better pastures of local varieties of grasses in the Rajasthan Canal area to get maximum production from our animals.

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ANIMAL PRODUCTION IN THE DESERT ECO-SYSTEM

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The areas in which evaporation rate exceeds precipitation are termed as arid areas. The excessive evaporation may be either due to high temperature or due to low rainfall and very low temperatures. In both the cases deficiency of water results into poor vegetation. In general, the Rajasthan desert, encompassing western half of Rajasthan and parts of Gujarat and Haryana extends over nearly 2,18,100 sq. km. and fulfils the general characteristics of a desert, viz., low and highly variable rainfall, large diurnal temperature variation, high evaporation, scanty vegetation, sparse nomadic human population depending more on animals than agriculture. Rao *et al.* (1972) developed indices for humidity, aridity and moisture with respect to arid areas of Rajasthan, Haryana and Gujarat. The figures for humidity index ranged from 0.0 to 3.5, aridity index from 70.6 to 89.4 and moisture index from -89.4 to -67.2.

2. The Rajasthan desert possesses many peculiar properties uncommon to other arid regions. With respect to temperature-precipitation diagram it occupies the worst position (Banerji, 1952). Sand storms and sand dunes indicating predominant wind action are most common features. The soils are generally sandy and deficient in organic matter (Roy and Kolarker, 1968). In spite of low rainfall in the area, the relative humidity is fairly high (Krishnan, 1968). Wherever water is available, the crop yield figures are comparable to other areas. Rajasthan desert is rich in flora, for as many as 507 species of plants including 46 exotics have been recorded (N.C.A. report, 1974). In fact, during a good monsoon year the area does not look like a desert. In spite of meagre rainfalls, certain species of perennial grasses viz. Anjan (*Cenchrus setigerus*), Dhaman (*Cenchrus ciliaris*) and Sewan (*Lasiurus indicus*) known for their high nutritive values grow extensively. The grass cover in grazing lands lasts only for three to four months after monsoons.

3. With the recurring failure of monsoons the principal source of livelihood of the people is livestock raising. Some of the well-known breeds of Sheep (Marwari, Jaisalmeri, Nali, Chokla, Magra, Pugal and Pattanwadi), Cattle (Rathi, Tharparkar, Kankrej, Haryana and Nagauri), Buffalo (Mehsena type) and Camels (Jaisalmeri, Marwari, Bikaneri etc.) are found in this area. In addition to sheep,

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cattle, camel, buffaloes and goat rearing is also contributing substantially to the rural economy of the people of this region. According to the 1972 livestock census, the total livestock population of the state of Rajasthan was 39.09 million. Of this the 11 western arid districts had 16.3 million livestock including 5.11 million sheep, 3.47 million cattle, 1.12 million buffaloes, 0.62 million camels and 5.82 million goats. The total livestock and total cattle, buffaloes, sheep, goats and camels in this area as percent of the corresponding totals for the whole state were 41.6, 27.8, 23.9, 59.6, 47.8 and 83.7, respectively. Similarly, in the contiguous areas of Gujarat and Haryana, animals are maintained in large numbers. During the periods 1961-1972 the livestock figures for the desert area of Gujarat revealed a decreasing trend in cattle and sheep (3.56 lac. to 2.8 lac. and 1.8 lac. to 1.5 lac., respectively) populations, whereas an increasing trend was evident in the buffalo, goat and camel (1.02 lac to 1.35 lac and 1.14 lac to 2.50 lac, and 0.068 lac to 0.112 lac, respectively) populations. Similarly, during the years 1966 to 1972 the cattle, buffalo and camel populations in the desert areas of Haryana registered an increase whereas sheep and goat populations declined which may be the result of progressively increased area coming under canal irrigation leading to shrinkage in the grazing areas for sheep and goat.

4. In spite of such a great importance of livestock rearing in the economy of desert areas, serious efforts aimed at developing and maintaining pastures, providing incentive marketing facilities for livestock and livestock products, bringing in improvements in the existing animal husbandry practices and rehabilitating the livestock owners are yet to be taken up. Migratory type of animal husbandry is more a compulsion than choice. Though, the cattle owners of most of the areas of Rajasthan desert practice limited migration, the sheep farmers travel long distances in search of grazing and water availability for their animals. It has been estimated that about 38 percent of the sheep population of Rajasthan is migratory. An estimated 1.5 million sheep migrate to other states every year of which about 0.6 million are on permanent migration. The sheep owners of the desert districts (Jaisalmer, Barmer, Jodhpur, Bikaner etc.) migrate to the adjoining areas of U.P., M.P., Haryana and Gujarat states. On account of this annual migration the livestock owners have to suffer heavy losses due to high mortality and poor production and reproduction performance of their animals. In addition to the poor grazing conditions available in the desert areas, the increasing livestock pressure per unit area of land over the last two decades or so is posing additional problems which further emphasise immediate need for undertaking effective programmes for augmenting fodder resources.

5. In view of the above status of animal production in the desert areas a coordinated approach of animal improvement is the answer. Such programmes should envisage;

- (i) containing, if not reducing the livestock population,
- (ii) ensuring adequate nutrition of the animals by augmenting feeds/fodder resources,
- (iii) settling the nomadic/migratory animal owners, and
- (iv) improvement in the production performance of the local livestock through planned breeding, improved management and effective disease control measures.

Although, some area of the Rajasthan desert is already being commanded by the Gang and Bhakhra canals with progress in the Rajasthan Canal Project and completion of the Lathi series projects in Jaisalmer district additional acreage will be irrigated, thereby considerably augment the feed and fodder resources for livestock. In spite of these irrigation projects, large areas will still remain unirrigated and hence fodder deficient implying the need for animal improvement programmes for the irrigated and non-irrigated areas separately.

The determining pre-requisite for the success of any animal improvement programme is adequate feed and fodder availability. Extensive pasture development and improvement programmes need to be taken up through regulated/rotational grazing, re-seeding and fertilizer application etc. In the irrigated areas agronomical practices need to be developed such that most efficient use of the available water resources are made. Aiming at a 200 percent crop intensity about 12-15 percent area should be put under fodder crops both in the summer and winter seasons. Such a cropping pattern will ensure sufficient green fodder for prosperous/intensive animal husbandry in the irrigated areas and will provide adequate dry fodder for unirrigated areas.

6. The incentive for the farmers of the irrigated areas to cultivate fodder crops has to be expected financial returns from fodder cultivation. Such a venture can be remunerative if high producing animals are maintained. Crossbred animals (cattle) will be ideally suited for such areas. Comparative returns from a buffalo, crossbred cow and an indigenous cow suggest that a crossbred cow gives twice as much monthly profit as a buffalo whereas an indigenous cow at the levels assumed is uneconomical. Similarly, crossbred sheep are also much more economical than the indigenous animals.

For optimising the land use and to maximise the profits, in the irrigated areas, mixed farming should be practiced. This system of farming will provide—

- (i) an extra remunerative employment to the farmer's family,
- (ii) the soil fertility will improve by extra manuring and production of leguminous and other feeders for the animals eliminating the need for fallowing the land,
- (iii) agricultural by-products can be remuneratively utilised by the animals, and
- (iv) intensive land utilisation by adopting intensive cropping patterns.

In order to effectively integrate Animal husbandry with agricultural operations in these areas bold animal improvement programmes need to be initiated. Extensive crossbreeding of the indigenous livestock species with suitable exotic breeds are required to be taken up to improve the production performance. It has been observed that Holstein Friesian X Sahiwal halfbreds were better suited for milk yield, peak yield and lactation efficiency as compared to other grades (Chaudhary *et al.*, 1974). In other reports on performance of crossbreds involving various exotic and indigenous breeds of cattle the recommended level of exotic inheritance is 50 to 67.5 percent. Preliminary information on Red Dane X Rathi first cross (halfbred) cows also suggest considerable improvements in both production and reproduction traits. The Jersey breed, in view of its medium size and because of the anticipated milk marketing to be on product basis rather than fluid milk, may be used in this area. In order to avoid the need for maintaining large number of high priced exotic bulls and to extensively use outstanding bulls artificial breeding technique will have to be used. In the beginning years the exotic inheritance may be fixed at 50% level until such time that the farmers have become conversant with the rearing of crossbred animals and green fodder production has increased. In later years, the policy may be reviewed and if found necessary, exotic inheritance may be raised to higher levels.

In the non-commanded areas the animals will continue to be maintained on seasonal grazing and crop residues. In view of the higher nutritional demands of the crossbred animals both for maintenance and higher production, it would be desirable to follow selective breeding of the indigenous breeds for specific purposes viz. Rathi, Tharparkar and Kankrej for milk production and Nagori for draft purposes. In order to attain this objective large cattle breeding farms for each breed may be required to undertake scientific breeding programmes.

to produce superior bulls. In areas where cattle population is relatively stationary and concentrated artificial breeding may be practiced. In other areas where the cattle population is thin and scattered, genetically superior bulls may be distributed to the village organisations for natural breeding. In order to avoid unwanted effects, the bulls must be changed between artificial breeding centres and villages after every 2-3 years when the progeny of a bull in a given area reach each breeding age.

7. As in the case of cattle, sheep improvement programmes should also be taken up on regional basis. Crossbreeding studies in sheep have shown that introduction of exotic inheritance in indigenous sheep definitely improves the quality and quantity of wool, body weight at different ages and growth rates. Further, it is also evident that maximum improvements are attained in the first cross progenies. However, before any sheep improvement programme is launched on a large scale, the capacity of the area to support high producing animals and the anticipated improvement in the carrying capacity of the area should be the guidelines. The home tracts of Chokla and Nali breeds of sheep, producing high quality carpet wool and some apparel wool, have comparatively better rainfalls. These breeds may be used in crossbreeding for wool production. In the areas where flocks are stationary and sheep population is thick artificial breeding technique with fresh semen may be used. As mentioned earlier it may be advisable to maintain 50 percent exotic inheritance in the earlier phase of the programme. In the migratory/scattered flocks crossbreeding has to be achieved through distribution of rams. Since the purebred exotic rams will not be adaptable to the local husbandry practices the objective may be achieved by distributing crossbred rams. Where the use of purebred exotic rams can produce 50 percent crossbred progeny in one generation, distribution of crossbred rams required two generations to achieve the same object, however, under the existing husbandry practices it is desirable. In the first phase $\frac{1}{2}$ bred rams may be distributed which will produce $\frac{1}{4}$ crossbred progenies. After 1-2 years the halfbred rams may be replaced by $\frac{3}{4}$ crossbred rams which when used on the $\frac{1}{4}$ crossbred ewes will produce $\frac{1}{2}$ bred progeny. It has been estimated that this type of breeding programme may take about 6-7 years to transform the indigenous sheep population into 50% crossbred sheep.

In view of the adverse agro-climatic conditions to prevail in home tracts of Jaisalmeri and Marwari breeds efforts need to be made to improve body weights and increase wool yield of uniform quality without adversely affecting their adaptability to the local conditions. Though, considerable improvements can be envisaged by improving

the pasture condition, distribution of superior rams among the flock owners need to be adopted. For this purpose large sheep breeding farms for these breeds using superior base stock need to be started and planned selective breeding be practiced to produce sufficient number of superior rams. In addition to selective breeding field trials on crossing these breeds with dual purpose exotic sheep breeds, viz. Corriedale also need to be taken up on these farms to improve body weights and wool yield and quality.

8. The livestock figures for the desert areas of Rajasthan reveal an increasing trend in the goat population. The important goat breeds of the area are Marwari, Kutchi, Mehsana type, Sirohi and Zalawadi. The goats are contributing considerably in the rural economy. In addition to the milk the farmers are getting remunerative prices through the sale of goats to be slaughtered in the neighbouring states. It is estimated that nearly 0.25 million goats are sold for slaughter from Barmer, 0.3 million from Jodhpur, and about 40,000-50,000 from Jaisalmer districts. In view of existing conditions of the desert areas, upgrading of the goats may be taken up for increased milk yield and heavier body weights through the use of selected bucks of superior indigenous breeds viz. Jamnapari, Beetal, Barbari etc.

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PHYSIOLOGICAL ADAPTATION OF ANIMALS TO THE DESERT ECO-SYSTEM

P. K. Ghosh

Animals living in the desert are periodically confronted with the problem of maintaining the constancy of the internal environment. This constancy is mainly regulated by the maintenance of the volume and osmotic pressure of the extracellular and intracellular fluid compartments of the body which, together form about 70 percent of the body weight in mammals.

As regarded from the view point of osmotic regulation, the two major physiological problems of desert life, water and heat, are reduced to one, for the only active defence against a rising body temperature is evaporation, which require water resources that may not be available. It is indeed surprising that even under such harsh conditions, the deserts of the world harbour such a varied and interesting fauna;

Our present state of knowledge regarding the peculiarities of water conservation in desert animals can be summarized as follows: (1) The desert animals are broadly classified into two categories, viz., those that require water for temperature regulation and those that do not; (2) Most of the small desert mammals fall in the latter category although there are notable exceptions; (3) The rodents usually manage to escape the impact of the high radiant heat of the desert by their nocturnal habits and by living inside burrows. The microclimate inside the burrow is usually suitable for normal living during the day. Their food habits and pattern of excretory water losses also help in maintaining their critical water balance; (4) The lower forms of animals periodically go into torpor or hibernation, thereby reducing the metabolic rate to the minimum when the external conditions are extremely severe.

For man and the large land animals like the cattle, gazelles, antilopes, camels and donkeys, absolute avoidance of the daytime conditions is not practicable, although man is at a distinct advantage in this respect by virtue of his housing and clothing techniques and other cultural methods like digging of wells and transportation of water for drinking purposes over long distances.

Like man, the larger desert mammals also require water for evaporative cooling of the body surface and, as such, they have to roam over long distances during the dry season in search of water holes.

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The rate of evaporation per unit surface area is almost the same (0.6 kg water/sq.m./hr.) in man and several other species of mammals examined (Schmidt-Nielsen, 1964). If we assume that the usual domestic animals of our desert evaporate water at the same rate, then we can estimate that:

- a 500 kg camel would evaporate 3.86 litre/hour
- a 200 kg cow would evaporate 2.09 litre/hour, and
- a 40 kg sheep would evaporate 0.71 litre/hour.

Since faecal and urinary water losses in animals are usually small in comparison to evaporative water loss, it is apparent that any major reduction in water loss when water is scarce would have to involve a reduction in evaporation. A variable, rather than a constant, body temperature would be one way to reduce evaporation when water is scarce. The hydrated camel originally maintains a nearly constant body temperature by sweating. When water is scarce and the animal becomes dehydrated, it usually has a very low body temperature in the morning (Schmidt-Nielsen et al. 1957). Since the camel is a large animal with relatively small surface area and low metabolism per unit mass, it warmed slowly during the day. Its temperature increased as much as 7°C during the course of a day. Even in the hot desert the dehydrated camel seldom reached a body temperature where sweating was necessary. A similar situation apparently holds true for the African desert dwelling antelope Oryx (*Oryx beisa*) (Taylor, 1971) and in some breeds of desert sheep. Two other possible strategies for reducing evaporation in the heat are extreme hyperthermia (simply letting the body temperature exceed the surrounding environmental temperature) and selective cooling of the more heat sensitive parts of the body such as the scrotum or the brain.

Both the camel and the desert-dwelling donkey are known to ingest enormous quantities of water in a single drinking bout when they have access to water after a dehydration regime. In fact, the maximum drinking capacity in the camel corresponds to about 30-33 per cent of the dehydrated body weight. Tolerance to such an extremely high degree of dessication of the body together with a low overall water expenditure, particularly a low evaporative water loss during dehydration in the summer, enables the camel to withstand dehydration. (Schmidt-Nielsen, et al., 1957).

A reduced metabolism when water is scarce would be another effective means of minimising water loss. A reduction in metabolism would result in reductions in faecal, urinary and respiratory water losses. This has been found to happen in certain ungulates, e.g. the Oryx and gazelle of the African deserts; metabolic rate decreased in direct proportion to the amount of water lost during dehydration (Taylor, 1972).

Some of the larger mammals of the desert can live independently of drinking water for indefinite periods. It seems likely that by grazing mainly at night these animals take in food containing an average of 30 per cent water. The relative humidity of the desert air increases as the temperature falls at night. The dried grass collects moisture from the desert air at night, even when there is no dew. Thus, the moisture trapped in the grass at night plus the oxidation water formed in the body would be sufficient to meet the minimum water requirements of these animals. Certain common top feed species of desert regions, e.g. *Acacia* sp. and *Prosopis cineraria*, have leaves containing nearly 50-60 per cent water even during severe droughts. By calculating the weight of such leaves that a large ungulate would eat to meet its normal metabolic requirements, it has been found that the leaves would provide about 5 litres of water/100 kg body weight/day, or, almost exactly the amount needed by that ungulate for survival without drinking. An animal that can obtain this much water by browsing can probably live indefinitely without drinking.

The smaller desert mammals like the rodents do not, and cannot, withstand the daytime desert environment, hence their burrow-dwelling habit. The rodents have a much larger body surface relative to mass compared to the larger animals and, as a result, they have a low "thermal inertia". Since the metabolic rate of animals is proportional to the $\frac{3}{4}$ power of the body weight, each gram of tissue of a small animal has a higher metabolic rate than that of a gram of tissue of a large animal. The high metabolic heat production and surface evaporation rates make it impossible for the smaller mammals to keep the body temperature from rising in a hot environment. The temperature and humidity conditions within the burrow systems of these animals are fairly conducive to living without any dependence on evaporative cooling of the body even during the hottest and the driest parts of the year (Prakash *et al.*, 1965; Schmidt-Nielsen, 1964; Vorhies, 1945).

Most of the physiological studies on Indian desert rodents has been done on the Indian desert gerbil, *Meriones hurrianae* (Ghosh, 1975). As with all desert animals, the gerbil is primarily concerned with maintaining its water balance under severe water stress conditions. In consequence, it has to deal with two problems: (1) how to reduce water requirement; and (2) how to increase water conservation. The rodent tries to tackle the first problem by habitually avoiding the intense heat and radiation of the day. It overcomes the second problem on physiological bases (i) by minimising pulmo-cutaneous moisture loss, (ii) by concentrating its urine to a great extent, and (iii) by depositing excess body fat as a potential source of metabolic water.

A theory of renal function which is now generally accepted is that the loops of Henle in the kidney act as a "hair-pin" countercurrent

multiplier system" making possible the production of hypertonic urine (Wirz *et al.*, 1951). The greater the length of the loops, and, consequently, greater the thickness of the renal medulla, the more concentrated urine can be formed as is found in most of desert rodents (Schmidt-Nielsen, 1964). These animals can, thus, dispense with free water virtually for indefinite periods. Presumably the performed water in the food plus the metabolic water is sufficient to maintain their internal environment (Schmidt-Nielsen, 1964). The relatively lower nasal mucosal temperature, compared to body temperature, in certain desert rodents is probably aimed at condensing considerable moisture from the warmer saturated air coming from the lungs, before this water is expired (Chew, 1964).

All desert-dwelling rodents are not, however, physiologically adapted to fight heat and water stress, e.g. the wood rat (*Neotoma albigula*), an inhabitant of the American desert and the Mongolian gerbil (*Meriones unguiculatus*) cannot survive water deprivation for any length of time. It is by virtue of their feeding on succulent desert vegetation that these animals can maintain water balance (Bodenheimer, 1957; Winkelmann and Getz, 1962).

These are remarkable interspecific differences in water requirement and in the concentrating capacity of the kidney of the desert rodents, e.g. *M. hurrianæ* and *Gerbillus gleadowi* (Ghosh and Gaur, 1966). These phenomena are partly explicable in behavioural terms. Although both these desert rodents are adapted for fossorial life, *G. gleadowi* is strictly nocturnal in its habit while *M. hurrianæ* is a diurnal animal. Being comparatively less exposed to the desiccating daytime desert atmosphere, *G. gleadowi* are presumably less efficient in economizing on water expenditure in comparison to *M. hurrianæ*. Moreover, *G. gleadowi* being of a relatively smaller size the gap between its total water loss and metabolic production of water is theoretically greater than that of *M. hurrianæ*.

The importance of metabolic water for desert survival has been dramatically shown in a laboratory study involving *M. hurrianæ* maintained without water on a diet of moisture-free grains. The gerbils survived and maintained body weight for 16 months on this regime (Ghosh and Purohit, 1964).

An interesting feature of the gerbil's body fat dynamics is the gradual unsaturation of its body fat as the period of water deprivation is prolonged, along with a significant increase in the total body fat content of the water-deprived animals (Ghosh and Purohit, 1964). The fat deposits are likely to act not only as energy stores, but probably also as potential water stores, as 106 parts of water can be obtained from 100 parts of fat by oxidation. The reasons for the increased unsaturation of the body fat remain, however, unknown.

The gerbil utilises plasma water during water crisis, rather than the intracellular water contained in its vital organs (Ghosh and Gaur, 1966). This is in marked difference to the situation holding in water-deprived desert sheep (Purohit *et. al.*, 1971). Obviously there are large inter-specific living.

ABASTRACT

Hot deserts pose two serious physiological problems for animals that live there: heat and lack of water. These problems are not unrelated, for to avoid overheating, animals must either escape from the desert heat or use evaporation to keep cool.

Small desert mammals like rodents employ both behavioural and physiological strategies for adaptation to the desert conditions. Nocturnality, fossoriality, seasonality of food habits and urine concentrating ability of kidneys are the principal keys to the rodents' success in the desert.

Large desert-dwelling animals mainly depend on physiological means of adaptation. Body water loss is minimised by varying body temperature, lowering metabolic rate, etc. Night grazing also helps some of the larger herbivores in getting considerable amount of moisture from their feeds.

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