SILVIPASTORAL SYSTEMS IN ARID AND SEMI-ARID ECOSYSTEMS

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FOREWORD

About 1.26 million km^2 area of India is arid and semi-arid, which accounts for 38% of the country's geographical area. The fragile ecosystems of these areas are threatened because of explosion in human and livestock population. Continuing overexploitation of natural vegetation cover has resulted in extensive degradation of pasture lands and deforestation in these tracts with consequent negative impact on agricultural production. The scattered multipurpose tree species on grazing lands are common scene in arid and semi-arid landscapes of India. Silvipastoral system is the vital life support system of rural folks. It is a matter of concern that such an important life support system is continuously degrading. The need for improvement and efficient management of such silvipastures was felt long back in 1958, when a scheme of pasture development was initiated at Central Arid Zone Research Institute (then Desert Afforestation and Soil Conservation Station), Jodhpur, India, under the leadership of Mr. C. S. Christian, an UNESCO expert. Since then the UNESCO and Central Arid Zone Research Institute, Jodhpur, are having close co-operation in research and developmental activities in various fields.

Recognizing the pioneering work of Central Arid Zone Research Institute in the field of silviculture, agrostology, agroforestry and range management, UNESCO entrusted the task of organizing an International training course on "Silvipastoral systems for Arid and Semi-arid Ecosystems" to the institute. This course organized from November 15 to December 5, 1995, attracted a number of participants from seven Asian countries besides seven from within the country. The lectures delivered during the training programme by a galaxy of scientists and other professionals on various aspects of silvipastoral systems have now been brought out in form of present compendium.

The book contains all the necessary informations related to structure, function, management, improvement, utilisation, etc. of silvipastoral systems of arid and semi-arid regions of India. The informations given in the book is up-to-date and based on the exhaustive research work of various researchers. I am sure that this book will be a valuable addition to literature on silvipastoral systems.

28-2-97

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PREFACE

Developing countries in South and South East Asia primarily have peasant agriculture with livestock as their mainstay, especially in arid and semi-arid regions. Increasing human and livestock population on one hand and sustainability considerations on the other dictate greater focus on research and training on silvipastoral systems. Research efforts in the past two decades have generated interest and awareness about silvipastoral systems. Silvipastoral systems are of paramount importance in livestock based economies of tropics as these systems have higher biomass output per unit of lands over the productivity of the single component systems. Components of silvipastoral systems vary across South and South East Asians countries but their problems are similar.

Silvipastoral system encompasses a wide spectrum of subjects in the fields of various biological sciences like agrostology, silviculture, pasture management, tree genetics, animal sciences, etc., and social sciences. The scientists at Central Arid Zone Research Institute, (CAZRI) Jodhpur, representing 33 disciplines in various biological, physical, chemical and social sciences, have contributed substantially to research and development of silvipastoral systems since its inception. The United Nations Educational, Scientific and Cultural Organisation (UNESCO), realizing the importance of training in this field, assigned the *responsibility of conducting an international training to CAZRI. The material provided during* the Training-cum-Workshop on 'Silvipastoral Systems in Arid and Semi-arid Ecosystems' held from November 15, to December 5, 1995 has been arranged in this book to give a comprehensive update of theoretical aspects and techniques of management of different silvipastoral systems in the perspective of arid and semi-arid ecosystems.

Fifty two topics broadly cover various aspects of resource appraisal and management, characterization propagation and genetic improvement of different components, alternate landuse systems, fodder and livestock management, integrated pest management, and socio-economic aspects and transfer of technology. The book will help readers get an insight of the structure, dynamics and productivity aspects of the silvipastoral systems for arid and semi-arid regions.

The support and services received from UNESCO, Indian Council of Agricultural Research (ICAR) and National Tree Grower's Co-operative Federation Ltd., Anand, India are gratefully acknowledged. Editors acknowledge the secretarial services rendered by Shri M.M.Batra, Mrs. Sreedevi Mohanan, Shri P.P.Mishra and Mrs. Kamla. Our special thanks are due to Shri S.B.Sharma for efficient word processing and formatting the book for publication.

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SILVI-PASTORAL APPROACH FOR ARID AND SEMI-ARID AREAS : ISSUES AND STRATEGIES

A.S. Faroda

Introduction

Agronomic researches have shown that under specific soil and climatic conditions, planting certain combinations of crops and trees simultaneously and/or sequentially can increase efficiency in resource use (Gupta and Gupta 1993). India accounts for about 15% of the total livestock population of the world with only 2% of the total geographical area. Due to ever increasing population pressure of human and associated demands, there is little possibility of allocating arable areas for forage production. Therefore, the increase in forage production is expected from the lands otherwise not suitable for sustainable agricultural production. Vast tracts of such lands which are suitable for forage production are available in arid and semi-arid regions of the country.

In India 12 million ha area is said to be under permanent pastures and grazing lands but biomass production from these lands is very meagre (Singh 1989). Similarly, based on the recent surveys, 158 million ha area is classified as wastelands (Singh 1989).. This provides ample opportunities to exploit such lands for production of forage and fuelwood. Integrated silvi-pastoral system of farming is low input technology for efficient utilisation of marginal and sub-marginal lands, especially in arid and semi-arid regions. Through this, forage and leaf fodder is obtained besides timber and fuelwood. This seems to be most effective proposition to feed our livestock in arid and semi-arid areas.

Problems

India has a large human population crossing over 800 million, which is next to China, and it has been estimated that by 2000 AD it would be around one billion. As mentioned earlier, we have huge livestock population comprising about half of the world's buffaloes, one-fifth of cattle in addition to 78 million goats and 48 million sheep but the production in respect of milk, meat, wool, etc., is too meagre to meet the demand of ever rising human population (Deb Roy 1989). The principal factor behind low livestock productivity is inadequate feed and fodder including their poor quality.

The projected estimates of availability and requirement of green fodder by 2000 AD are in the tune of 540 and 700 million tonnes, respectively. Similarly, there is acute shortage of fuelwood and other forest products with per capita available woodland of less than 0.12 ha against the world average of 1.6 ha, and moreover, the wood productivity of these lands is very low, 0.5 m^3/ha/yr. against the world average of 2.1 m^3/ha/yr. The deficit and high cost of fuelwood leads to prevalent wasteful burning of 300-400 million tonnes of freshly collected dung which could otherwise have been used in building and improving soil fertility status (Deb Roy and Pathak 1983).

Growing perennial woody species with grasses offers many advantages at a very low expense. Infact, highly productive, modern agricultural systems are efficient in terms of human energy and time but are highly inefficient from overall energy point of view, as 5 to 10 units of energy from various sources are required to produce single unit of food energy as output (Steinhart and Steinhart 1974). However, systems for enhancing productivity of land under different uses are available but its full benefit is not achieved, mostly due to short sighted policies for quick gains (Tewari *et al.*, 1991). Moreover, technologies as on time are more suitable for better environs. Resource poor farmers constitute 75% of the community and they farm 25% area. Their lands, being marginal are more suitable for agro-forestry/silvi-pasture as an alternative system of land use (on the basis of land capability).

Silvi-pastoral systems which have been well recognised as low input and cost effective technology can be grouped into two categories : browse grazing and forest or plantation grazing. In the former, woody component is grown for fodder; and in the latter it is grown for the timber, while livestock mostly graze on forest floor vegetation, mainly grasses. The hostile environmental conditions in arid and semi-arid regions often reduce substantially, the level of herbage production even in improved pastures, causing large scale livestock migration due to forage scarcity (Singh 1995). To meet this situation and also to provide green browse during the lean period, there is the need of contingency planning, devoted to overall pasture improvement programme. Silvi-pastoral approach would be the right kind of thing and a silvi- pasture would serve as an insurance against unforeseen situations.

Available Land Resources for Grazing

According to Tyagi and Singh (1988), the total area available for grazing is over 121.2 million ha and this includes forests, pastures, miscellaneous tree groves and other types of lands like cultivable wastelands and fallow lands. This roughly accounts for 40% of the total geographical area of the country. States of Himachal Pradesh, J and K, Meghalaya, Nagaland and Arunachal Pradesh have more than 70% of their land available for grazing (Table 1). In extreme desertic (hot) landscape, especially in Jaisalmer district of Rajasthan 95% of its geographical area is used for grazing domestic herds (Shankar and Kumar 1987). These pasture lands provide main support to over 406 million livestock in India (Fig. 1), whereas forage support in the form of stall feeding is not sufficient enough to feed even the dairy cattle.

Land Degradation And Grazing Resource Depletion

Due to ever increasing human and livestock population there is tremendous pressure on land and water resources of India. Of the total geographical area of India (328.6 million ha), 53.2% is estimated to be affected by soil erosion and land degradation of one type or other (Table 2). This process of land degradation is ultimately leading to desertification.

If we see the arid tract of Rajasthan, this process appears to be more acute. This part of the country is ecologically and economically in one of the most disadvantaged regions. However, like in other parts of the country, human and animal population is continuously increasing in this tract. The human population in this part of country increased by 50% in first four decades of this

Table 1. Land resources available for grazing in India (thousand ha)

State	Forest	Pastures	Misc. tree crops and groves	Culti - vable waste - land	Total fallow land	Total area availa- ble for grazing	Total repor - ting area
Andhra Pradesh	6200	901	8276	894	3217	11488	27480
Assam	1985	184	250	107	177	2703	7852
Bihar	2923	142	232	418	3165	6880	17330
Gujarat	1966	845	4	1989	801	5605	18829
Haryana	130	27	(a)	47	185	390	4394
Himachal Pradesh	862	1161	40	129	59	2251	3186
Jammu & Kashmir	2759	123	94	145	96	3217	4506
Karnataka	3030	1246	337	485	1378	6476	19050
Kerala	1081	5	55	129	70	1340	3885
Madhya Pradesh	14006	2806	167	1842	1675	20396	44211
Maharashtra	5303	1572	185	987	1664	8713	37556
Manipur	602	(b)	24	(b)	(a)	623	211
Meghalaya	812	17	145	454	312	1740	2249
Nagaland	288	-	200	62	359	909	1112
Orissa	6640	559	409	246	782	8635	2249
Punjab	221	4	5	33	33	296	5033
Rajasthan	2163	1845	82	5741	3770	13402	34235
Sikkim	265	97	2	1	9	37	729
Tamil Nadu	3030	151	183	316	2097	4777	12994
Tripura	578	(b)	98	2	4	682	1048
Uttar Pradesh	5612	298	549	1121	1132	9029	29759
West Bengal	1091	7	57	176	543	1874	8846
Arunachal Pradesh	5150	-	35	173	463	2796	3520
Others	2116	11	33	173	463	2796	3520
All India	67334	12002	3462	15451	22872	121121	304313

a) Less than 500 hectares

b) Included under the head miscellaneous tree crops and groves

Source : Singh (1995).

century, while it was 170% in the next four decades. Added to this, is the increase in density of cattle population in terms of Adult Cattle Units (ACU) per km^2. It increased from 32 in 1956 to 51 in 1983. This state of affair is leading to ruthless exploitation of resources resulting in denudation of already thinly vegetated areas (Fig. 2). More and more land is being brought under cultivation of arable crops, though crop husbandry is gamble in arid regions, if not

Table 2. Area under soil erosion and land degradation

Type of land degradation	Area (million ha)
Area subject to water erosion	111.30
Area subject to wing erosion including 7m ha area infested by sand dunes	38.70
Area degraded through	
a) Water logging	6.00
b) Alkali soil	2.50
c) Saline including coastal sandy	5.50
d) Revines and gullies	3.97
e) Shifting cultivation	4.36
f) rivers and torrents	2.73

impossible. Surveys conducted by Central Arid Zone Research Institute, Jodhpur, India indicate that under existing soil and climatic conditions, a maximum of only 50% of the total land area in arid regions of Rajasthan, which accounts for over 60% of India's total hot arid regions, is suitable for arable farming. Surprisingly, three arid districts of Jodhpur, Jalore and Barmer, which sustain major parts of large animal population of desert region have, at present only 4.8-7.3% of the land under permanent pastures (Ghosh and Bohra 1993).

Likewise, in semi-arid regions, the grazing resources are continuously getting depleted. The grazing pressure on semi-arid rangelands is estimated at 3.2 Adult Cattle Unit/ha/yr. (Rekib 1981), whereas a semi-arid rangeland of good condition class has carrying capacity of 0.2 to 0.5 ACU/ha/yr. (Raheja 1966). In general, grazing resources are depleting rapidly as a consequences of ever increasing human population pressure and heavy grazing pressures on grasslands/pastures, and also because of the lack of soil and water conservation measures and proper regeneration strategies, which are highly essential for improving rangelands/pastures.

Silvi-pastoral Approach : A Multipurpose Production System

The question has to be raised whether silvi-pastoral systems, indeed constitute an optimal formula for degraded regions of arid and semi-arid tracts. In both, the prime necessity is to upgrade environmental hospitability for plants and animals so as to increase it for humans Upgrading through classical means of irrigation, fertilisation and the use of improved crop or pastoral species is a slow and highly expansive business. On the other hand, trees are the organisms with an ecological investment strategy (Oldeman and Westra, 1980). Matter and energy are immobilised in long lived woody structures. Litter recycling functions by virtue of these structures as a long term process with very few losses. To integrate trees into pasture lands, that is to build a silvi-pastoral system, is the equivalent of creating some degree of

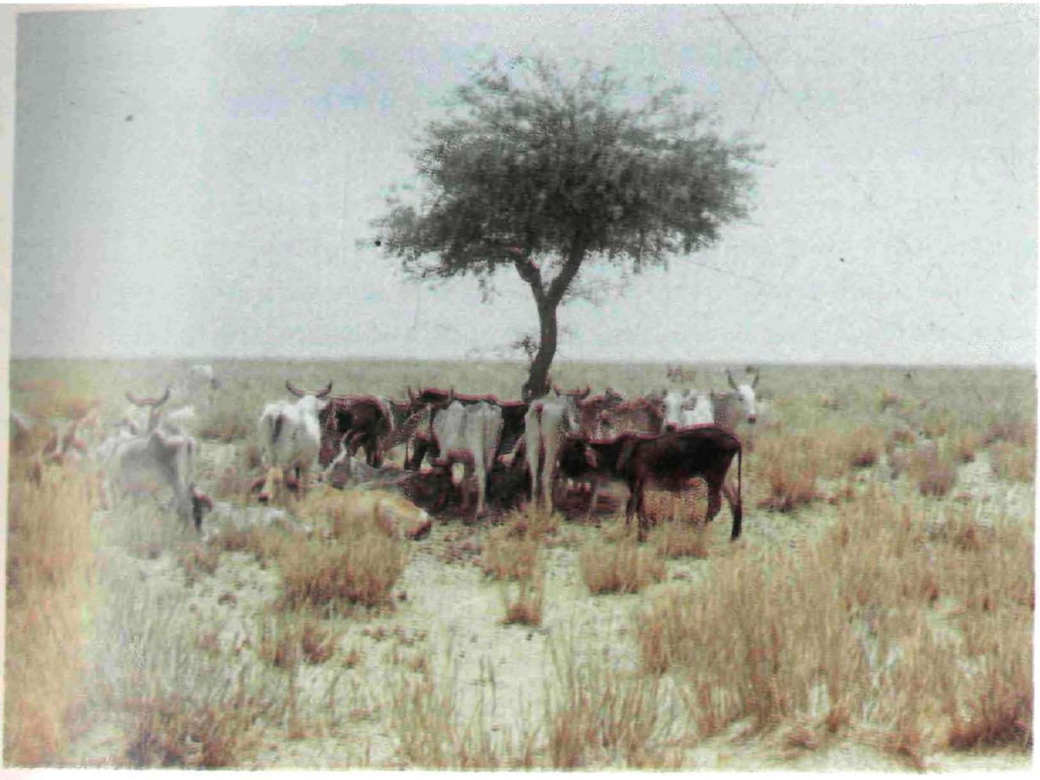

Fig. 1 A *Lasiurus sindicus* pasture in extreme Thar desert - Herd of cattle under *Prosopis cineraria*

Fig. 2. Sparse vegetation in a degraded land grazed by sheep and goats

decrease in immediately available productivity; an increase of accumulated production to be harvested with longer intervals; and a cheaper production method, because of its recycling virtues.

Owing to all above mentioned benefits of silvi-pastures, United Nations Education, Scientific and Cultural Organisation (UNESCO) under Man and Biosphere (MAB) programme launched an integrated project on arid land (IPAL) in northern Kenya during early seventies (Lamprey 1983). The project's area resembles larger parts of the Sahel and dry north-eastern Africa which were being degraded due to overgrazing and excessive exploitation of arboreal species. Action strategies mainly centred on integrated silvi-pastoral approach. This integration has been accepted by the project as an important aspect of rational development of the region.

From all above discussions, it may safely be said that silvi-pastoral approach is a technology, a landuse system. Systems of silvi-pasture may be either extensive or intensive. Extensive systems include larger tracts of land of widely scattered trees with pastoral herbaceous ground flora. Widely distributed *Prosopis cineraria* trees with many grass species in floor vegetation in arid tract of Rajasthan, India is one of the best example of extensive silvi- pastoral system. Similarly, in semi-arid regions of India, where productivity is low due to limitations of soil and/or climate many such systems are common with different combinations of tree and grass/herb species. Unfortunately, not much precise data related to productive and protective aspects of these extensive systems are available to draw some inference. Intensive silvi-pastoral systems include man engineered systems which are often location/site specific or in form of improvement of traditional silvi-pastoral systems. Sufficient data related to various aspects of such intensive silvi-pastoral systems are available, first let us discuss some cases in very brief.

In a study of silvi-pasture carried out at CAZRI's regional research station, Pali (located at transitional zone between arid and semi-arid regions of Rajasthan) involving four tree species: *Acacia tortilis*, *Azadirachta indica*, *Albizia lebbeck* and *Holoptelia integrifolia*, each of which were planted with four grass species: *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum* and *Pannicum antidotale*. Plots of each tree without grasses were served as control. The study showed that there was no significant difference in grass production under different tree species. The average dry grass yield was 28.0 q/ha for *D. annulatum*, 25.1 q/ha for *C. ciliaris*, 25.0 q/ha for *C. setigerus* and 26.1 q/ha for *P. antidotale* (Tewari *et al* 1989). The growth of all the four tree species in control as well as with grasses was recorded periodically upto 48 months. *A. tortilis* attained the maximum average height (375 cm/tree)followed by *A. lebbek* (327 cm/tree). *H. integrifolia* grew least (239 cm/tree). The maximum reduction in height of all tree species was observed when grown with *D. annulatum* grass, which varied between 27% to 51% over the control (trees without grasses). All the four tree species exhibited least reduction in height with *C. setigerus* (reduction ranged from 1% to 3.6%). The study revealed that on location specific basis, combination of *A. tortilis* trees with *C. setigerus* grass is best for the transitial belt between arid and semi-arid regions.

Production potential of silvi-pastoral systems in semi-arid region can be judged from the study of Deb Roy *et al.* (1978) involving *Albizia amara* and *Hardwickia binata* as woody component and *C. ciliaris*. *Chrysopogon fulvus* and *Sehima nervosum* as grass component. A mixture of *C. fulvus* and *S. nervosum* grass produced 3.25 t/ha of forage under canopy of five year old *Hardwickia binata*, a very good timber and fodder species, planted at 4 x 6 m spacing. The forage production from *C. ciliaris* was in an order of 3.06 t/ha. These pasture grass species were slightly better under *A. amara*, another important fodder and fuel tree. Roy and Deb Roy (1986) found that two-third annual lopping of the canopy gave higher and more consistent leaf fodder with 10 year old *A. amara* (10.95 t/ha green and 5.59 t/ha dry fodder), the corresponding dry fuelwood production was 10.2 t/ha. Annual lopping (one third intensity) of *H. binata* produced 3 67 kg/tree of dry leaf fodder and 5.53 kg/tree of fuelwood (i.e., 1.16 and 1.77 t/ha, respectively), at 10 years age.

A number of similar kind of studies are also available from various kinds of degraded land situations. Studies of Singh *et al.* (1993) on silvi-pastoral system involving *Prosopis juliflora* as a tree component and *Leptochloa fusca* as grass component on saline-alkaline soils of Karnal, India, revealed that in 6 years under different spacement, wood biomass of 161.3, 68 7 and 80.9 t/ha. respectively in 2x2 m, 3x3 m and 4x4 m spacing was obtained, while the grass yield was 55.6, 68.7 and 80.9 t/ha, respectively,

There are many such examples to cite to elucidate the productive potentials of silvi-pastures in arid, semi-arid and degraded land situations. However, to assess the relative importance of silvi-pastoral systems in terms of productive potential as compared to pure pastures and pure tree blocks in arid environmental conditions, the study of Harsh *et al.* (1992) is worth mentioning. The results of this study revealed that silvi-pastoral approach is highly efficient as far as sustainable production is concerned and more over, such systems have multi facet roles to play (Table 3).

Silvi-pastoral Systems : Some Crucial Issues

The agro-forestry research and development, whose silvi-pastoral system is an important component, is highly useful because rural poor are commonly portrayed as being its primary beneficiaries. Silvi-pastures, like other agro-forestry based systems is a landuse particularly suitable for resource poor marginal lands, even for wastelands. Because such lands is usually owned and cultivated by poor and small farmers and therefore, researches in silvi- pastoral systems should be promoted as a way to improve social equity by increasing productivity of poor lands. Before, initiating any silvi-pasture development programme, thorough knowledge of local socio-ecological environs should be gathered. ICRAF's diagnosis and design (D and D) methodology has been found highly useful in identifying silvi-pastoral potentials for a particular locality or area or region and this in turn is quite helpful in setting priorities for research. In fact, these are the fundamentals for the success of any silvi-pasture establishment programme.

Stand Management : To manage the silvi-pasture stands, it is absolutely essential to have clear cut idea of general objectives of the programme-such as to improve the well being of poor people in a defined social and bio-physical circumstances-and also the specific objectives-such as to sustain yield at certain level. In silvi-pasture research and development programmes it is always assumed that objective is to increase yield, and yield is often the only

Table 3. Fodder production and carrying capacity in different systems

	Pure pasture a[1]		Pure tree blocks b[2]		Silvi-pestoral system c[3]			
Years after initial field planting	Grass fodder yield (q/ha)	Carrying capacity (sheep/ ha/yr.)	Leaf fodder yield (q/ha)	Carrying capacity (sheep/ ha/yr.)	Grass fodder yield (q/ha)	Carrying capacity (sheep/ ha/yr.)	Total fodder productio n (q/ha)	Carrying capacity (sheep/ ha/yr.)
1	10	2.4	-	-	8.2	-	8.2	1.9
2	15	3.6	-	-	12.3	-	12.3	2.9
3	20	4.8	-	-	16.4	-	16.4	3.9
4	25	6.0	-	-	20.5	-	20.5	4.9
5	20	4.8	-	-	16.4	-	16.4	3.9
6	20	4.8	-	-	16.4	-	16.4	3.9
7	15	3.6	38.5	9.2	12.4	23.1	35.5	8.5
8	10	2.4	11.0	2.6	8.4	6.6	15.0	3.6
9	10	2.4	11.0	2.6	8.4	6.6	15.0	3.6
Average of 9 years	16.1	3.9	6.7	1.6	13.3	4.0	17.3	4.1
Average fuel Production (q/ha)	-	-	440	-	-	2.64	-	-

a[1] = *Cenchrus ciliaris* was constituent species of pure pasture;

b[2] = *Hardwickia binata* and *Colophospermum mopane* were component species of pure tree blocks, established in spacement of 3m x 3m (1,100 individuals/ha);

c[3] = Cenchrus ciliaris was used as grass species and *Hardwickia binata/Colophospermum mopane* were constituent tree species of the system.

Fuel production from tree starts after the fifth year of initial field planting; only average values of fuel production are given.

6 sheep : one adult cattle unit.

Source: Harsh *et al.* (1992).

output measured. Infact, there are usually other, often more important objectives like conserving soil and its fertility and like minimising risk of fuelwood and fodder scarcity.

For better stand management it is pre-requisite to select the species (whether it is woody component or grass) according to specific objectives. Once the silvi-pasture is established, protection of stand is single most important factor. Social fencing of the stand is most viable proposition. Fencing by physical means is not a long term solution. Public awareness can only help in development of such stands as they are meant for their use. For better stand management, application of silvi-cultural technique at right time and right place is very important and therefore, plant management is key factor for proper stand management to achieve desired results.

Managing Tree/Grass Interactions : Various management practices, such as the following, can minimise the negative interaction between trees and grasses in silvi-pasture system (Harsh *et al.* 1993).

When the tree seedlings are small, leguminous grass crops should be sown among them to avoid shading by tall grasses. This is very helpful in initial stages of tree establishment and once the tree species are established (i.e., after 2 years) then perennial grasses can be introduced. When trees are fully matured both the canopy and roots can be pruned. The canopy should be lopped, pollarded or thinned, and roots may be pruned by digging trenches (50-70 cm deep) near the trees to cut trees' subsurface roots. Tree rows should be oriented east to west to minimise the effects of shade.

As tree/grass interaction in a silvi-pasture is of prime importance and therefore, both above ground and below ground interactions needed thorough investigation so that system can be utilised fully.

Seed Production Aspect: Perennial grasses and tree species often pose seed production problems. Unsynchronised seed ripening, sudden and untimely seed shading, difficulties in seed collection and storage, etc., are common problems associated with grass seed production. In case of tree species, high fluctuations in seed setting, seed dormancy, collection and storage problems, poor germination, etc are very common. Good germplasm is back-bone of any silvi-pasture development programme and therefore, maximum attention should be given to production aspect of grass as well as of tree seeds.

Silvi-pastures and Extension Strategies : Under ideal conditions the mechanism by which the technologies and techniques are transmitted-are simply the links of researchers with the farmers in a circular system with balanced flows of information and feed back. But this has not yet affected agro-forestry and silvi-pastoral extension programme in India. Indeed the need of extension in these fields has been recognised only recently (Warren, 1993). The demonstration of successful silvi-pasture in a treeless landscape has been the primary tool for expansion of such systems. Managing such systems by village level cooperatives are very successful in some areas (Barua, 1990). Such participatory approach for extension of silvi-pastoral system establishment in village common lands can be highly rewarding. Non-governmental organisations can also play an important role in promotion of silvi-pasture development by imparting education to farmers in this technology as inspite of the fodder and fuel wood supply crisis, farmers are still reluctant to take up such systems in their own lands Three basic regions for this hesitant adoption of silvi- pasture and other agro-forestry techniques under farmers' fields conditions are that:

- only few silvi-pasture models are suited to field conditions.
- extension efforts to create awareness about benefits of such system are weak.
- infrastructural facilities are lacking to make such systems viable.

Land and Tree Tenure vs. Silvi-pastoral Systems : Land tenure giving security to land owners and a sound land record base would encourage long term investment by the farmers. Since silvi-pastoral approach depends on people's right to plant and use trees, the national or provincial rules of tree tenure and their relationship to land tenure is critical for designing viable silvi-pasture development plans. The component of tree tenure i.e., right to own or inherit the trees; the right to plant trees; the right to use trees and tree products; and right to dispose tree, if followed in true spirit for larger interest of rural masses can be very helpful in expanding the silvi-pastoral development programmes. The scheme like "Tree patta", in which cultivator has some rights on trees but no right on land contain several undesirable clauses, sufficient to make the scheme unpopular among farmers.

Epilogue

The silvi-pastoral or agro-forestry systems are biologically more complex than other ways of using land alone through arable farming or sole grass cropping or forestry. Consequently such systems require greater management skill. The current rapid rate of deforestation in arid and semi-arid regions of India is largely outcome of continuing pressure on arable lands for different commodities and ruthless exploitation of natural resources. It is against this background that recent efforts for the integration of compatible components of forestry and crop/grass production system viewed (Tewari *et al.*, 1989)

Even though such silvi-pastoral systems have been in practice for centuries in hot arid and semi-arid regions of India, new technical and socio-economic approaches are needed to increase productivity and sustainability. The complexity of process that determines the responses of grasses and trees to the environment and to each other require large scale scientific assessment involving both "on station" and "on farm" researches. However, beneficial an alternative model of land utilisation may be, it will only be adopted if it is culturally and financially sound. But on the basis of available evidences from the researches carried out so far, it could be concluded that if compatible tree species are properly incorporated on pastures or on farm lands, over all biomass level could be enhanced, even under unfavourable climatic, edaphic and economic conditions in arid and semi-arid regions.

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CLIMATIC CONSIDERATIONS IN THE DEVELOPMENT AND MANAGEMENT OF SILVIPASTORAL SYSTEMS

A. S. Rao, K.C. Singh and R.S. Singh

Introduction

The Indian arid zone extends in an area of 0.32 million km^2 in parts of western Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, Andhra Pradesh. These areas experience an annual rainfall between 100 and 500 mm with a coefficient of variation varying from 40 to 70%. Since arable cropping is successful only once in three years, silvipastoral systems significantly contributes for the economy of the people of arid region by supporting its 23.32 million livestock through its milk and meat production. A large number of natural habitats of tree and grass species of the Indian arid region have been identified which performed well under the harsh climatic conditions of the region. However, for the management and development of vegetation resource, an integrated knowledge on climatic range for component survival and system requirements in the naturally distributed areas of tree and grass species in comparison to the agroclimatic conditions of the areas of introduction need to be carried out. Some of the Indian arid zone tree and pasture grasses in relation to micro-climatic variations, rainfall and radiation utilization, drought impact and forage yield predictions using the weather data are discussed below:-

Rainfall and Silvipastoral Systems

Rainfall and its distribution at a particular location determines the choice of trees and grasses for development of silvipastoral systems. Trees interfere rains to come to soil surface through their canopy (interception, canopy drip) and their branches (stemflow) modifying the rain water availability within the field.

The mean annual rainfall in the arid western Rajasthan varies from less than 100 mm in the extreme western parts of Jaisalmer district to more than 400 mm in the eastern parts of the arid region of Rajasthan (Fig.1). The assured crop growing period in arid and semi-arid areas of Rajasthan varies from 3 to 13 weeks under shallow soils and from 5 to 15 weeks under deep soils (Rao *et al.*, 1994). Before the rainfall reaches the soil surface, tree canopies intercept rain water which is lost as canopy interception. Rainfall interception losses from 13 years old *Acacia tortilis* and 7 years old *Holoptelia integrifolia* at Jodhpur were 14-33% and 3-8%, respectively under moderate to heavy rainfall conditions (Ramakrishna and Sastri 1977; Ramakrishna 1984). Some of the hardy tree species suiting to the rainfall conditions are *Acacia tortilis, Acacia senegal, Acacia nilotica, Prosopis juliflora* and *Prosopis cineraria*. Some of these tree species grow naturally on arid lands. The perennial grasses like *Lasiurus sindicus, Cenchrus ciliaris, Cenchrus setigerus* etc., grow in association with these trees.

High variability of rainfall in both time and space impinge on the phenological behaviour of tree species. Studies on the influence of climate on *Acacia* species in Central Australia showed that soil moisture over various lag periods was the best predictor of flowering, while soil

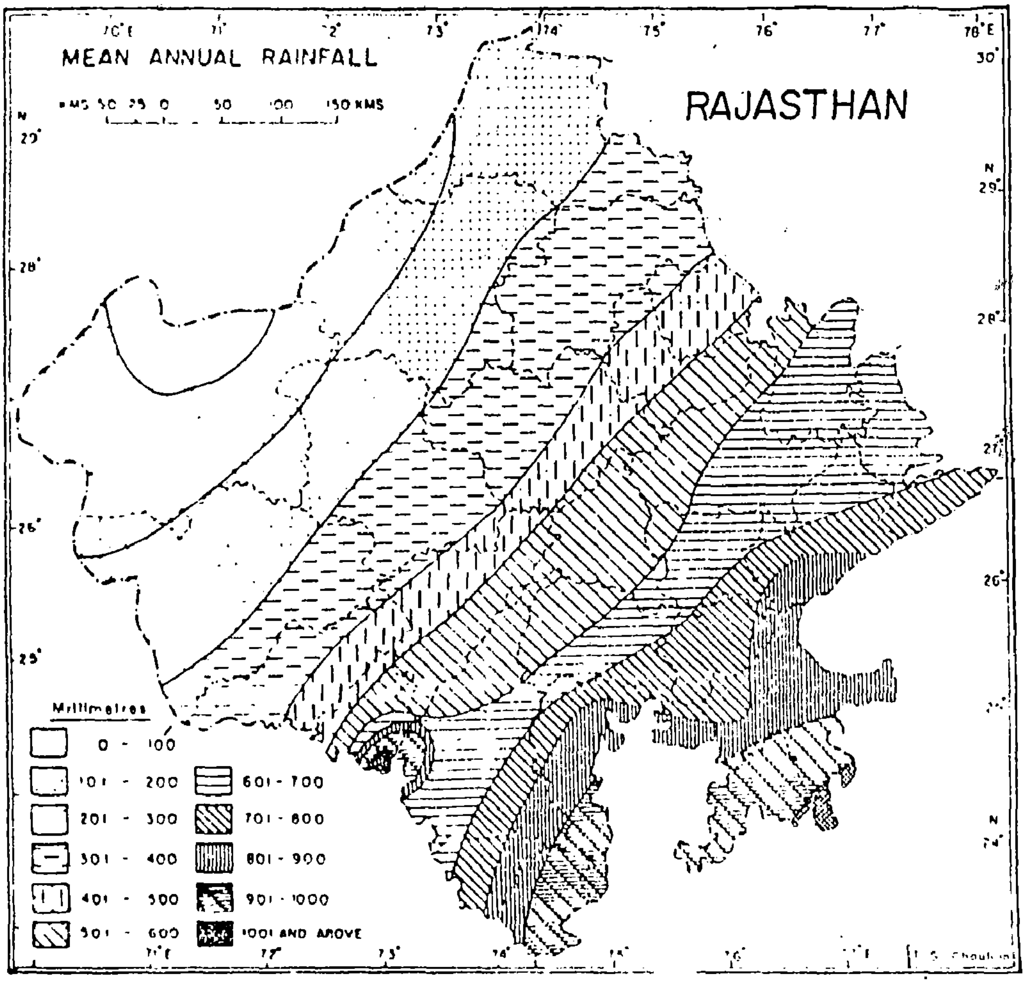

Fig. 1 Mean annual rainfall of Rajasthan

moisture, site differences and day length (time of year) were better predictors of fruiting (Friedel *et al.*, 1994). Bertiller *et al.*, (1991) found that the timing of phenological events in arid zone shrubs depended primarily on the depth of root systems and access to soil moisture and nutrients. Deep rooted species were less dependent on immediately preceding precipitation. However, a certain amount of moisture stress is required for arid zone tree species for initiating flowering and fruiting. For example, a drought year producing greater water stress (1.3 MPa) than a wet year (1.0 MPa), had significantly greater inflorescence production and 3.3 times greater pod production from mesquite (Scott and Felker, 1992).

For establishment of tree component in silvipastoral systems rainfall should be adequate during the first three years of establishment. To know the behaviour of rainfall, an analysis of rainfall over entire western Rajasthan was carried out during different decades. The study revealed that except in three decades 1921-30, 1931-40 and 1941-50, the remaining period was favourable for the establishment of tree component in the region. The decade 1971-80 was exceptionally good (Fig.2). Trees normally do not compete for soil moisture during the first three years, but in subsequent years tree-grass competition occurs depending upon the water requirement, soil depth and spacing.

Grasses sprout after onset of the monsoon in the first week of July and their physiological maturity coincides with the withdrawal phase of the monsoon. Under Jodhpur conditions, among some of the *Cenchrus* species, *Cenchrus ciliaris* produced higher dry matter yield, water and energy use efficiency than *Cenchrus setigerus*, whereas under high rainfall conditions *Cenchrus setigerus* performed better than *C. ciliaris*. Accumulated stress degree days showed that *C. ciliaris* developed an early stress than *C. setigerus* (Rao *et al.*,1994). In very low rainfall areas of Jaisalmer, 150 to 250 mm in a growing season *Lasiurus sindicus* performs well.

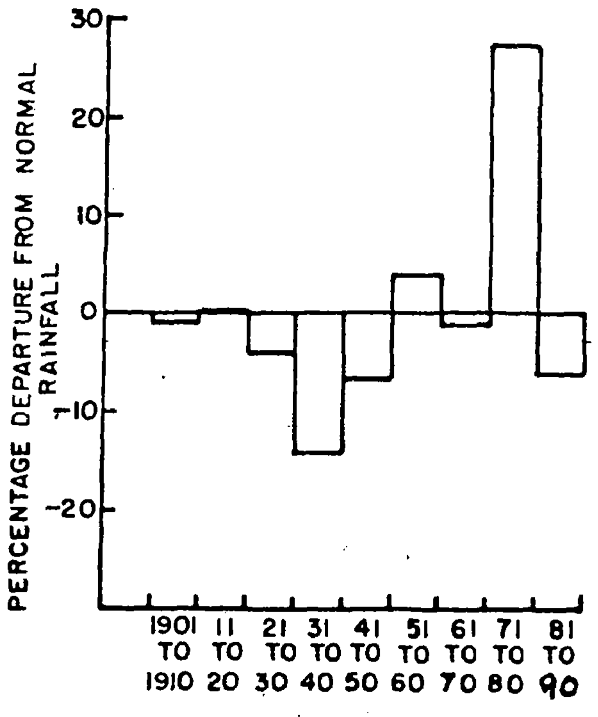

Fig. 2 Decennial variation in rainfall over western Rajasthan

Under better moisture supply and moderate fertilization, grasses show good root biomass and productivity of above ground biomass during rainy season. Rao *et al.*,(1996) reported the productivity of *C. ciliaris* in relation to rainfall and fertilization. The maximum yield response to N fertilization occurred with growing season rainfall between 180 and 250 mm.

Impact Of Drought On Forage Production

Most of the grass species practised in silvipastoral systems are drought hardy, but sensitive to extreme water stress like any other crops. Droughts frequently occur in the region at a rate of once in every 2.5 years making arable cropping not economical. Hence, silvipastoral systems is a boon for the region to get fodder support for the large livestock of the region. Earlier studies conducted at CAZRI, Jodhpur (Shankarnarayan, *et al.* 1985) revealed that the promising grasses of the desert like *L. sindicus, P. turgidum, Panicum antidotale* and *Cymbopogon jwarancusa* can survive under extreme arid and severe drought conditions (rainfall < 200 mm) and give an average dry forage yield of 290 kg/ha/year meeting to some extent forage requirement of the livestock of this region.

It is observed that the probability of experiencing severe drought conditions affecting grass production in a rainfall zone below 200 mm is nearly 50%. Further, drought analysis in western Rajasthan indicated that the region experienced only one disastrous nature of drought in 1918, 7 severe, 14 large and 24 moderate nature of droughts during 1901 to 1990. Decennial frequency of drought years i.e., the number of drought years of each category that occurred in each successive decade revealed that the two decades 1931-40 and 1941-50 had the maximum droughtiness and each experienced 7 drought years of different intensities. The decade 1971-80 was the most favourable for establishment of silvipastoral system in the region in comparison to the other decadel periods with just three drought years and that too with two moderate and one large intensity of drought (Fig.3).

In a silvipastoral system, normally the grasses take up most of the water from the upper layers of the soil, whereas shrubs/trees take up most of the water from lower layers of the soil (Sala *et al.*, 1989). *Acacia* and *Prosopis* species have long tap root to reach 5-12 m deep under ground water resources and are highly adapted to drought conditions. *P. tamarugo* is adapted to

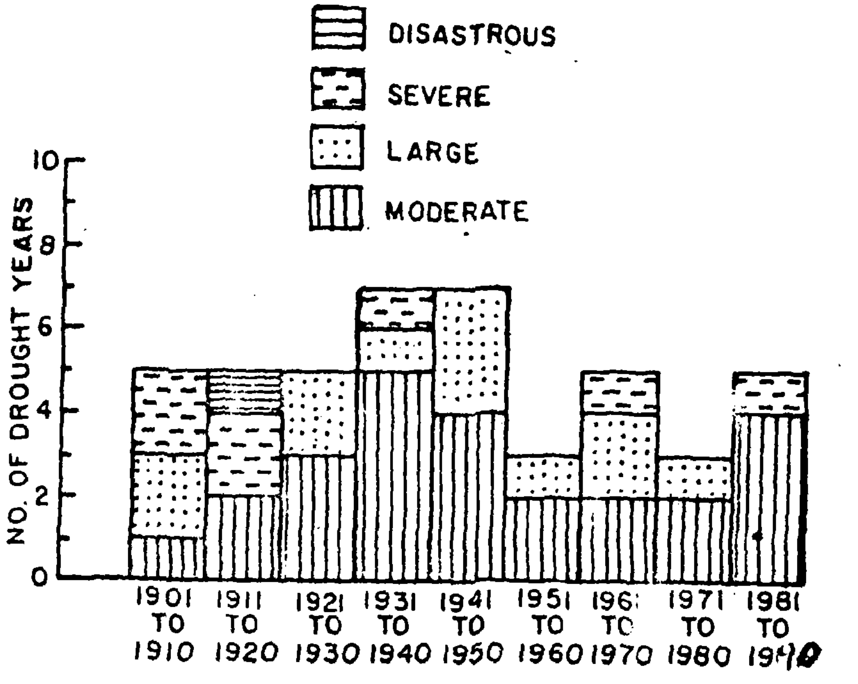

Fig.3 Decennial frequency of drought years - western Rajasthan

salt and drought conditions of the Atacama Desert of northern Chile, where temperature ranges from -12 to 36°C, the mean annual rainfall is less than 10 mm and the soil surface is covered by a salt crust up to 50 cm thick (NAS, 1980).

Solar Radiation and its Utilization

The tree/shrubs and pastures interact and modify the solar climate of a silvipastoral system. The various processes include radiation interception by tree stands of various densities, effect of canopy structure, effect of row orientation and spacing, effect of latitude and time of year on solar paths, shade from a single crown and spectral quality of sunlight under partial shade (Reifsnyder and Darnhofer, 1987).

In an experimental study conducted at the Central Arid Zone Research Institute, Jodhpur on radiation penetration in silvipastoral system during post monsoon month (October), 1992 revealed that *Hardwickia binata* along with grass allowed only 14% of global radiation to reach the ground level. However, individual tree (*H. binata*) and grass components permitted 18 and 48% radiation to reach ground level respectively, during peak day hours. Albedo values were 33, 25 and 26% from pure *Hardwickia binata*, pure grass strips and *Hardwickia binata* with grass, respectively at maturity stage of grasses. In another study at Jodhpur, the radiation penetration under *A. tortilis* was between 14 to 30% of that in the open during the day time. The net radiant energy availability beneath the tree canopy was between 15 to 24% of that in the open indicating the low levels of solar radiation is available to the grass grown under unlopped *Acacia tortilis* plantation (Ramakrishna *et al.*, 1981)

Studies were conducted at Chandan on silvi and horti-pastoral systems with *P. cineraria* + *L. sindicus*; *C. mopane* + *L. sindicus*; *Z. mauritiana* (cv. seb and gola) + *L. sindicus*; *D. nutan*- *L. sindicus* and *A. nilotica* + *L. sindicus* to find out variations with respect to soil moisture and micro-climate.

The solar radiation interception studies (Table 1) indicated that the highest interception was in *P. cineraria* + *L. sindicus* (84%) systems followed by *D. nutan*- *L. sindicus* (81%), sole *A. nilotica* (79%), sole *L. sindicus* (78%), *C. mopane* + *L. sindicus* (68%),*Z. mauritiana* cv seb + *L. sindicus* (63%) and *Z. mauritiana* cv gola- *L.sindicus* (49%).

Net radiation values also followed the total radiation in these different tree grass systems. The lowest albedo of 19.3% was observed in grass systems with *A. nilotica* and *C. mopane* followed by *D. nutan* and *Z. mauritiana* cv. gola (20.7%), *P. cineraria* + *L. sindicus* (21.8%), *L. sindicus* (22.1%) and *Z. mauritiana* cv.seb + *L. sindicus* (23.8%). The growth of *L. sindicus* was not affected by trees in the initial stage. The average dry forage yield of *L. sindicus* at Chandan was 1750 kg/ha.

Table 1. Micro-climatic conditions (13:00 h IST) in different silvi and horti-pastoral systems at Chandan (Jaisalmer)

Date	Solar radiation below canopy Wm^{-2}	Net radiation Below canopy Wm^{-2}	Net radiation Above canopy Wm^{-2}	Albedo
L. sindicus				
29.07.1993	237.1	710.0	97.1	22.1
15.08.1993	235.6	658.4	130.3	24.6
02.09.1993	241.6	628.3	265.6	28.4
08.10.1993	110.2	551.7	84.3	23.2
Z. mauritiana (cv. seb) +L. sindicus				
29.07.1993	401.7	582.3	166.0	23.8
15.08.1993	270.3	143.6	250.3	24.1
08.10.1993	312.6	597.0	140.5	26.6
Z. mauritiana (cv. seb) +L. sindicus				
29.07.1993	563.2	628.3	388.2	20.7
15.08.1993	675.0	630.8	444.4	24.3
02.09.1993	436.4	628.3	314.1	21.0
08.10.1993	398.6	567.0	43.4	25.2
A. nilotica +L. sindicus				
29.07.1993	226.5	528.7	25.5	19.3
15.08.1993	191.8	559.3	166.0	25.5
02.09.1993	297.5	521.0	355.0	24.9
08.10.1993	386.6	490.4	260.5	22.7
P. cineraria L. sindicus				
29.07.1993	140.4	97.1	33.2	29.4
15.08.1993	155.5	150.7	46.0	34.0
02.09.1993	196.3	166.0	102.2	22.2
08.10.1993	419.8	613.0	299.9	24.9
D. nutan + L. sindicus				
29.07.1993	205.4	702.4	21.7	20.7
15.08.1993	462.1	669.1	63.9	24.5
02.09.1993	428.8	669.1	426.5	23.1
08.10.1993	326.2	163.5	38.3	33.8
C. mopane + L. sindicus				
29.07.1993	353.3	600.2	79.2	19.3
15.08.1993	450.0	658.9	56.2	20.7
02.09.1993	530.0	694.7	444.4	28.9
08.10.1993	36.5	52.4	2.55	26.4

Micro-climatic Interactions in Silvipastoral Systems

The Indian arid region is subjected to extreme temperatures between -4.4 to 50.0°C, considerably influencing the vegetation demanding higher water requirements. In silvipastoral systems, the canopy and pasture make the micro-climate more favourable by maintaining lower temperatures (by 2 to 9°C) and high humidity (by 3 to 11%). Energy balance studies at Jodhpur on *Cenchrus* grasses showed that the net radiation, soil heat flux and latent heat of vaporization over the grass were higher during wet years compared to the values during low rainfall years (Rao *et al.*,1993).

In general, leaf fall in deciduous trees like *P. cineraria* in silvipastoral systems starts during the winter months. The appearance of new leaf synchronizes with the increase in atmospheric temperature in the beginning of spring season (February and March). This phenomena takes place every year with the fall and rise in atmospheric temperature over the region. However, concentrated leaf drop is not observed in evergreen and coniferous trees found in tropical forest region.

Studies on micro-climatic impact on *Cenchrus ciliaris* at Jodhpur showed that high air temperature and windspeeds prevailing in the arid region at Jodhpur had a negative correlation whereas, rainfall, humidity and rainy days had a positive correlation on forage and seed yield of *Cenchrus ciliaris*. Seed yield of *Cenchrus ciliaris* increased from 67 to 153 kg ha^{-1} with a gradual increase in quantum of rainfall from 150 to 400 mm. Rainfall at flowering and seed setting stages reduced the seed yield (Rao and Singh, 1994).

Tree Shelters for Reduction of Wind Speed and Water Losses

In silvipastoral systems, trees/shrubs help in protection of the soil from the high winds. Studies on the role of shelterbelts in reduction of windspeed, evaporation rate, soil moisture and wind erosion were conducted at Jodhpur. The studies showed that the tree system of *Cassia siamea + Albizzia lebbek* was more efficient in reducing wind velocity followed by *Acacia tortilis + A. lebbek* type of shelterbelt. There was also a decrease of 5-14% in pan evaporation values in the leeward side at 2H distance. Soil moisture content was also higher in 0-30 cm depths in *C. siamea + A. lebbek* than other combination of trees (Gupta *et al.*,1984; Muthana *et al.*,1984).

Estimation of Fodder Production through Computer Models

Studies on finding quantitative relationships between growth of tree/grasses in relation to environmental variables is under progress at the Central Arid Zone Research Institute, Jodhpur.

RANGETEK model predicted yields of *L. sindicus* within +8 to -12% of recorded yields (Singh and Rao, 1995). The yield index (T/T_P), computed using the model showed that in general with the increase in yield index from 0.40 to 0.85, the seed production of *C. ciliaris* increased from 0 to 172 kg/ha. Rainfall explained 1% seed and 36% forage yield, whereas the yield index was useful for prediction of variations upto 24% seed and 76% forage yield (Rao and Singh, 1994).

SPUR model is being used for Simulation of Production and Utilization of Rangelands. The model consists of five components viz., climate, hydrology, plant, animal and economics (USDA,1987). The SPUR model takes into consideration the climate and day to day variations in weather which have major influence on range processes such as forage production, livestock water, insect dynamics and erosion. Hydrological estimations like runoff and sediment yield and available soil moisture for plant processes are important components in the simulation model. The plant component simulates the flow of carbon and nitrogen through several compartments of the plant. Inputs required include the initial biomass content of each compartment and parameters that control photosynthesis, respiration and nitrogen utilization. The animal component considers forage palatability, abundance and location to control plant utilization by animals.

The computer models which simulate the soil moisture availability to tree and pasture production can help fodder estimations over large regions and also can help in management of fodder resources from surplus to deficit regions during different drought conditions.

Conclusions

In silvipastoral systems, climatic interactions with tree and pasture grasses are very important. High variability in rainfall of the arid regions influence choice of trees/grasses and productivity from the systems. In silvipastoral systems, the tree canopy and pasture make the micro-climate more favourable by reducing intensity of solar radiation, air temperature, wind velocity and evaporation rates. Weather information can be made use of for estimation and management of fodder resources for increasing forage production through suitable silvipastoral systems in this forage deficit region.

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APPRAISAL OF BIOPHYSICAL RESOURCES OF THE ARID ECOSYSTEMS FOR SUSTAINABLE LANDUSE PLANNING

Surendra Singh

Introduction

It is an established fact that for the sustainable integrated landuse planning, appraisal, assessment and management of the biophysical resources of the degraded arid ecosystems is of paramount importance. Accordingly, the integrated natural resources surveys, involving landforms, soils, surface and ground water, vegetation and present landuse, using remote sensing and field survey techniques have been completed in 0.24 million km^2 area of the hot Indian desert (Abichandani *et al.* 1975; Singh *et al.* 1976; Shankarnarayan and Singh, 1979; Dhir and Singh, 1986; Shankarnarayan and Kar, 1983; Chatterji and Kar, 1992). The above resources, using the concept of Major Land Resources Units (MLRUs) developed by Abichandani *et al* 1975 and Abichandani and Sen, 1977, have been integrated in the form of resource units (ecosystems) The sustainable integrated landuse planning and management for different resource units/ecosystems to develop them into croplands, grazing lands (pastures/silvipastures) and forest lands at district, river basin, block and taluka level, has been suggested (Singh 1982, 1985)

In the present paper, the concept of ecosystem, type, evolution, and appraisal and assessment of biophysical resources of arid ecosystems for their sustainable development into silvipastoral/pastoral systems and rainfed/irrigated agricultural systems through proper landuse planning and management have been highlighted.

Concept of Ecosystem

According to Tansley (1955), the ecosystem includes not only the organism complex but also the whole complex of physical factors forming what we call the environment of biome - the habitat factors in widest sense. The natural environment has two main components-the living organisms including man (biotic) and their non-living environment (abiotic) and these two components interact upon and related to each other to produce an exchange of material in an area designated as ecosystem (Fig. 1).

The living organism (biotic) has three parts viz., (1) producers, (2) consumers, and (3) decomposers. These three constitute naturally renewable resources capable of growth and reproduction with the rate of renewal, depending upon the physical environment and magnitude of propagating stock. In terms of natural resources, the non-living substances are classified as either stock resources (mineral deposits) which have no means of renewal, or flow resources (water in hydrologic cycle, solar radiation, oxygen) which are in continuous supply.

Type and Evolution of Ecosystems

Jodhpur is a representative district of arid Rajasthan where different type of ecosystems evolved during Quaternary period by denudational, fluvial and aeolian processes, have been

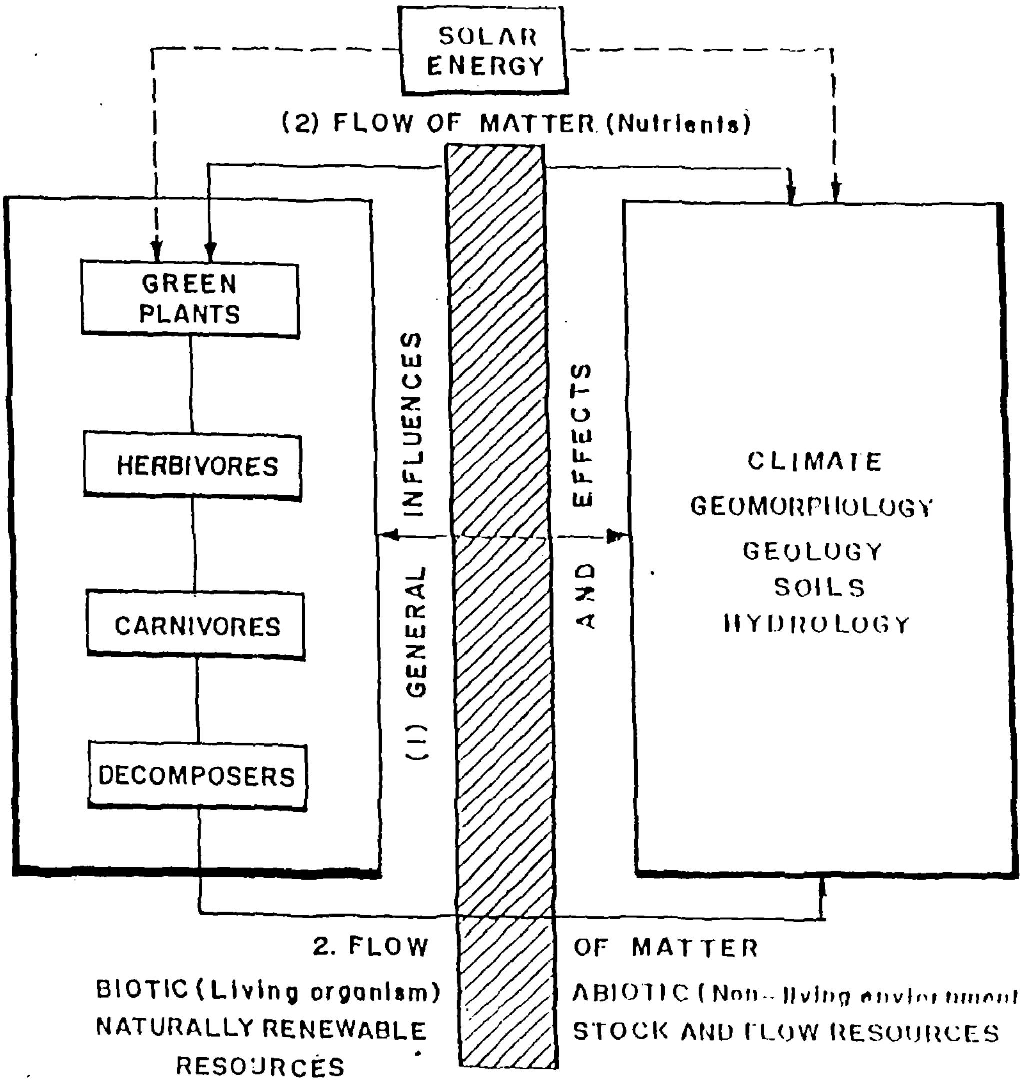

Fig. 1 Ecosystem structure

identified (Fig. 2). Denudational ecosystems such as hills and rocky/gravelly pediments have resulted due to weathering, erosion and slope retreat. Fluvial ecosystems viz; flat buried pediments and plateaus, shallow to moderately deep, moderately deep to deep, and deep to very deep flat aggraded older alluvial plains, deep saline flat aggraded older alluvial plains, flat interdune plains, gravelly aggraded older alluvial plains, younger alluvial plains and river beds and saline depressions had been created by fluvial process around 50-40 ka before present (BP). Aeolian ecosystems such as sandy undulating buried pediments, sandy undulating older alluvial plains, sand dunes and sandy undulating interdune plains were originated due to aeolian process around 18-10 ka BP (Singh, 1983; 1992).

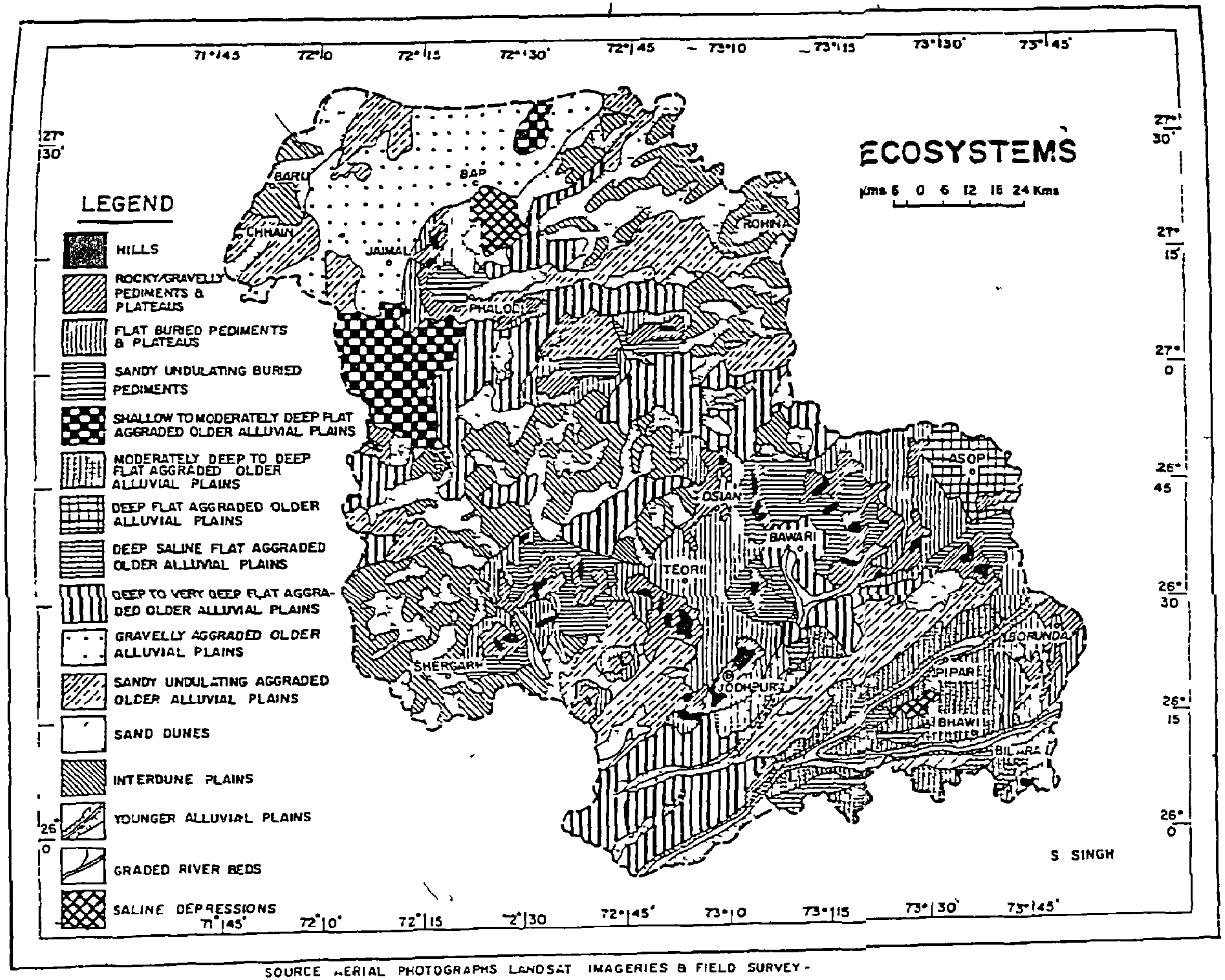

Fig 2 Different types of ecosystems in Jodhpur district

Appraisal and Assessment of Biophysical Resources of Ecosystems

Salient spectral and spatial characteristics of the dinudational, fluvial and aeolian ecosystems and their associated biophysical resources are distinctly discernible from Landsat band 5 image (Fig.3).

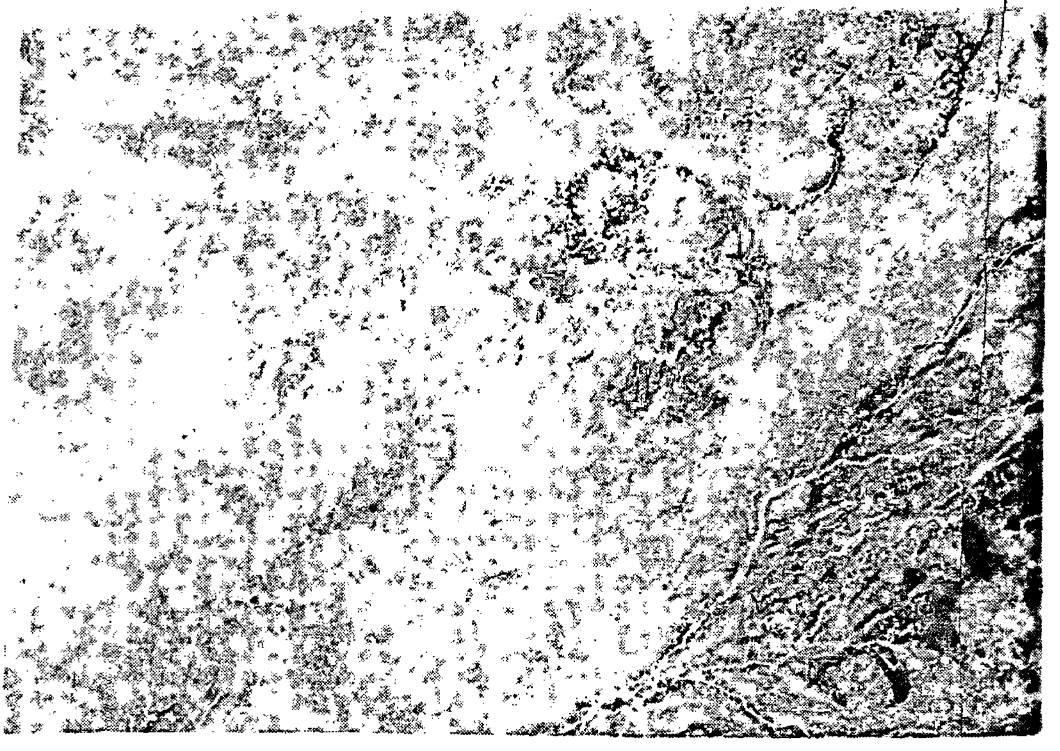

Fig. 3 Landsat band 5 image showing spectral and spatial characteristics of denudational, fluvial and aeolian ecosystems and their associated biophysical resources.

Denudational Ecosystems

Hills: This ecosystem comprising of sandstone, limestone, granite and rhyolite rocks cover 287.34 sq.km (1.26%) area of the district. It is, by and large, devoid of soil cover except along the joints and fractures where thin cover of coarse deposits exists. The slopes are steep, varying from 20^{0} to 24^{0} and they are affected by severe to very severe sheet to rill and rill to gully erosion. The dominant plant community of this ecosystem is *Acacia senegal-Euphorbia caducifolia*. The rocky surfaces fall under land use capability class VIII and the areas having sediment cover belong to land use capability class VII c, ew (Anon. 1982).

Rocky/gravelly pediments and plateaus: This ecosystem occurs at the base of the different hills and occupies 1446.72 sq.km area (6.33%) of the district. Due to physical limitations like the rocky surfaces, devoid of soil cover and moderate rill to gully erosion, this ecosystem falls under the land use category of rocky/gravelly waste and is being used as grazing lands/pastures. The surface and ground water potentials are very good and they have not been fully exploited. The joints and fractures with thin soil cover support *Acacia senegal-Maytenus emarginatus* plant community This ecosystem belongs to landuse capability class VII c, ew and rock outcrops to class VIII c, ew.

Fluvial Ecosystems

Buried pediments and plateaus: This ecosystem lies at the base of the rocky/gravelly pediments and plateaus and covers 1762.98 sq.km area (7.71% of the district). It is almost level and free from physical hazards. Due to good ground water potentials and better fertility of the soils having 0.20 to 0.28 per cent organic carbon; 15 to 24 kg/ha available P_2O_5 and 230 to 350 kg/ha available K_2O, these lands are used under double cropping. The crops like wheat, chillies, cumin, pearl millet, green gram and clusterbean are raised. The plant community of *Capparis decidua-Ziziphus nummularia* occurs on this ecosystem and its soils qualify for landuse capability class III ew, c and of irrigated areas to class II c.

Shallow to moderately deep flat aggraded older alluvial plains: This ecosystem covers 1634.12 sq.km area (7.15%) of the district. These lands due to the physical and climatic limitations like the shallow light textured soils underlain by hard *kankar* pan, moderate to severe sheet to rill erosion and low rainfall are largely used as grazing lands. The soils can retain 25 to 50 mm moisture/m depth, 8 to 18 kg/ha available P_2O_5 and 125 to 175 kg/ha available K_2O. The cultivation is done in 20 to 30 per cent area and the crops like pearl millet, green gram and clusterbean are grown. The growth of the vegetation is stunted and the trees of *Prosopis cineraria* are widely scattered with 0.5 to 1 plant/ha. The ground water is brackish to saline and surface water could be harvested in *nadis* and tanks. The soils belong to landuse capability class VI c, sh (Anon. 1982).

Moderately deep to deep flat aggraded older alluvial plains: This ecosystem covers 1800.10 sq.km (7.87%) area of the district. The soils have good moisture retention capacity and adequate fertility with 0.25 to 0.45 per cent organic carbon, 12 to 25 kg/ha available P_2O_5 and 140 to 220 kg/ha available K_2O. This unit falls under the favourable rainfall zone and is free from hazards. *Prosopis cineraria-Capparis decidua* is the dominant plant community. The rainfed crops like pearl millet, green gram, wheat and chillies are raised. The soils of this ecosystem fall under landuse capability class III c, ew (Anon. 1982).

Deep flat aggraded older alluvial plains: This ecosystem covers 507.14 sq.km area (2.22%) of the district. These plains due to the almost level slope, absence of hazards, medium to fine textured soils (sandy loam to loam and silty clay loam to clay) with 0.25 to 0.50 per cent organic carbon, 12 to 24 kg/ha available P_2O_5, 160 to 350 kg/ha available K_2O and 180 to 230 mm moisture retention capacity are intensively cultivated. The crops like pearl millet, clusterbean, sorghum, wheat and cumin are raised. The potentials of surface and ground water are good. This ecosystem supports the plant community of *Prosopis cineraria-Acacia nilotica* ssp. *indica-Salvadora oleoides* and its soils belong to landuse capability class III c, ew.

Deep saline flat aggraded older alluvial plains: This ecosystem covers 261.19 sq.km area (1.14%) of the district. The salinity/alkalinity hazard has developed due to the man's interference with natural systems, excess irrigation by saline water and weathering of granite.

Very severe salinity/alkalinity hazard has completely written off 2705 ha land from the agricultural account and 10,705 ha land is affected by severe salinity/alkalinity hazard and the cultivation is done only in pockets. The soils have 0.20 to 0.25 per cent organic carbon, 10 to 20 kg/ha available P_2O_5 and 135 to 245 kg/ha available K_2O. *Kharchia* wheat is grown under saline irrigated conditions. Ground waters are highly saline with 8 to 10 mmhos/cm electrical conductivity. This ecosystem supports *Salvadora persica-Prosopis juliflora* plant community and its soils belong to land use capability class V c,sa.

Deep to very deep flat aggraded older alluvial plains: This ecosystem covers 3629.11 sq.km area (15.87%) of the district. These lands have light to medium textured deep to very deep sand to loamy sand and sandy loam soils underlain by weakly developed calcium carbonate layer at 160 to 250 cm depth. The major limitations of the soils of this ecosystem are deep percolation, poor moisture retention capacity, low fertility status having 0.08 to 0.20 per cent organic carbon, 12 to 20 kg/ha available P_2O_5, 100 to 225 kg/ha available K_2O and highly susceptible to aeolian hazard

The rainfed crops like pearl millet, green gram and wheat are raised. The surface water potentials due to rapid percolation of surface runoff are not good but ground water potentials are good. The dominant plant community of this ecosystem is *Prosopis cineraria- Ziziphus nummularia-Capparis decidua* and its soils fall under the landuse capability class III c, ea (Anon. 1982).

Flat interdune plains: This ecosystem covers 1267.71 sq.km area (5.56%) of the district. These lands are almost level, their morphological and physico-chemical characteristics and fertility status are almost similar to the moderately deep to deep flat aggraded older alluvial plains. Rainfed crops like pearl millet, green gram and clusterbean are grown here.

The ground water potentials in the concealed sandstone formation are good and the surface runoff generated by the surrounding stabilised sand dunes is stored in the *tankas* (cisterns) and *nadis*. The dominant plant community is *Prosopis cineraria-Salvadora oleoides*. This ecosystem falls under landuse capability class III c, ea, ew.

Gravelly aggraded older alluvial plains: This ecosystem covers 782.41 aq.km area (3.42%) of the district and due to the physical and climatic limitations like presence of the rock fragments and boulders, shallow soils in pockets underlain by rocky strata, slight to moderate sheet to rill and gully hazard and low rainfall varying from 200 to 240 mm is largely used as grazing lands. The soils contain 0.1 to 0.2 per cent organic carbon, 8 to 16 kg/ha available P_2O_5 and 160 to 325 kg/ha available K_2O. The rainfed crops like pearl millet and clusterbean are grown in pockets. Surface runoff potentials are good. The growth of the vegetation is poor and the dominant plant community is *Capparis decidua-Ziziphus nummularia*. The soils of this ecosystem belong to landuse capability class VI sh and soils of rocky areas to class VII c, ew.

Younger alluvial plains and graded river beds: This ecosystem covers 668.81 sq.km (2.92%) area of the district. The soils are light textured and can retain 65 to 85 mm of moisture/m depth. They have 0.20 to 0.32 per cent organic carbon, 10 to 12 kg/ha available P_2O_5 and 150 to 280 kg/ha available K_2O. These lands due to the availability of ground water are agriculturally very productive except the areas which are affected by salinity and aeolian hazards. The crops such as wheat, cumin, corriander, pearl millet and green gram are grown. The industrial effluents and occasionally floods have spoiled and damaged the adjoining agricultural lands, resulting in the stunted growth and depletion of yield of rainfed and irrigated crops. *Prosopis cineraria-Acacia nilotica-Salvadora oleoides* is dominant plant community.

Majority of the soils of this ecosystem belong to landuse capability class III c, ew and of irrigated areas to class II c. The soils of the areas affected by salinity/alkalinity and aeolian hazard, flood and industrial effluent belong to landuse capability class V sa and VI c, ea, ew.

Saline depressions: This ecosystem covers 211.67 sq.km area (0.93%) of the district and is highly saline and fall under landuse category of saline waste. It is being used for extracting salts of commercial value and also as grazing land. The ecosystem is devoid of vegetation excepting scattered bushes of *Suaeda fruticosa*. Its peripheries, however, support *Prosopis juliflora, Salvadora oleoides* and *Capparis decidua*. Soils are highly saline and belong to landuse capability class VIII sa (Anon. 1982).

Aeolian Ecosystems

Sandy undulating aggraded older alluvial plains: This ecosystem covers 2977.92 sq.km (13.03%) area of the district. Physical and climatic hazards are the major limitations of these plains for the crop production. The soils are deep to very deep, sand to loamy sand having poor moisture retention capacity 40 to 50 mm/m depth and organic carbon 0.04 to 0.14 per cent, 12 to 18 kg/ha available P_2O_5 and 70 to 1130 kg/ha available K_2O. Moderate, severe and severe to very severe wind erosion/deposition hazard has affected this ecosystem. The undulating lands are largely used as grazing lands and flat areas are cultivated with pearl millet and green gram. The dominant plant community is *Ziziphus nummularia-Calligonum polygonoides*. The ground water potentials are good. The soils of flat areas belong to landuse capability class IV c, ea and of associated dunes and hummocks to class VI c, ea.

Sandy undulating buried pediments: This ecosystem largely occurs in the south-western flanks of the hills and covers 1295.35 sq.km (5.67%) area of the district. These lands in spite of the physical limitations like the irregular slope, loose and highly permeable aeolian deposits, moderate to severe and severe to very severe wind erosion/deposition and water erosion hazards are used for growing rainfed and irrigated crops such as wheat, cumin, green gram and pearl millet. The soils can retain 65 to 90 mm of water/m depth and have 0.08 to 0.20 per cent organic carbon, 12 to 20 kg/ha available P_2O_5 and 100 to 225 kg/ha available K_2O. This ecosystem supports the plant community of *Acacia senegal, Calotropis procera-Calligonum polygonoides* and its soils belong to landuse capability class IV c, ea, ew and associated dunes to class VI c, ea.

Sand dunes: This ecosystem occupies 3059.31 sq.km area (13.38%). of the district. The obstacle, parabolic, longitudinal and transverse sand dunes belong to the old dune system. They are well stabilised and vegetated and alternate layers of calcium carbonate are developed within them. But due to increasing biotic stress such as cultivation by unscientific methods, overgrazing, lopping and cutting of trees, the crests and flanks of these dunes have been reactivated, resulting in the accumulation of fresh sand of 1.5 to 4.0 m thickness. The moisture in these dunes occurs at 40 to 90 cm depth and it is more at the crest (2.24 to 2.59%) and gradually decreases towards the windward side (Singh, 1977). They have 0.40 to 0.15 per cent organic carbon, 8 to 15 kg/ha available P_2O_5 and 70 to 150 kg/ha available K_2O. These dunes are also well supplied with micro-nutrients viz; iron 2.9 to 15.4 ppm; zinc 0.20 to 0.40 ppm and copper 0.33 ppm. The dominant plant communities are *Acacia senegal-Calligonum polygonoides Prosopis cineraria-Calligonum polygonoides* and *Calligonum polygonoides Clerodendrum phlomoides* (Anon. 1982).

The sand dunes of new dune system are barchan and shrub-coppice which largely occur in the west of 250 mm isohyet. The dunes of this system due to loose and structureless sand and absence of vegetation are active and cause enormous damage to the adjoining agricultural land and engineering structures. The soils of this ecosystem fall under the landuse capability class VI c, ea.

Sandy undulating interdune plains: This ecosystem constitutes 1275.12 sq.km (5.55%) area of the district. The morphological and physico-chemical characteristics, fertility status and landuse pattern of the sandy undulating interdune plains are almost similar to the sandy undulating aggraded older alluvial plains. The ground water potentials under concealed sandstone and limestone are good. The dominant plant community is *Calligonum polygonoides-Ziziphus nummularia-Calotropis procera*. This ecosystem belong to landuse capability class IV c, ea and associated dunes and hummocks to class VI c, ea (Anon.1982).

Erosional, Depositional and Salinity/alkalinity Hazards

Water erosion, wind erosion/deposition and salinity/alkalinity are the major natural and man-induced hazards which limit the agricultural productivity of different ecosystems (Fig. 4 & 5). These hazards, according to their severity and extent have been classified into 'slight', 'moderate', 'severe' and 'very severe' classes.

Water Erosion Hazard

Slight rill to gully erosion: This hazard in the form of rills of 0.2 to 0.4 m depth and 0.4 to 0.8 m width and gullies of 0.4 to 1.0 m depth and 0.8 to 1.5 m width has affected 4.50 sq.km (0.02%) area of the ecosystem of flat buried pediments and plateaus.

Slight to moderate sheet to rill erosion: This hazard in the form of gullies of 0.5 to 1.2 m depth and 0.7 to 2.6 m width occurs in 993.52 sq.km (4.35%) area of the ecosystems of flat buried pediments and plateaus, shallow to moderately deep flat aggraded older alluvial plains, gravelly aggraded older alluvial plains and flat interdune plains. Such hazard has affected the largest area 587.06 sq.km (2.57%) in the shallow to moderately deep flat aggraded older alluvial plains In some of these ecosystems, the sediments have been washed away by the sheet erosion and the *kankar* pan is exposed, resulting in the depletion of their agricultural production and productivity.

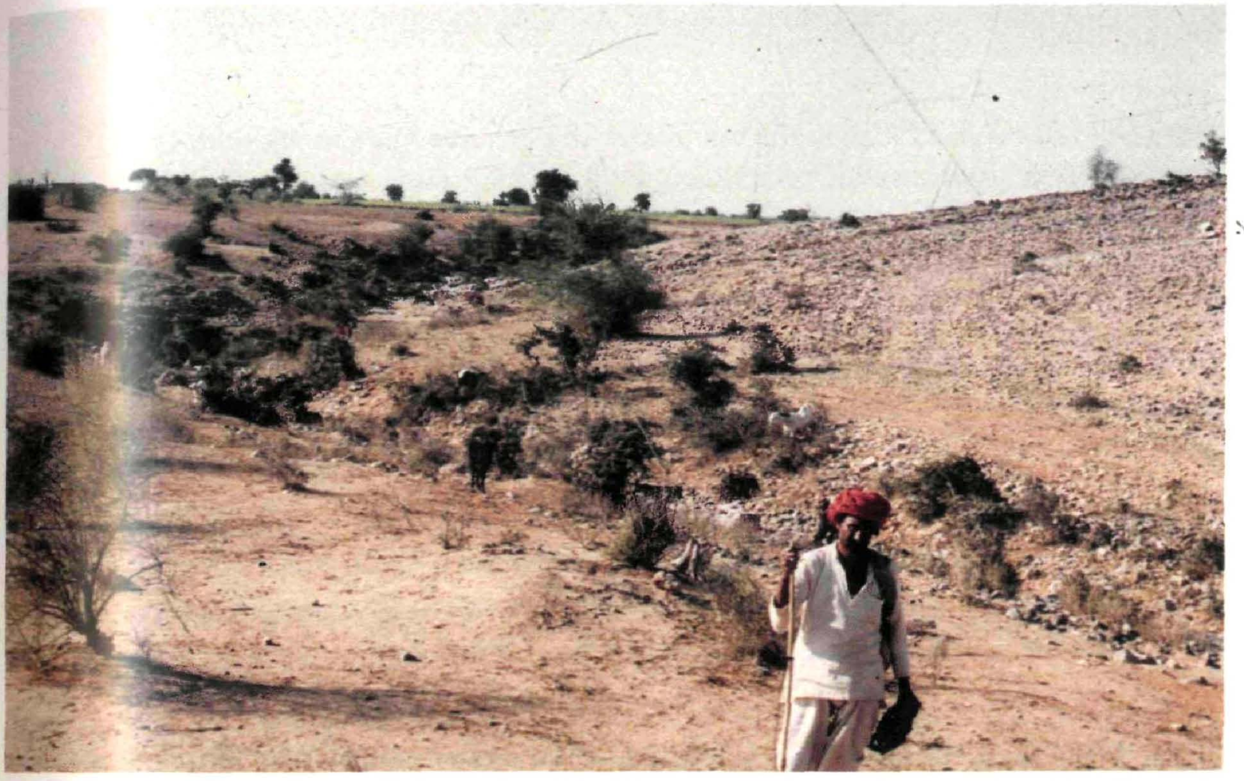

Fig. 4 Water erosion in the form of gullies and rills affecting biophysical potentials of the denudational and fluvial ecosystems

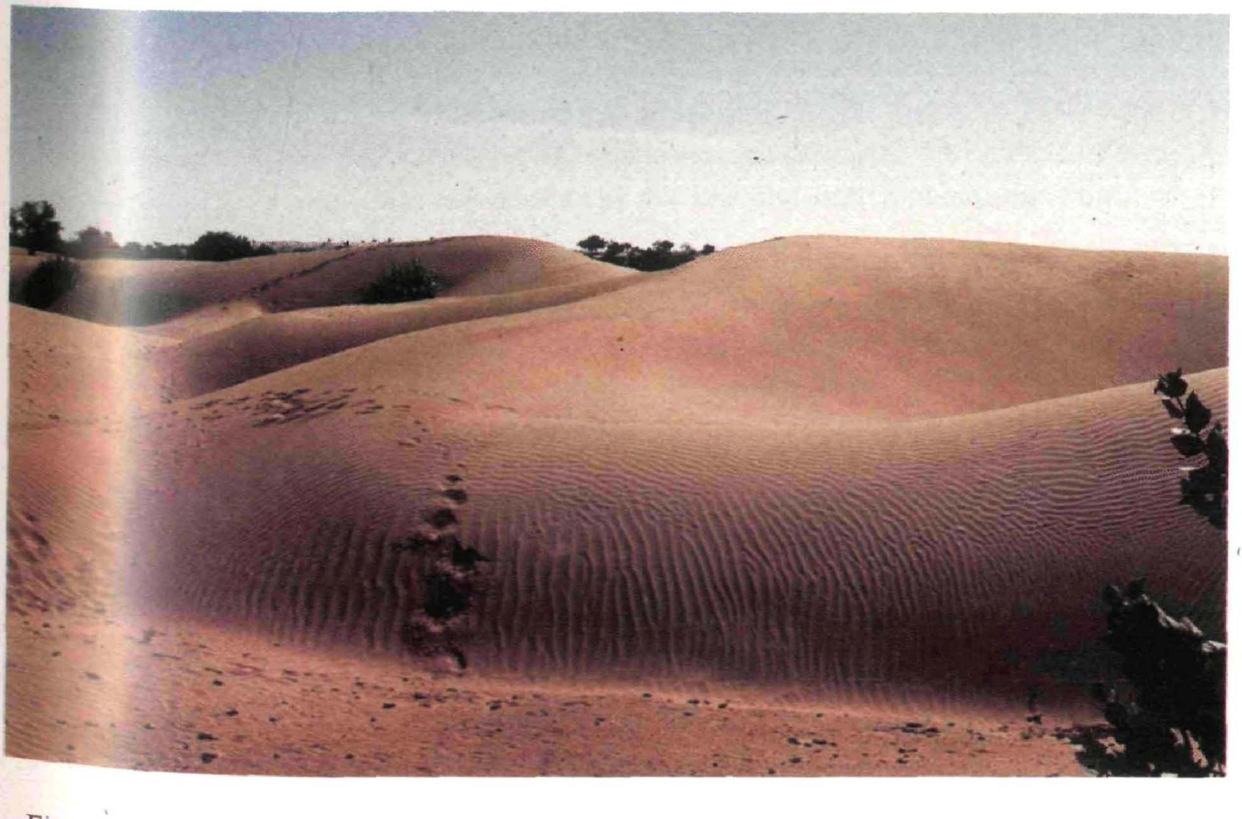

Fig. 5 Wind erosion/deposition in the from of sand dunes and sand sheets degrading biophysical potentials of fluvial and aeolian ecosystems

Slight to moderate rill to gully erosion: This hazard has affected 27.37 sq.km (0.11%) area of flat buried pediments and plateaus,flat gravelly aggraded older alluvial plains, sandy undulating aggraded older alluvial plains and younger alluvial plains. The rills and gullies created by such hazard are of 0.4 to 0.9 m depth and 0.9 to 1.25 m width and 1.0 to 1.5 m depth and 1.5 to 3.5 m width, respectively.

Moderate sheet to rill erosion: This hazard in the form of sheets and rills has affected 488.07 sq.km (2.14%) area of the ecosystems of flat buried pediments, shallow to moderately deep flat aggraded older alluvial plains and younger alluvial plains.

Moderate rill to gully erosion: This hazard has desertified 571.39 sq.km (2.50%) area of the ecosystems of the rocky/gravelly and buried pediments, deep to very deep flat aggraded older alluvial plains and gravelly aggraded older alluvial plains. The rills and gullies created by this hazard are of 0.4 to 0.7 m depth and 0.7 to 0.9 m width and 1 to 1.5 m depth and 1.5 to 1.75 m width, respectively.

Moderate gully erosion: This hazard in the form of gullies of 2 to 5 m depth and 3 to 8 m width has desertified 5.20 sq.km (0.02%) area of the ecosystems of the flat aggraded older alluvial plains and flat buried pediments and plateaus.

Moderate to severe bank erosion: This hazard is present in 29.10 sq. km area (0.13%) of the district along the banks of the Luni, the Mitri, the Jojri and the gotabar rivers. The amount of dissection in the upper reaches of these rivers varies from 5 to 8 m and in the lower reaches between 4 to 6 m.

Severe rill to gully erosion: This hazard has desertified 301.37 sq.km (1.32%) area of the ecosystems of the hills and rocky/gravelly pediments and plateaus. The gullies of 5 to 12 m depth and 8 to 25 m width have been created by this erosion hazard in these ecosystems.

Severe to very severe sheet to rill and gully erosion: This hazard has desertified 1149.04 sq.km (5.03%) area of the ecosystems of the rocky/gravelly pediments and flat interdune plains. The rills of 0.5 to 0.9 m depth and 0.9 to 1.5 m width and gullies of 2 to 8 m depth and 5 to 12 m width have been created by fluvial action in these ecosystems.

It has been estimated that if this hazard continues unchecked, 133.07 sq.km and 755.35 sq.km area will be affected in future by moderate to severe and severe to very severe water erosion, respectively in different fluvial ecosystems.

Wind Erosion/Deposition Hazard

Slight wind erosion/deposition: This hazard in the form of deflation hollows, sand sheets of 100 to 200 cm thickness and low dunes of 0.9 to 1.25 m height has desertified 1889.51 sq.km (8.27%) area of the ecosystems of the flat interdune plains, shallow to moderately deep aggraded older plains and deep to very deep flat aggraded older alluvial plains.

Slight to moderate wind deposition: This hazard in the form of sand sheets of 150 to 450 cm thickness, hummocks of 0.9 to 1.5 m height and sand dunes of 2 to 4 m height has affected

1069.68 sq.km (4.68%) area of the ecosystems of deep to very deep flat aggraded older alluvial plains, sandy undulating interdune plains and graded river beds.

Moderate wind deposition: This hazard in the form of hummocks and sand dunes of 1 to 2 m and 2 to 6 m height has desertified 2616.65 sq.km (11.45%) area of the ecosystems of the sandy undulating aggraded older alluvial plains and sandy undulating interdune plains.

Moderate to severe wind deposition: This hazard has affected 226.40 sq.km (0.99%) area of the ecosystems of the sandy undulating aggraded older alluvial plains and sandy undulating interdune plains.

Severe wind deposition: This hazard has desertified 1663.94 sq.km (7.28%) area of the ecosystems of the sandy undulating aggraded older alluvial plains and sandy undulating interdune plains.

Very severe wind deposition. This hazard in the form of sand sheets of 2 to 4 m thickness and barchan dunes of 3 to 5 m height has desertified 2993.01 sq.km (13.09%) area of the ecosystem of different type of sand dunes.

In case this hazard is not checked, it is expected that in future severe to very severe wind deposition hazard will desertify 358.21 sq.km area of the deep to very deep aggraded older alluvial plains.

Wind Erosion/Deposition and Water Erosion Hazards

Moderate wind deposition and gully erosion: These hazards in the form of sand dunes of 3 to 5 m height and gullies of 2 to 3 m depth and 4 to 5 m width have affected 49.67 sq.km (0.22%) area of the ecosystems of the sandy undulating aggraded older alluvial plains and sandy undulating buried pediments.

Moderate to severe wind deposition and slight to moderate gully erosion: These hazards in the form of sand dunes of 5 to 10 m height, sand sheets of 250 to 450 cm thickness and gullies of 2 to 5 m depth and 5 to 10 m width have affected 242.86 sq.km (1.05%) area of the ecosystem of the sandy undulating buried pediments.

Severe to very severe wind deposition and gully erosion: These hazards in the form of sand dunes of 10 to 20 m height and gullies of 4 to 8 m depth and 10 to 15 m width have affected 1052.49 sq.km (4.69%) area of the ecosystem of the sandy undulating buried pediments.

Salinity/Alkalinity Hazard

Slight salinity alkalinity: This type of man-induced hazard developed due to tank irrigation has affected 15.05 sq.km (0.06%) area of the ecosystem of younger alluvial plain of the Mitri river.

Slight to moderate salinity/alkalinity: This man-induced and natural hazard has degraded 188.30 sq.km (0.82%) area of the ecosystems of the flat aggraded older alluvial plains, saline younger alluvial plains and the graded river bed of the Luni river.

Severe salinity alkalinity: This man-induced hazard has affected 117.20 sq.km (0.51%) area of the ecosystems of the deep saline flat aggraded older alluvial plains and the saline younger alluvial plains of the Luni river.

Severe to very severe salinity/alkalinity: This natural salinity hazard has desertified 238.72 sq km (1.05%) area of the ecosystems of the saline flat aggraded older alluvial plains and saline depressions

In case this hazard is not checked, it is expected that 215.35 sq.km area in younger alluvial plains and 275.75 sq.km in moderately deep to deep flat aggraded older alluvial plains will be affected by severe salinity/alkalinity hazard in the near future.

Based on the extent of different hazards, it has been observed that out of the total 22,860 sq km area of the district, the largest area 10459.19 sq.km (45.76%) is affected by wind erosion/deposition, followed by water erosion 3586.11 sq.km (15.69%), complex hazard 1345.02 sq km (5.89%) and the salinity/alkalinity hazard 559.27 sq.km (2.44%). The remaining 6910.41 sq.km (30.22%) area is free from all the above hazards. The distribution and extent of these hazards will enable to fix up the priorities for the reclamation of the major problematic areas for rational landuse planning of different ecosystems.

Biophysical Characteristics of Common Grazing Lands (*orans*)

The biophysical and Landsat image characteristics of the common grazing lands (*orans*) have also been evaluated under different ecosystems (Table 1). The variations in geomorphic features and soils of ecosystems have caused the variations in the type of vegetation, its growth and density and are closely related with the Landsat image characteristics. The degraded common grazing lands (*orans*) on rocky/gravelly pediment and saline alluvial plain appear in milky white to light grey and whitish yellow in tone on the Landsat TM false colour composite. Whereas, these grazing lands on sandy alluvial and younger alluvial plains appear in whitish yellow to light brown and light red in tone due to the better stand of vegetation.

Temporal Changes in Common Grazing Lands (*orans*)

The superimposition of maps of grazing lands prepared from the Survey of India topographical maps of 1958 and Landsat TM false colour composite of 1986 revealed that over a period of 28 years the extent of common grazing lands decreased by 9 to 30 per cent under various ecosystems (Table 2). The decrease in the extent of grazing lands associated with the saline alluvial plain is lowest due to the salinity hazard and highest in case of rocky/gravelly pediment as much of the land has been reclaimed for cultivation due to the availability ground water The decrease in the extent of common grazing lands (*orans*) due to the increased human activity like cultivation of marginal lands, construction of residential dwellings and industries in them and the increasing trend of urbanisation (Sharma *et al.*, 1989) disturbed the ecological balance of the fragile ecosystems, resulting in desertification and depletion of the productivity of the common grazing lands (*orans*) and adjoining agricultural lands.

Table 1. Biophysical and Landsat image characteristics of grazing lands (*orans*) located under different ecosystems

Ecosystem	Extent of grazing land (ha)	Geomorphology	Soil	Vegetation	Landsat image characteristics
Sandy alluvial plain	15-150	Flat and undulating topography, irregular slope varying from 1° -30 °, presence of moderate to severe wind erosion/ deposition hazard	Fine sand to loamy sand underlain by caco3concretionary zone	*Prosopis cineraria, Ziziphus mauritiana, Prosopis juliflora, Acacia senegal, Acacia tortilis, Tecomella undulata, Calotropis procera, Capparis decidua, Calligonum polygonoides, Aerva pseudotomentosa, Ziziphus nummularia, Cenchrus biflorus, Eleusine compressa, Eleusine granulata, Lasiurus sindicus, Aristida funiculata*	Fine texture, whitish yellow tone
Younger alluvial plain	25-438	Flat topography, upto 1° slope, deep to very deep sediments and rills and gullies in pockets	Coarse textured sand to loamy sand and sandy loam	*Acacia nilotica, Prosopis cineraria, Prosopis juliflora, Salvadora oleiodes, Capparis decidua, Ziziphus nummularia, Eleusine compressa, Cynodon dactylon, Cenchrus ciliaris, Cenchrus biflorus, Desmostachya bipinnata, Dactyloctenium sindicum*	Coarse to mottled texture, light brown to light red tone
Saline alluvial plain	58-290	Flat topography upto 1° slope, moaerately deep to very deep sediments and presence of salinity hazard	Saline sandy loam to loam and clay loam underlain by *kankar* pan	*Salvadora persica, Salvadora oleoides, Prosopis juliflora, Capparis decidua, Desmostachya bipinnata, Aleuropus lagopoides*	Fine to mottled texture, whitish yellow to milky white to whitish grey tone
Rocky/ gravelly pediment	35-1000	Eroded flat rocky/ gravelly surfaces, coarse textured sediments along faults and fractures, presence of rills and gullies	Coarse sand to loamy sand and gravelly sand underlain by weathered and solid rocky strata	*Ziziphus mauritiana, Acacia senegal, Acacia nilotica, Capparis decidua, Ziziphus nummularia, Calotropis procera, Cenchrus biflorus, Eleusine compressa, Dactyloctenium sindicum, Aristida funiculata, Panicum antidotale*	Fine to mottled texture, light yellow to brown to light grey tone

Source : Sharma *et al.* (1989).

Suggested Landuse Planning And Management

Ecosystems Suitable for Development of Silvipastoral/Pastoral Systems :

Appraisal and assessment of physical potentials and limitations of the biophysical characteristics of different ecosystems revealed that hills, rocky/gravelly pediments and plateaus, shallow flat aggraded older alluvial plains with hard *kankar* pan, gravelly aggraded older alluvial plains, sandy undulating aggraded older alluvial and interdune plains, sandy undulating buried pediments and sand dunes are the most suitable ecosystems for the development and management of silvipastoral/ pastoral systems (Fig. 6). Adoption of these systems would not

Table 2.Temporal changes in the extent of common grazing lands (*orans*) under different ecosystems

Ecosystem	Extent of grazing land (ha) 1958*	1986**	Reduction in the area (%)	No. of samples
Sandy alluvial plain	316	223	29	59
Younger alluvial plain	154	125	19	26
Saline alluvial plain	170	155	9	13
Rocky/ gravelly pediment	527	367	30	25

* Based on survey of india topographical maps.

** Based on landsat TM false colour composite.

only be consistent with the landuse capability class of the ecosystems but will also generate higher biomass yield per hectare without further degradation of their biological productivity.

Degraded hills could be developed into woodlands by providing exclosures and planting of *Acacia senegal, Prosopis juliflora* and *Euphorbia caducifolia* along the joints, fractures and crevices.

Rocky/gravelly pediments and plateaus and gravelly aggraded older alluvial plains could be developed into silvipastoral system by reseeding with grasses like *Cenchrus ciliaris, Cenchrus setigerus* and *Dichanthium annulatum* and planting of *Dichrostachys nutan, Acacia tortilis, Acacia senegal, Prosopis juliflora, Albizzia lebbeck, Commiphora wightii* and *Euphorbia caducifolia*, using suitable soil and water conservation measures and by providing water points for animals. Shallow flat aggraded older alluvial plains with hard *kankar* pan are best suited for the development of pastoral system by reseeding with improved grasses like *Cenchrus ciliaris* and *Cenchrus setigerus* with proper management practices and by providing water points for the animals (Anon. 1982).

Sand dunes and undulations of the sandy undulating aggraded older alluvial and interdune plains and sandy undulating buried pediments in the form of dunes and hummocks, are recommended for the establishment of silvipastoral system with suitable wind erosion/deposition control measures like wind breaks, shelterbelts, stubble mulching and wind strip cropping. The trees, shrubs and grasses suited for establishment of silvipastoral system are *Acacia tortilis, Acacia senegal, Prosopis cineraria, Ziziphus nummularia, Calligonum polygonoides, Acacia jacquemontii, Cenchrus ciliaris, Lasiurus sindicus* and *Cenchrus setigerus* (Saxena and Singh, 1976). The watering points should also be provided in the adjoining interdune plains for the animals.

Sandy undulating aggraded older alluvial and interdune plains and sandy undulating buried pediments in the west of 250 isohyet should not be used for cultivation except those falling under Indira Gandhi Canal Command area. They are best suited for the development of silvipastoral and horti-silvipastoral systems with proper wind erosion/deposition control measures like wind breaks, shelterbelts, stubble mulching and wind strip cropping and by providing watering points for the animals.

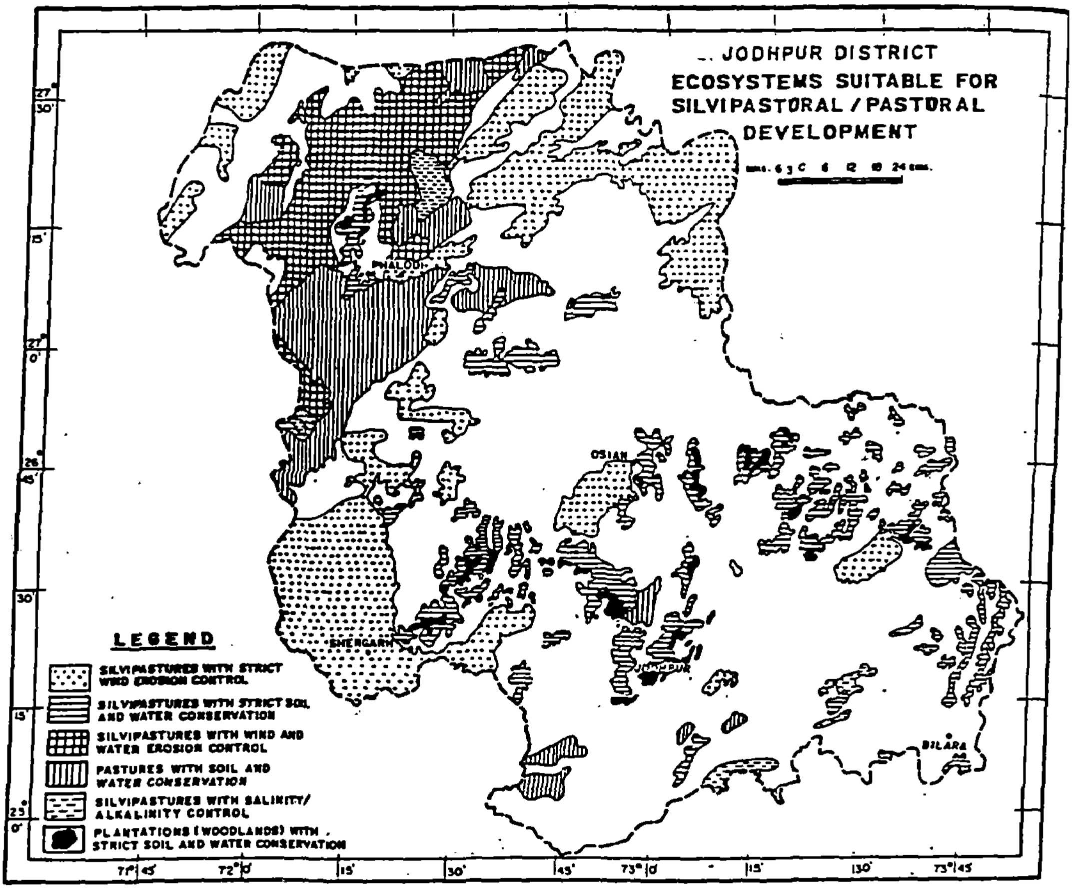

Fig. 6 Ecosystem s suitable for silvipastoral/pastoral development in Jodhpur districts.

In the east of 250mm isohyet, the undulating parts of these ecosystems like dunes and hummocks are recommended for establishment of silvipastoral and horti-silvipastoral systems with suitable wind erosion/deposition control measures. In the above proposed systems, the grasses viz; *Cenchrus ciliaris, Cenchrus setigerus* can be taken between the rows of fruit and non-fruit trees i.e. *Ziziphus mauritiana, Prosopis cineraria, Acacia tortilis* and *Albizzia lebbeck* (Vashishtha, 1994).

Saline flat aggraded older alluvial plains and saline depressions, not fit for cultivation, could be developed into silvipastoral/ pastoral systems with salt tolerant species like *Tamarix articulata, Prosopis tamaruga, Atriplex nummularia, Cressa cretica, Salsola bryosma, Dichanthium annulatum* and *Sporobolus helvolus* (Anon. 1982).

Ecosystems Suitable for Development of Rainfed/Irrigated Agricultural Systems

To the east of 250 mm isohyet, fluvial and aeolian ecosystems viz; younger alluvial plains, flat buried pediments, flat aggraded older alluvial and interdune plains and flat sandy aggraded older alluvial plains and flat parts of the undulating aggraded older alluvial and interdune plains and sandy undulating buried pediments are fit for development of rainfed/irrigated agricultural systems (Fig. 7). The sustainable development and management of these ecosystems need

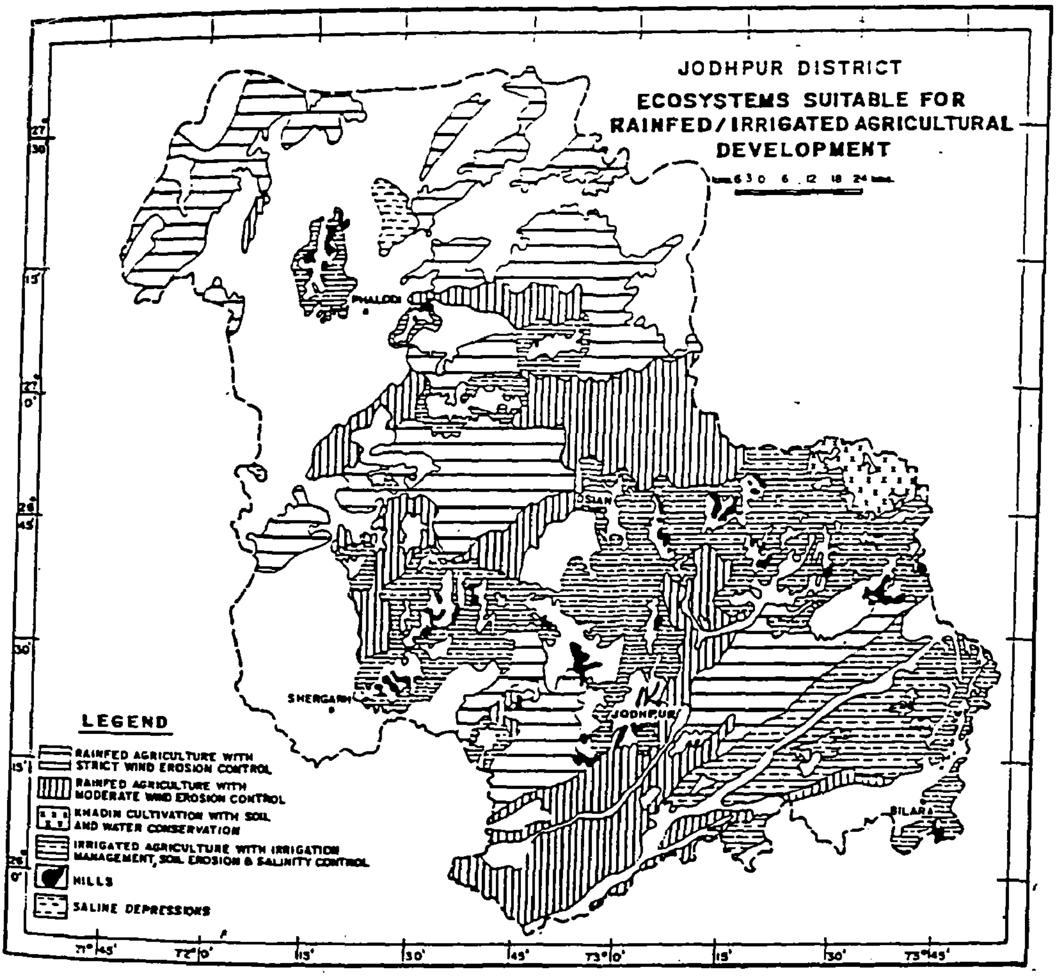

Fig.7 Ecosystems suitable for rainfed/irrigated agricultural development in Jodhpur district

suitable measures like contour bunding, contour furrows, shelterbelts, appropriate landuse pattern, suitable crop rotation, improved scientific methods of cultivation and irrigation, proper maintenance of fertility status and harvesting of surface runoff in farm ponds for supplementary irrigation.

Intercropping of grain legumes such as green gram, clusterbean, cowpea and groundnuts with pearl millet and sunflower, grain legumes with fodder legumes and legumes with trees has been proved a viable system for sustainable development of rainfed agriculture under above ecosystems (Daulay, 1994).

Conclusion

In the study area, sixteen arid ecosystems created by denudational, fluvial and aeolian processes have been identified and mapped These ecosystems were formed during Quaternary period, under two major wet and two dry climatic phases Accelerated wind erosion/deposition, water erosion, wind erosion/deposition and water erosion combined and salinity/alkalinity are the major environmental hazards affecting the biological productivity of these ecosystems Significant variations exist in the physical potentials and limitations of biophysical resources of different ecosystems Based on these factors and landuse capability, sustainable development of each ecosystem into silvipastoral/pastoral and rainfed/irrigated agricultural systems, using proper soil and water conservation measures, has been suggested

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CHARACTERISTICS AND BEHAVIORAL ASPECTS OF ARID AND SEMI-ARID ZONE SOILS

R.P. Dhir

Introduction

Rock dependent variability of parent material, physiography, past history of landscape evolution and climate have combined to give a large variety of soils in drylands. The range of soils includes the sticky, dark coloured clay soils or Vertisols from basalts, limestone and shales, through reddish coarse to medium textured soils or Inceptisols/Alfisols of granite and schist terrain to highly sandy soils of dunes and plains (Toripsamments). The soil variability together with the climate and physiography create a vast range of situations which influence the choice of tree-grass combination as also on management seeds. Of course, in developing countries with a high population dependency on land, the first priority is always for cropping and plantation crops. Not only the lands which capability wise are suited for the purpose, but often even marginal lands are put to farming. Therefore, it is only such lands which posses a severe limitation for cropping due to soil depth, slope, erosion, salinity or climate that are available for pasture or silvipasture uses. The paper briefly discusses the characteristics, properties and behavioural aspects of these soils of arid and semi-arid zones.

Arid Zone Soils

Sandy Soils : These highly coarse textured soils have a prominent occurrence in Indian subcontinent, Persian Gulf countries as also in Central Asia. In the Indian arid zone, such soils occupy 11.4 MHa or 42.7 per cent of the area (Dhir *et al.*, 1991). These occur often in form of dunes and hummocks. The soils usually contain 4-12% clay, 3-12% silt and rest is sand fraction with some lime and gypsum. These soils do not show any profile development and are classified as Torripsamment.

These soils have a high infiltration rate (8-38 cm h^{-1}) but a low water retention capacity (4 to 15% w/w). However, under unsaturated situation, the water conductivity is very low and decreases very fast with increasing tension. Thus, whereas the saturated state conductivity of a sandy soils is five times larger than a sandy loam soil, the conductivity at 500 k Pa is 200 times less in a sandy soils (Oswal and Khanna, 1981). This property has significant implications. Highly restricted water movement will permit full utilisation of moisture only if plant roots are able to reach the sites where the water is held in the soil. Thus plants with a fibrous root system stand to use stored moisture fully. This resistance to water movement is also a great advantage in arid zone situation with a high atmospheric moisture deficit during a major part to the year. The stored soil moisture remains protected in the soil till such time that it is utilized by the growing plant. Gupta (1979) found that soils of bare dunes and sandy plains remained almost of field capacity through out the year except in top 50 cm layer.

The sandy soils pose hardly any aggregation. Therefore these have a high basic erodibility. This fact together with strong wind regime and sparseness of perennial vegetation cover create severe wind erosion. Gupta (1981) reported a soil loss of 325 and 615 t ha^{-1} from partially stable and unstable sand dunes. Dhir (1994) reported similar losses from cultivated lands and degraded pasture lands in the sandy plains for the study year 1985. Interestingly, lands with optimum stand of vegetation experienced very little erosion. Drift sands whether in form of barchans or sheet are unstable and therefore a protection in form of micro-wind barriers is a necessity before establishment of a silvipasture system.

The sandy soils often contain only half to one-third of nutrient reserves compared to loams and fine textured soils. These are also very low in humus (Dhir *et al.*, 1991). However, despite this, the picture in term of available form of various major and micro nutrient elements, except nitrogen is satisfactory (Table 1). The soils are able to support a healthy perennial vegetation cover such as permitted by the agro-climatic condition of arid zone without resort to costly fertilizer inputs.

Table 1.Organic carbon and available phosphorus and potassium (mean values) in soils

Soil series	Organic carbon (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Sandy			
Dunes	0.05	13.8	142.
Chirai normal	0.11	11.6	180
Chirai hummocky	0.09	14.4	166
Kolu	0.09	17.3	190
Kumprawas	0.14	21.0	195
Molasar	0.12	16.6	189
pal	0.17	18.4	247
Sandy loam			
Pipar	0.22	19.2	240
Panchroli	0.24	20.4	260
Khatawas	0.20	18.3	247
Clay loam			
Gajsinghpura	0.20	11.0	273
Asop	0.31	11.0	337

A sizeable part of whatever rainfall is received in arid areas comes in form of few wet spells. Because of the above described low water retention capacity, considerable fraction of water percolates to deeper strata. This feature makes the sandy soils, particularly those of the dunes, where permanent vegetation cover is desirable from conservation view point, ideally suited for a silvipasture system. In this situation, the grasses and shrubs utilized the moisture from n upper 2 m strata or so whereas trees make use of the deeply percolated water. Thereby, a full use of the rainwater is ensured for maximization of biomass production as well as enhancement of grazing period. A schematic representation of silvipasture system in relation to quantum of annual rainfall is presented in Fig. 1.

Hardpan Soils: In some situations, the solum is underlain by a cemented lime-nodular strata at depth ranging from 30 to 60 cm. This indurated strata has some permeability to water but acts

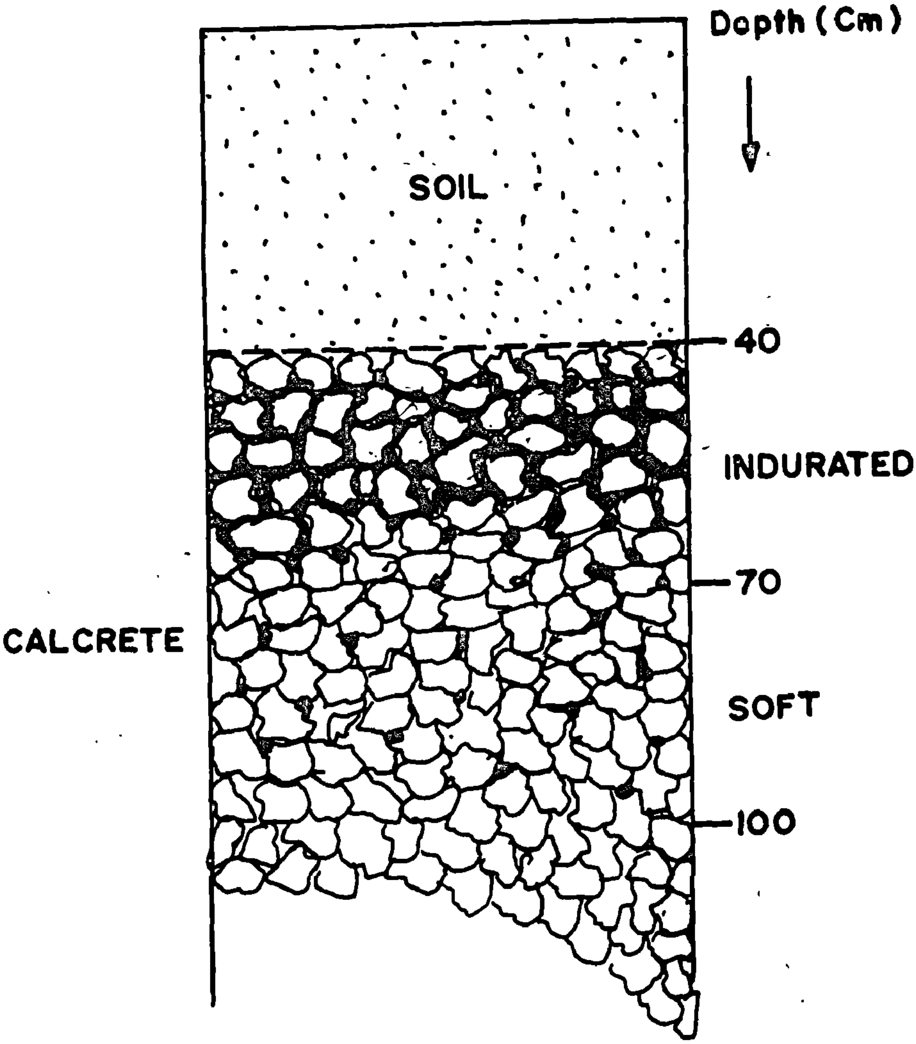

Fig. 1 Hardpan soils with strongly developed calcrete. The calcrete at 40-70 cm depth is highly indurated and needs rupturing for successful establishment and growth of trees.

as a serious barrier to roots of grasses and most of the trees. It is only species like *Zizyphus nummularia* which has tenacious enough roots that penetrate this strata. Therefore the hardpan soils as such permit a very stunted growth of trees compared to deep soils in the vicinity.

It is often seen that the hardpan is most strongly cemented only in upper 20-50 cm (Fig. 2). In such situations breaking of the upper cemented strata can permit establishment and reasonable growth of tree species. Therefore, the treatment needed is mechanical breaking of the hardpan in pits meant for tree plantation.

Rocky, Gravelly Plains and Hills : Such lands occupy nearly 6.3% of arid zone of Rajasthan. The soil cover is thin and patchy. The situation permits raising of short grasses only.

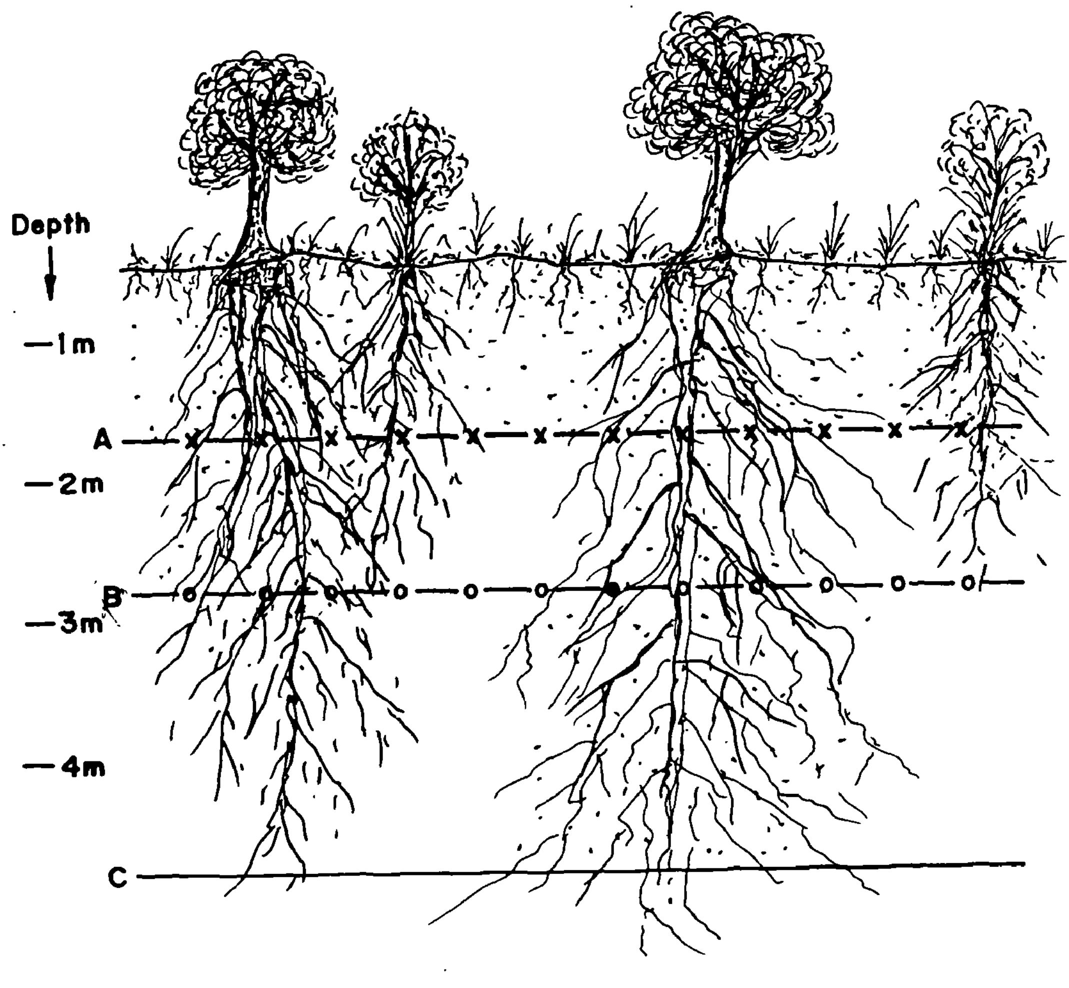

Fig. 2 Schematic sketch of a silvi-pastoral system on duny habitat. It also shows depth of wetting front for a modal rainfall region-A, B and C represent depth of wetting for sub-normal, normal and above normal rainfall years, respectively.

Ahuja (1977) showed that such lands could provide a mean average dry forage yield of 334 to 1335 kg/ha depending on soil depth and rainfall regime in a combination of *Aristida-Eleusine-Cenchrus*. Contour trenching was found advantageous and resulted in 60-70% increase in productivity. The land has serious limitation for trees. It is only hardy species like *Acacia senegal* which are able to survive, though growth rate remains sub-normal.

Saline Soils : Soil salinity is a problem in most arid tracts. In Rajasthan arid tract there are 0.23 Mha of such lands. The soils are often loam to clay loam and have mean profile ECe of 15 to 80 dSm^{-1}. Such lands are devoid of a significant vegetation cover. The tolerant species like *Sporobolus sp* form some cover in rainy season when the salts concentration gets diluted. Biomass production is only 50-250 kg ha^{-1} depending on severity of salinity. *Salvadora sp,* *Capparis* and *Prosopis juliflora* are some of the trees and bushes found in moderately saline situation.

Because of various factors, leaching of salts is not feasible. However, some improvement is possible through manipulation of land surface. Ahuja and Bhimaya (1966) found that digging of trenches was helpful in growth of grass. Further, creation of 0.75 to 1 m high mounds ridge-cum-furrow were found useful in establishment and growth of trees like *Acacia nilotica, A. tortilis, Tamarix, Salvadora* and *P. juliflora*.

Semi-arid Zone Soils Poor Landuse Capability

Lands suffering from severe soil depth limitation, gully erosion and salinity are amenable to silvipasture landuse. However, here the texture of soils have a vast range i.e., from dark coloured, silty clays over basalt and shales to gravelly loamy sand over granite, sandstone and some gneisses.

Shallow Soils in Basaltic Zone : These occur on mesas and plateaux of varying height and on side slopes. The soil is often gravelly clay and dark coloured but the thickness of solum is 30 cm only. Besides, there are frequent rock exposures. However, in many situations, the thin soil is underlain by a thick weathering zone, which is fine textured and pervious to roots and water. Such lands permit a very productive silvipasture system.

Amongst the trees, *Albizia lebbeck, Acacia tortilis, Dichrostachys* sp., *Leucaena* sp. and *Pongamia* sp. are more suitable. Results of an experiment are given in Table 2. Continuation of this work has since shown that over a period of seven years the grazable biomass production average 3.56 to 4.45 t h^{-1}, which was about the same as obtained from control without tree component.

Pruning of tree provided 200 to 425 kg ha^{-1} of dry leaf and 720 to 890 kg ha^{-1} of fuel wood. *Hardwickia binata* is another promising species. The silvipastoral system also brought about considerable improvement in soil fertility compared to grass cover alone (Table, 3). Staggered trenching and contour bunding have been found highly advantageous.

Red Gravelly Shallow Soils : These soils have a widespread occurrence in peninsular India. Though the solum is thin, it is underlain by a weathering zone. Thus the situation permit establishment and maintenance of a good stand of trees alongwith the grass cover as stated in case of black soils above.

Salt Affected Soils : There are nearly 8 M ha of salt affected and waterlogged soils essentially in arid and semi-arid zones. Most of these are alkali or sodic with pH 1:2 value of 8.5 to 10.5. The surface 50 cm shows maximum deterioration of soil properties and it also has higher concentration of dissolved soils.

Though reclamation of these lands using gypsum, sometimes pyrites, as an amendment, has been practised for several decades with commendable results, in situation of non-availability of good quality irrigation waters, or resource constraints or community lands, adoption of this costly technology is not a feasible proposition. In these cases, a productive silvipastoral system

Table 2. Dry leaf fodder and fuel yield of MPTS pruned at different height from ground level and dry forage yield of natural grasses and introduced species on medium black soils

MPTS	Dry Yield From MPTs (kg/ tree)				Dry Forage Yield (t/ha)
	Pruning upto 50% height		Pruning upto to 75% height		Total
	Fuel	Fodder	Fuel	Fodder	
A. indica	0.40	0.14	0.42	0.13	2.50
A. amara	1.41	0.15	0.42	0.07	2.66
A. lebbeck	0.10	0.02	0.08	0.03	2.32
A. tortilis	3.04	0.36	1.34	0.18	2.52
A. pendula	-	-	-	-	2.55
C. pentandra	-	-	-	-	2.15
D. strictus	0.30	0.42	0.26	0.19	2.42
D. cinerea	2.65	0.63	2.19	0.24	2.69
P. pinnata	0.04	0.05	0.10	0.11	2.73
L. leucocephala	0.18	0.03	0.35	0.05	3.00
T. belerica	-	-	-	-	2.52
Z. mauritiana	0.57	0.22	0.31	0.02	1.92

can be established. Studies at CSSRI have shown that *Casuarina equisetifolia, Acacia nilotica* and of course, *P. juliflora* can be established. The grass species *Leptochloa flusica* was found to perform well on these land and gave a yield of 47 t ha^{-1} in 15 cuttings spread over a period of 50 months (Singh *et al.* 1989).

Alkali soils have adverse conditions for early establishment of trees. There a series of approaches have been attempted to create a favourable niche by spot treatment of land. Several

Table 3.Soil physico-chemical properties under silvi-pasture and open grasslands after seven years

Silvipasture	pH	EC mmhos	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Field capacity	Dry forage yield (t/ha)
Leucaena leucocephala	7.2	0.18	0.98	237	16.6	15.6	5.28
Acacia nilotica	7.5	0.22	0.71	216	15.6	15.2	4.47
Albizia lebbeck	7.6	0.28	0.68	208	15.0	14.8	5.63
Albizia procera	7.6	0.30	0.62	197	14.2	14.7	4.21
Open grassland	7.7	0.28	0.60	178	13.0	14.3	5.95

Source: Hazra (1990).

Table 4.Effect of treatments and planting techniques on survival, height, DSH and DBH of mesquite 24 months after planting

Treatment	Survival (%)	Height (cm)	DSH (mm)	DBH (mm)
Soil				
With grass	92	294	38.6	13.1
Without grass	92	370	48.0	18.3
C.D. (P=0.05)	ns	62	6.9	4.9
Filling mixture				
Original soil	63	153	18.0	5.8
Gypsum	88	323	38.8	13.9
Gypsum + rice husk	100	394	55.0	21.1
Gypsum + FYM	100	412	54.0	18.9
C. D .(P = 0.05)	24	67	16.8	7.9
Planting method				
Pit	100	323	47.5	17.2
Auger	100	358	46.5	17.3
Trench	88	349	38.8	13.9
C . D . (P = 0.05)	ns	ns	7.0	ns

methods namely pit, auger hole, ridge plantation and trench plantation have been attempted. The results of one such study are presented in Table 4. It is seen that addition of gypsum and organic matter brought about significant improvement in survival percentage and growth of trees.

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DISTRIBUTION AND MAPPING OF SALT AFFECTED SOILS UNDER DIFFERENT ARID ECOSYSTEMS FOR THEIR UTILIZATION OF GRAZING RESOURCES

Nepal Singh

Introduction

Accumulation of salts in the soil profile and weathering zone/substrata or retention of salts transported from outside the area are characteristic features of arid environments. However, the magnitude and composition of the salts vary greatly, depending upon the nature of source rock, geomorphic evolution of the area, mechanical composition of surface sediments and drainage. So far as the vast area of arid Rajasthan and Gujarat is concerned, these factors are far from constant and thus we have great irregularity in the distribution of salt affected soils. Though local and regional saline depressions or playas are sporadically dotted all over this arid region, there are three large tracts, two in arid Rajasthan and one in Kachchh area, where soil salinity assumes an unusual proportion and poses a real regional problems (Dhir and Singh, 1979; Kolarkar *et al.*, (1980). The first one is in the extreme north-west in the flood plain of old Ghaggar system, where about 0.2 million ha area is occupied by salt affected soils (Dhir *et al.*, 1978). Second is located in the south and south-west of Jodhpur, forming the Bilara-Pali-Sanchor and Balotra triangle in Jodhpur, Pali, Barmer and Jalor districts where nearly 7000 km^2 area is occupied by salt affected soils (Dhir *et al.*, 1979;, Kolarkar *et al.*, 1980 Singh *et al.*, 1992 and Singh and Kolarkar 1995). The third one is located in Kachchh and Saurashtra region in Gujarat state where 31000 km^2 is occupied by salt affected soils (Singh and Kolarkar 1990). Apart from these natural salt affected soils, a large area also has secondary salinisation problem due to use of saline and high RSC water for irrigation. These secondary salinised soils also behave like natural salt affected soils and remain out of cultivation for a number of years (Dhir *et al.*, 1975., Singh *et al.*, 1994). There are some areas under canal irrigation, particularly in Sardar-Samand (Pali district) and Bilara (Jodhpur district) where secondary salinisation took place due to seepage from canal and high amount of water used for irrigation. The ground water table has risen upto 1-2 metre and due to capillary action the salts are deposited on surface even in cultivated lands. Some of the cultivated lands have gone out of cultivation (Kolarkar *et al.*, 1980). The present discussion deals with the occurrence of salt affected soils, their characteristics under different ecosystem of arid region and suggest some amelioration measures for planning and development of these lands.

Environment

The present discussion is essentially related to the arid western Rajasthan and adjoining Kachchh region of Gujarat state lying in the 200 to 450 mm rainfall zone. About 90 per cent rain is received during June to September and. the average minimum and maximum temperature is around 19°C and 34°C, respectively. Temperature reaches as high as 48°C in the month of May and June and goes down to 8°C in winter. The evapotranspiration rate is 3102 mm per year and humidity varies from 60 to 80%. Topographically, the region is characterised by vast alluvial plains, pediments, buried pediments with small dunes and hills.

Identification and Mapping

Natural and man-induced salt affected soils can be easily identified, separated and mapped from aerial photos, Landsat black and white images and TM FCC due to the distinct variations in their shape, size, pattern tonal, spatial and spectral characteristics. The genetic and physico chemical characteristics also enabled to separate these salt affected soils from each other.

Natural salt affected soils are, by and large associated with saline depressions and low lying older alluvial plains and exhibit whitish yellow to whitish grey tone on Landsat TM FCCs. They are of semi-circular to circular and elongated shape. Most of them have low density of natural vegetation. These soils have grass cover in pockets like *Dichanthium annulatum, Sporobolus marginatus, Eleusine compressa, Chloris virgata* and *Cyprus rotundus,* and are dominantly sandy loam to loam and clay loam in texture. The lands have high density of *Prosopis juliflora, Capparis decidua, Ziziphus nummularia* and *Salvadora persica* in random specks of whitish grey and dull red tone on FCCs in the similar textural class soils. These salt affected soils in association with rocky/gravelly and buried pediments occur in pockets and appear in dull white to whitish grey tone with specks of red on Landsat TM FCC. The salt affected soils associated with younger alluvial plains and river beds could be easily and quickly identified and mapped due to their location, pattern and presence of high density of *Saccharum bengalensis, Acacia arabica, Prosopis juliflora* in pockets. They are of elongated shape and constitute highly saline, loam to clay loam soils with high moisture regime. Due to surface crust, mottled texture and high spectral reflectance these exhibit white to whitish grey tone with dark grey specks on Landsat MSS band 5 black and white image. Some river beds and saline Rann exhibit in similar milky white tone because sand and high salt crust surfaces appear in similar tonal reflectance without any natural vegetation cover. Some of the saline soils have spotted *Prosopis juliflora* vegetation which appear in red.

Man-induced salt affected soils or secondary salinised salt affected soils associated with canal and saline-sodic wells water irrigation in the older alluvial plains appear in whitish to dull red tone on Landsat TM (FCC). The whitish tone of these lands is due to high spectral reflectance from surface salt crust and dull red tone is caused by chlorophyll content of standing crops in field. They occur in continuous patches and in elongated slope under different physiographic setting. These wastelands appear in white to dark grey tone and mottled texture on Landsat band 5 black and white image (Singh *et al.* 1992).

Genesis And Morphology

Genesis of Salt Affected Soils : During the Pleistocene period alternate dry and wet phases have played a significant role in the formation of saline depression (*rann*), saline alluvial plains and associated natural salt affected soils. Calcium sulphate being less soluble was deposited in the upstream of drainage basin and created saline alluvial plains, whereas more soluble sodium chloride was carried downstream to the confluence of the rivers resulting in the formation of saline depressions. Due to capillary action, evaporation and upward movements of salts, the salt affected soils came into being (Ghosh, 1964, Ghosh and Singh, 1968, Taylor, 1955). The whole profile of alluvial sediments is highly charged with soluble salts and maximum concentration is found at surface through capillary action and high temperature during the period of May and June (Dhir and Singh, 1979).

Such saline-alkali soils associated with rocky/gravelly and buried pediments resulted due to the deposition of salt from weathered rock material. The soluble salts released from the weathered material were transported and deposited in nearby areas through the surface runoff (Kolarkar *et al.*, 1980).

Morphological and Physico-chemical Characteristics of Salt Affected Soils

The distribution of various categories of salt affected soils under different ecosystem were identified and mapped in arid Rajasthan from Landsat TM FCC, in conjunction with ground truth (Table 1 and Fig. 1).

(a) *Medium to fine textured older alluvial plains salt affected soils*: The dominant morphological characteristics of medium to fine textured older alluvial plains soils are almost level slope, surface salt crust and highly saline through out the profile. These are moderately deep to deep, light greyish brown to dark greyish brown (10 YR 6/1 to 10 YR 4/2) sandy loam to loam and clay loam, medium moderate sub-angular to angular structure, strongly calcareous, underlain by moderately hard to very hard substrata of lime concretion or weathered rock. These soil profiles have subsurface drainage problem due to hard underneath substrata. The dominant tree vegetation is *Prosopis juliflora* and *Capparis decidua* shrub. *Eleusine compressa* and *Dichanthium annulatum* are the grasses in patches.

The dominant soluble salt in saturation extract of these soils are sodium-chloride, followed by calcium and magnesium-sulphate. The ECe value ranges from 1.32 to 182.0 dS m^{-1} and pH from 8.1 to 8.8. The SAR and ESP values range from 9 to 1442 and 9 to 86, respectively (Table 2).

(b) *Light to medium textured soils of younger alluvial plains*: The morphological characteristics of salt affected soils of younger alluvial plains are nearly level to gentle slope with superficial sediments. These are deep, loamy sand to sandy loam and loam, moderately hard, brown to yellowish brown (10 YR 5/3 to 10 YR 5/4), medium sub angular blocky structure, strongly calcareous, underlain by thick zone of gravel/pebbles of riverine nature. The associated tree species are *Prosopis juliflora* and *Acacia arabica* and shrub *Tamarix* spp. The common grass of these soils is *Saccharum bengalensis* in patches. The whole profile is saturated with salt and flooded water during the rainy season.

The physico-chemical characteristics of saturation extract revealed that the salinity in the profile is sodium-chloride followed by calcium and magnesium-carbonate. The ECe value of saturation extract ranges from 2.5 to 30.0 dS/m and pH (1:2) 8.3 to 8.8. The SAR and ESP value ranges from 12 to 45 and 22 to 30 respectively (Table 2).

Table 1:Distribution of saline/alkali soils under different land forms

Categories	Area km^2		
	Jodhpur district	Sojat-Pali Rohit tract	Pali-Jalor-Balotra tract
A. Natural saline/alkali soils			
(a) Medium to fine textured soil of older alluvial plains	160	1213	1106
(b) Medium to fine textured soil of younger alluvial plains	86	200	300
(c) Fine textured saline depr- ession (Rann)	31	15	117
B. Relict-salinity/alkalinity	30	465	531
C. Man-induced secondary sali-nised saline/alkali soil			
(a) Medium to fine textured, canal irrigated high water table area of older alluvial plains	110	270	-
(b) Medium to fine textured soils of older alluvial plains irrigated by saline and RSC well waters	68	460	200
(c) Coarse to medium and fine textured soils of younger alluvial plain irrigated with saline and RSC well waters.	75	160	492

(c) *Natural depression (Rann)*: The morphological characteristics of saline depression (Rann) soils are characterised by well levelled, bowel shape, high salt crust at surface and remain under water for 3-4 months. These are deep, clay loam to silty clay loam and silty clay, light greyish brown to pale brown (10 YR 6/1 to 10 YR 6/3), hard on drying, angular structure, strongly calcareous, underlain by a thick zone of lime coated pebbles or hard rocks. These are completely ill-drained both at surface and internal drainage. The maximum salt concentration is at surface and in subsoil it decreases with depth. These are completely barren and *Prosopis juliflora* is found only near the periphery of the rann.

Saturation extract analysis of these soils revealed that the salinity is mostly sodium-chloride type and their first two layers have sizeable content of calcium and magnesium. There

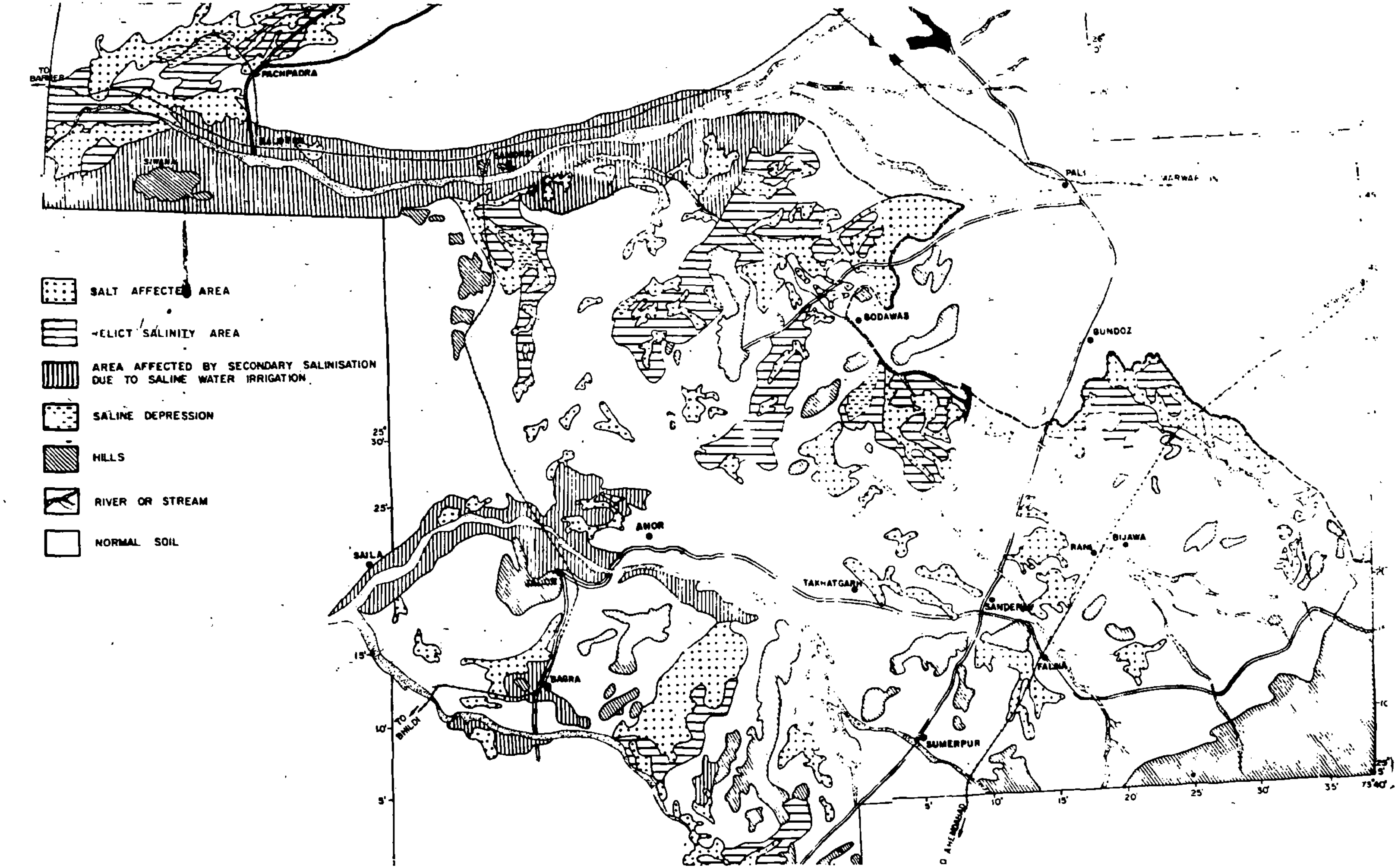


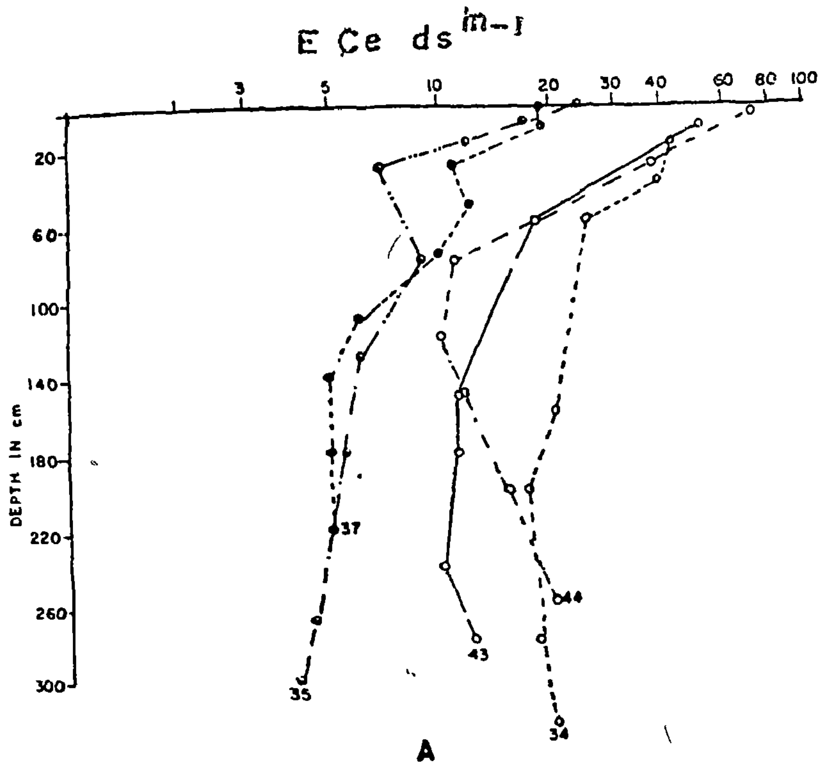
Fig. 1 Degraded salt affected areas of south - west tract of arid Rajasthan

Table 2. Physico-chemical characteristics of saline-alkali wastelands in w. Rajasthan

					Cation met $^{-1}$				Anion met $^{-1}$				
Type of wasteland and location	Soil depth (cm)	Organic carbon (%)	pH (1:2)	ECe (dSm-1)	Na	K	Ca	Mg	Cl	HCO3	SO4	SAR	ESP
A. Natural saline/alkali wasteland associated with													
Medium textured	0-10	0.25	8.6	1.32	6.5	0.10	5.2	3.7	7.5	8.02	0.12	3.1	9.3
flat older alluvial	10-30	0.38	8.7	2.61	16.3	0.13	3.0	6.0	15.0	10.8	0.04	7.7	20.6
plain	30-100	0.12	8.8	5.81	47.8	0.15	5.2	2.8	15.0	9.0	1.47	23.9	24.8
	100-120	0.12	8.2	8.22	69.5	0.50	5.0	7.0	62.5	19.0	0.24	28.4	25.9
Medium to fine	0-2	0.39	7.7	152.4	1391.0	43.5	87.5	32.5	1260.0	4.0	290.0	179	49
textured flat	2-12	0.47	8.0	99.8	913.0	37.5	36.5	31.5	7000.0	4.5	390.5	156	47
older alluvial	12-28	0.32	8.1	63.4	606.0	27.0	27.0	11.0	330.0	5.0	336.5	139	45
plain	28-70	0.21	8.7	18.1	146.0	10.0	3.0	1.5	90.0	6.0	64.5	97	39
	70-120	0.21	8.5	6.0	48.0	9.0	2.0	0.5	40.0	5.0	14.3	43	29
Younger alluvial	0-30	0.34	8.3	2.1	17.4	0.2	2.2	2.0	10.0	9.0	2.7	12	22
plains/river bed	30-60	0.28	8.7	4.7	47.7	0.2	2.2	2.0	35.0	7.0	4.0	29	26
	60-90	0.29	8.6	13.9	121.7	0.2	10.5	5.0	125.0	5.0	7.7	44	29
	90-120	0.25	8.8	27.3	221.7	0.3	32.0	16.0	250.0	10.0	10.0	45	30
Rocky/gravelly and	0-5	0.12	8.1	59.8	5888.2	20.5	27.2	8.2	4000.0	886.0	1475.0	1442	86
buried pediments	5-15	0.07	8.4	19.8	1883.6	6.6	34.5	16.0	1500.0	378.0	184.2	394	65
	15-30	0.06	8.8	9.4	839.1	3.3	5.1	21.1	750.0	111.5	154.6	40	29
Saline depression	0-20	0.18	8.3	166.1	4391.0	44.8	28.3	569.0	4500.0	45.6	428.6	283	81
(Kaparda)	20-55	0.16	9.2	68.6	652.1	1.08	14.6	30.2	600.0	5.0	23.5	137	67
	55-110	0.12	9.2	23.4	221.7	0.8	6.7	7.7	220.0	3.2	13.5	102	52
	110-140	0.08	9.2	27.6	260.8	0.9	9.6	8.0	260.0	2.8	16.7	67	66
	140-190	0.03	9.8	33.7	308.0	3.3	11.9	15.0	310.0	2.6	29.6	84	55
B. Man-Induced saline/alkali wastelands associated with													
Medium to fine	0-15	0.34	9.0	89.4	869.5	8.9	56.0	38.5	865.0	4.2	103.7	126	65
textured flat	15-25	0.22	8.6	168.4	1169.5	14.7	44.0	37.5	1580.0	3.7	2327.0	261	79
older alluvial	25-40	0.11	8.9	39.1	186.9	3.0	4.0	17.0	175.0	3.5	31.5	59	45
plain	40-65	0.06	8.9	16.0	160.8	3.3	6.0	4.0	140.0	5.0	28.1	80	51
	65-110	0.05	8.7	68.2	534.7	6.4	17.0	32.0	533.0	3.0	153.1	108	61
Younger alluvial	0-24	0.10	9.1	63.2	17.3	0.5	43.6	1.6	11.0	7.5	1.4	8	20
plain	24-45	0.28	9.7	24.9	21.2	0.3	1.5	0.9	8.0	14.5	1.4	19	24
	45-65	0.21	9.8	31.2	29.3	0.2	0.9	0.7	8.0	17.5	5.7	14	25
	65-75	0.11	9.8	34.4	28.3	0.1	4.7	1.0	10.0	18.5	5.6	17	23
Rocky/gravelly	0-15	0.11	8.0	129.6	1243.4	17.3	44.0	51.0	1230.0	2.5	123.2	180	50
and buried	15-25	0.09	8.0	25.5	243.4	3.4	4.5	8.0	195.0	2.5	62.8	97	39
pediment	25-40	0.05	7.9	69.0	695.6	6.9	13.5	18.5	605.0	3.0	226.5	194	49

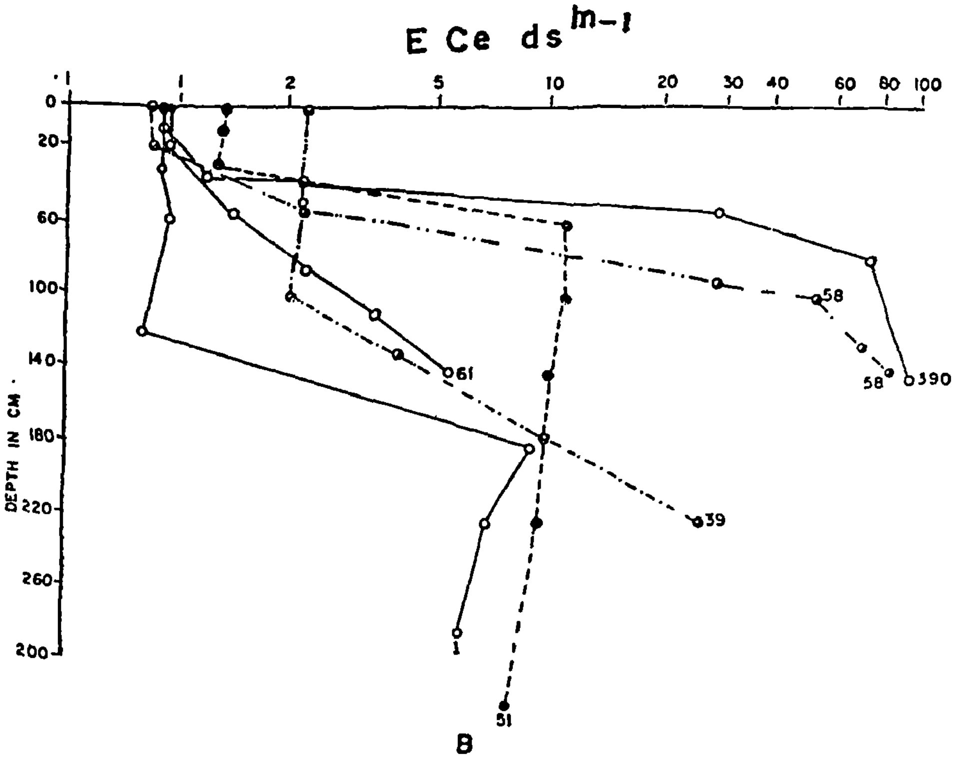
are few cases of sodium-calcium-chloride or sodium-chloride-sulphate type. The ECe value indicate that the profile have upward salts movement and the value ranges from ESP 84 to 283 and 52 to 81 respectively (Table 2). The distribution of salts in the natural salt affected soil profile presented in the Fig. 2.a.

Relict Salinity : The morphological characteristics of relict salinity soils are level surface and free of salt but their sub soil and sub strata have sizeable amount of salt. These soils have cultivation in pockets and associated with natural salt affected soils. These moderately deep to



A

Fig. 2A. Salt distribution in soil profiles of natural salt-affected soils



B

Fig. 2B. Salt distribution in soil profiles of relict soil salinity deep, sandy loam to loam and clay loam, brown to yellowish brown (10 YR 5/3 to 10 YR 5/4), granular surface and angular block structure in sub soils, moderate to strongly calcareous, underlain by lime coated gravelly substrata or weathered rock coated with lime These soils have good density of vegetation because of non-saline surfaces and cultivated crop in pockets

The physico-chemical characteristics of saturation extract indicate that the salinity is sodium-chloride followed by calcium-magnesium sulphate type and ECe value ranges from 2 0 to 10 0 dm and pH 7 8 to 9 5 The SAR value lies in between 2 0 to 32 (Table 2) The distribution of salts in the soil profile is presented in Fig 2 b

Man-induced Salt Affected Soils (Secondary Salinisation)

(a) *Secondary salinisation under canal irrigation due to high water table* About forty years back three major reservoirs namely Sardar Samand, Jaswant Sagar and Hemawas were built to develop surface irrigation The irrigation water is brackish with EC 1 5 to 3 5 dS/m and the command area soils have developed serious salinity problem During the rainy season, the ground water table reaches up to 1 to 2 metre which is saline in nature In summer through evaporation, high salt crust is formed at surface and entire area looks like salt affected lands A sizeable area is out of cultivation due to high salinity in the profile and *Prosopis juliflora* have grown on these barren lands The problem is clearly due to build up of permanent high water table and requires the internal drainage system Morphologically, these soils are deep, sandy loam to loam, and clay loam, dark greyish brown to dark yellowish brown (10 YR 4/2 to 4/4), sub-angular to columnar structure, strongly calcareous underlain by a thick zone of lime concretion or lime coated gravel/pebbles

The saturation extract analysis of salt affected soil indicate that the salinity is sodium(-) chloride, followed by calcium-magnesium-chloride-sulphate type The trend of salt movement is upward and maximum salt concentration at surface and in subsoil decreases with depth The ECe value ranges from 10 to 43 dS/m and pH between 7 8 to 8 1 The SAR value ranges from 30 to 140 and ESP 40 to 85 0 (Table 2)

(b) *Secondary salinisation due to use of saline and high RSC water for irrigation* These soils developed due to irrigation with saline and high RSC well water in the region About 80% wells have problematic water and on irrigation accumulate the salts in the profile Morphologically these are deep, loamy sand to sandy loam, loam and at places clay loam, brown to yellowish brown (10 YR 5/3 to 40 YR 5/4), slight to moderately calcareous, medium moderate sub-angular blocky, underlain by varied substrata like lime concretion, gravel/pebbles and weathered rock

The saturation extract analysis shows that the salinity is sodium-chloride, followed by calcium-magnesium-chloride-sulphate type unlike the natural salt affected soils The trend of salts in the profile is upward but not in continuity The ECe value ranges from 7 0 to 16 dS/m and pH from 8 0 to 8 5 The SAR value ranges from 20 to 35

The high RSC well water irrigated soils have low concentration of salts in profile but they show high pH values a manifestation of sodicity These soils are hard and compact and difficult to plough on drying and puddled on wetting The soil profiles have large variability in salt concentration. Morphologically these are deep loamy sand to sandy loam, brown to yellowish brown (10 YR 5/3 to 10 YR 5/4), moderately to strongly calcareous, weak to medium sub-angular blocky, underlain by gravel/pebble substrata along the drainage courses.

The saturation extract analysis of these soils revealed that salinity is sodium-chloride-carbonate type and calcium and magnesium are in a very small amount. The ECe value ranges from 2 to 5 dS/m and pH from 8.8 to 9.8. The crop fails due to high sodicity and infiltration rate is reduced.

Salt Affected Soils of Kachchh District : The salinity/alkalinity problem is more widely spread in Kachchh district than in arid Rajasthan. Nearly 70% area is occupied by these

Table 3. Salt affected soils in Kachchh district under different ecosystem

	Categories	Area		pH	ECe
		km^2	%	(1:2)	dSm^{-1}
1.	Saline eroded land along channels	784	1.72	8.1-8.5	23-92
2.	Fine textured flat deltaic plains	844	1.85	7.7-8.1	32-84
3.	Medium to fine textured coastal alluvium	1805	3.96	7.8-8.2	12.57
4.	Highly eroded gullied lands	536	1.18	7.6-8.0	4-39
5.	Banni marine alluvial flat	2353	5.16	8.0-9.5	0.93-129
6.	Coarse to medium textured alluvial plains	303	0.66	8.0-8.5	15-49
7.	Tidal affected mud flat	3392	7.44	7.8-8.4	74-96
8.	Little and great Rann of Kachchh	17156	37.61	8.0-8.6	60-180

soils under different physiographic relief. The cause of salt accumulation is aridity (200 mm rainfall), followed by landscape evolution and fine grain parent material, in conjunction with drainage pattern.

The area affected by the salinity/alkalinity under different ecosystems have been mapped with the help of TM FCC band 5 black and white images in conjunction with ground truth. The extent of salinity under different ecosystem is given Table 3.

The salt affected soils of Kachchh district are highly variable in texture, colour and parent material and physiographic relief. The district has large variability in parent material like sandstone ferrugenous rock, limestone and basalt and these soils have developed from the alluvial sediment of these rocks. Later on, the lime accumulated and coated the rock pieces or lime concretion zone developed. Because of hard substrata and surface physiographic relief these soils have drainage problem which have resulted in the salinity/alkalinity in the soils.

Morphologically, soils are moderately deep to very deep, loam to clay loam, silty clay loam, silty clay, highly variable in colour because of parent material variability. The dominant colour is greyish brown to dark greyish brown and reddish brown to dark reddish brown, olive grey and brown. These are calcareous and have lime concretion, lime coated gravel/pebbles or weathered rocks in substratum. These are completely barren except deltaic and Banni uplands. The dominant tree vegetation is *Prosopis juliflora* and grasses *Dichanthium annulatum* and *Sporobolus marginatus*.

The saturation extract analysis of these soils indicate that the salinity is sodium-chloride type, followed by calcium-magnesium-sulphate. The ECe value is highly variable and ranges from 32 to 294 dS/m and pH 7.6 to 9.5. (Table. 4). The surface has high salt crust with upward movements (Singh and Kolarkar, 1990).

Amelioration of Saline/alkali Soils

Natural Saline/Alkali Soils : Dominantly natural salt affected soils have a very severe limitation in arid region of Rajasthan and Kachchh, like excessive soluble salt in the solum, depth limitation, water erosion, poor drainage and devoid of natural vegetation, except very few plants of *Prosopis juliflora, Capparis decidua, Ziziphus nummularia* and *Salvadora persica*. The most important limiting factor in the arid region is non-availability of sufficient good quality water for reclamation of such salt affected soil through leaching.

Based on resource potential, limitation and physio-chemical characteristic of these salt affected soils, the suitable measures like field bunding, trenching, levelling, deep ploughing and adding of organic manure to improve the physical conditions of soil and to leach down the soluble salts through the ponding of rain water are suggested for the amelioration of these natural salt affected soils. Most of the salt affected soils of the region are barren or having vegetation in pockets. Their substrata is substantially hard and compact. These lands could not be brought under cultivation due to severe land limitation. A good pasture could be developed on these lands where slight to moderate salinity (ECe below 5-6 dS/m) exist. *Eleusine compressa, Chloris virgata and Cyperus rotundus* grasses under protection could be established. The trees like *Prosopis juliflora, Salvadora persica* and shrub like *Capparis decidua, Zizyphus nummularia* could be established along with grasses on large scale. The saline Rann after extracting the salt could be used for pasture and shrub like *Sporobolus marginatus* and *Haloxylon salicornicum* could be planted (Singh *et al.*, 1992).

Secondary Salinised Salt Affected Soils : The secondary salinised or man-induced salinity soils exist largely under older alluvial and younger alluvial plains. Earlier these were the good cultivated lands but use of saline, high RSC well water and canal water for irrigation have converted them into saline/alkali soils. The canal water irrigated soil could be reclaimed through the improved internal drainage. The lowering of ground water table will help to check the salts movement. The saline well water irrigation is accumulating the salt in the upper part of profile. These soils could be reclaimed if physical condition of soil could be improved through the adding of organic manure, green manure, deep ploughing and field bunding before

Table 4. Composition of salt in saturation extract of salt affected soils under various physiography in kachchh district (Gujrat)

Pysiographic units	Depth. (cm)	Soil texture	pH (1:2)	ECe dSm^{-1}	Cation meL^{-1}				Anion me L^{-1}			
					Na	K	Ca	Mg	Cl	HCO_3	SO_4	SAR
Highly eroded land along streams	0-8	Cl	7.6	286.7	1878.0	0.2	934.0	438.0	3165.0	6.0	79.0	72
	8-22	Sicl	7.4	164.2	521.0	1.3	710.0	362.0	1500.0	3.0	90.0	23
	22-48	Hcl	7.8	61.4	322.0	0.5	134.0	55.0	460.0	2.0	49.0	33
	48-90	Gcl	8.1	17.8	139.0	0.2	19.0	20.0	160.0	3.0	15.2	31
	90-110	Gl	8.6	19.2	154.0	0.4	17.0	29.0	170.0	3.0	27.0	32
Flat deltaic plains	0-10	Sicl	7.9	79.3	591.0	3.4	89.0	71.0	620.0	3.0	131.4	66
	10-28	Sic	7.8	104.3	757.0	4.7	115.0	149.0	890.0	2.0	133.7	65
	28-50	Sic	7.8	95.6	696.0	4.7	90.0	110.0	720.0	2.0	178.7	69
	50-85	C	8.0	46.4	396.0	2.8	52.0	46.0	380.0	2.0	114.8	56
	85-110	Sicl	8.4	19.5	164.0	1.3	23.0	17.0	165.0	3.0	42.3	37
Coastal alluvium	0-15	L	7.8	22.3	61.0	2.0	76.0	87.0	188.0	2.0	36.0	8
	15-55	Cl	8.0	66.0	463.0	2.0	122.0	101.0	615.0	2.0	71.0	43
	55-70	G sicl	8.1	97.6	561.0	1.8	136.0	238.0	897.0	2.0	39.0	41
	70-100	G sicl	8.0	65.2	430.0	1.8	92.0	120.0	615.0	2.0	26.2	41
	100-120	G sicl	8.2	45.8	320.0	1.2	76.0	96.0	445.0	2.0	46.0	34
Flat older alluvial plain	0-10	Cl	7.7	146.9	1183.0	1.2	160.0	104.0	1379.0	3.4	65.0	102
	10-40	Sicl	7.8	173.7	1061.0	0.9	358.0	342.0	1646.2	3.7	112.0	56
	40-80	Gl	7.9	75.4	531.0	1.2	92.0	88.0	580.0	3.8	128.4	56
	80-110	Sicl	8.1	45.3	400.0	1.0	43.0	49.0	450.0	2.6	40.4	59
	110-140	Clay	8.1	48.2	413.0	0.9	41.0	43.0	440.0	3.0	54.9	63

Lateritic reddish eroded land	0-5	Sicl	7.6	198.8	1739.0	0.6	184.0	134.0	1910.0	2.3	145.3	138
	5-15	Sic	7.6	155.2	1061.0	0.5	234.0	262.0	1396.0	1.3	160.2	67
	15-50	Hc	7.7	99.4	626.0	0.5	162.0	188.0	820.0	1.4	155.1	47
	50-80	Clay	7.6	82.9	570.0	0.5	118.0	122.0	655.0	1.3	154.2	52
Water saturated mud flat	0-15	Sicl	7.8	184.8	1373.0	20.7	42.0	438.0	1458.0	3.4	412.3	88
	15-30	Sicl	8.2	287.6	2125.0	29.0	70.0	460.0	2255.0	2.7	426.3	130
	30-50	Sic	8.4	216.9	1739.0	19.4	78.0	326.0	1985.0	3.0	194.4	122
	50-80	Hc	8.3	218.9	1843.0	17.6	78.0	307.0	1770.0	3.4	472.2	132
	80-160	Clay	8.3	221.6	2228.0	18.6	72.0	368.0	2445.0	2.3	239.3	140
Dry rann	0-5	Sicl	7.8	290.3	2052.0	2.0	160.0	124.0	2160.0	2.8	175.0	172
	5-20	Sic	7.4	275.4	2782.0	2.6	448.0	644.0	3530.0	2.6	344.0	120
	20-60	Sic	7.7	141.8	1078.0	3.2	188.0	184.0	1190.0	2.5	260.7	109
	60-110	C	7.7	146.0	1112.0	3.8	188.0	198.0	1040.0	3.6	458.2	86
	110-130	Sicl	7.7	156.0	1200.0	3.4	164.0	212.0	1380.0	3.2	216.2	85
	130-160	Sicl	7.6	144.0	1126.0	2.2	140.0	200.0	1280.0	3.2	185.0	86

Abbrivation :- Cl = Clay loam, Sicl = Silty clay loam, Hcl= Heavy clay loam, Gcl= gravelly clay loam ,Gl= gravelly loam, L= loam,
Gsil = gravelly silt loam, C= clay, Sic= silty clay,

rain to arrest the rainwater. The rain water will leach down the salts to the lower part of profile. These lands should be kept fallow for 3-4 year and Kharchia 65 wheat variety along with 40-80 kg/ha nitrogen will provide the good yield (Dhir *et al.*, 1977).

The use of RSC water well for irrigation have converted the land into sodic soils. The permeability of these soils reduced even in sand to loamy sand soils. These soils could be reclaimed by use of gypsum, depending on gypsum requirements of the soils. The RSC water up to 5 ml can be tolerated in the region (Joshi and Dhir, 1989, Singh *et al.*, 1994, Joshi and Singh, 1985). Above this value the crop yield decreases. It has been suggested 5-6 tonne/ha gypsum is sufficient to reclaim the sodic soils.

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INVENTORY AND STATUS OF FORAGE AND WOODY SPECIES IN DIFFERENT ECOSYSTEMS

Suresh Kumar

Introduction

Amongst three major structural components of an ecosystem, viz. i) the Primary producers, ii) the Consumers and iii) the Detritus, the primary producers or plants in arid and semi-arid regions have not only importance in sustaining the livestock as well as the economy, but also have a much greater role in maintaining ecological equilibrium of these lands. Though dry farming predominates in semi arid region with livestock rearing being a secondary vocation, the arid regions have perpetually livestock based economics. And with increasing grazing pressure for example, of 3.2 ACU/ha instead of 1 ACU/ha in one of the semi-arid areas (Rekib, 1981) and 1-4 ACU/ha instead of 0.2 to 0.5 ACU/ha in arid area (Raheja 1966), the forage and woody species in different habitats are being continuously and increasingly degraded. In order to achieve the twin objective of optimising the forage yield as well as maintaining natural production system in sustained condition, a first hand inventory of these resources is essential. The present paper describes such an inventory and its dynamics in the arid and semi-arid region of India.

The Environment : Amongst various approaches to delimit arid zones, the one based on moisture index:

Im = (Annual water surplus-Annual water need)/Annual water need x 100

of Thornthwaite is most acceptable. The regions having Im = -66.6 or less are classified as arid and those having Im = -33.3 to - 66.6 are semi-arid. Arid regions will therefore have an annual water deficit of two thirds of the potential evapotranspiration (PET) or more (Ramana Rao et al, 1983), while semi-arid regions will have such a deficit ranging from one third to two thirds of the PET. Going by this criteria semi-arid and arid areas in India occupy nearly 9.56 lakh km^2 (30.50%) and 3.18 lakh km^2 (10.16%) area, respectively (Table 1). Different attributes of forage and woody species occurring in this region are discussed below:

Species Composition

Grass covers : Of the five major grass covers identified by Dabadghao and Shankarnarayan (1973) following two have been identified for arid and semi-arid region:

Sehima-Dichanthium Type : This occurs on brown to dark grey to black soils with low soluble salts and poor in lime. The rainfall range is 300 to 2000 mm, with summer temperatures (June) 27-38°C and winter (January) 17-28 °C. This occurs on 17.4 x 10^5 sq. km area mainly in Peninsular India including Central Indian plateau, the Chhotanagpur plateau, the Aravalli ranges, covering 12 states, namely Gujarat, Maharashtra, Madhya Pradesh, Orissa, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala, as well as south-west Bengal, southern Bihar and southern hilly portion of Uttar Pradesh and Rajasthan. Floristically it is comprised of 24 perennial grasses, 129 other herbaceous species of which 56 are legumes. *Sehima* is predominant on gravelly land where its cover could be as high as 87 per cent. *Dichanthium* occupies mainly level land with its cover approaching 80 per cent. The woody perennials

Table 1. Arid and semi arid zones of India

State	Area	
	Lac km	Per cent of total
Semi-arid		
Maharashtra	1.89	19.82
Karnataka	1.39	14.57
Andhra Pradesh	1.38	14.49
Rajasthan	1.21	12.64
Tamil Nadu	0.95	9.95
Gujarat	0.90	9.47
Uttar Pradesh	0.64	6.72
Madhya Pradesh	0.59	6.22
Punjab	0.32	3.32
Haryana	0.27	2.80
Total	9.54	100.0
Arid		
Rajasthan	1.95	61.0
Gujarat	0.64	20.0
Punjab	0.16	5.0
Haryana	0.13	4.0
Andhra Pradesh	0.22	7.0
Karnataka	0.09	3.0
Maharashtra	0.01	0.4
Total	2.98	100.0

include different species of *Ziziphus, Acacia catechu, Mimosa rubicaulis, Anogeissus latifolia, Soymida febrifuga* and sometimes succulents such as *Euphorbia.*

Dichanthium-Cenchrus-Lasiurus Type : This occurs on undifferentiated alluvial soils, grey and brown of desert having high soluble salts. The annual precipitation ranges from 100-750 mm and the mean temperature during summer (June) is high; 42-43 °C with winter temperature touching -1 to 4°C. It occupies 4.36 x 10^5 sq. km area in the different states namely northern portion of Gujarat, Rajasthan (excluding Aravallis), western Uttar Pradesh, Delhi state and Punjab (semi-arid). This type has 11 perennial grasses, 45 other herbaceous species of which 19 are leguminous. The predominant woody perennials of this type are *Prosopis cineraria, Acacia nilotica, Salvadora oleoides, Ziziphus nummularia, Acacia senegal, Calotropis procera* and *Cassia auriculata* which often impart it a look of savanna.

Forest Covers : Besides, woody perennials are also scattered in forests of this area. As most forest stands are degraded these are serving as grazing grounds. Like grass covers, the predominant classes identified by Champion and Seth (1968) in the revised classification of forests are again two, as given below :

1. Tropical dry deciduous Forests (Group 5)

2. Tropical Thorn Forests (Group 6)

These two largely correspond to the two grass cover described above in respect of species composition and spatial extant,, though forest cover distribution is more precise. In the former type, two major classes i.e. Teak (*Tectona grandis*) and non teak are identified. In the Teak forests, *Anogeissus latifolia* and *Terminalia* are major associates. In the non teak bearing forests, the dominant genera are *Anogeissus, Terminalia* alongwith *Diospyros, Boswellia* and *Sterculia*. The most important factor is absence of Dipterocarps i.e. species of *Shorea*. It has three climax formation and a variety of edaphic formations.

Tropical thorn Forests are dominated by a variety of species of *Acacia, Euphorbia, Capparis* and *Prosopis* alongwith many edaphic variants. Thus, it is evident that the composition of woody perennials given by Dabadghao and Shankarnarayan (1973) in two afore cited grass covers broadly matches that of Champion and Seth (1968).

The important top feeds in this zone are *Acacia catechu, A. nilotica, A. leucophloea, Adina cordifolia, Ailanthus excelsa, Albizia lebbeck, A. amara, Anogeissus latifolia, Azadirachta indica, Bauhinia purpurea, Butea monosperma, Cassia siamea, Dalbergia sissoo, Hardwickia binata, Ficus bengalensis, F. religiosa* and *Ziziphus rotundifolia*. These herbaceous and woody elements in Indian arid zone have been shown to have strong habitat affinities. On the basis of physiognomic features of vegetation on different landforms and rainfall situations, following six major vegetation types have been identified (Satyanarayan, 1964).

Major Vegetation Types In The Indian Thar

Mixed Xeromorphic Thorn Forest : Besides the Aravallis as the boundary line, there are several rugged scattered hills which are mostly made up of sandstone, granite and rhyolite. The plant communities growing on these hills are grouped under the mixed xeromorphic thorn forest because the communities are largely dominated by thorny and spiny species, which include some evergreen non-thorny species as well. The soils of such habitats are skeletal, yellowish brown to brown, loamy sands. Low hills and rocky areas of 150 to 350 mm of rainfall zone are largely dominated by the *Acacia senegal* community which under protection attains density of 72 plants per ha and 100% frequency. The *Anogeissus pendula-Acacia senegal* community occurs in 350-500 mm rainfall zone where as in 500-700 mm zone *Anogeissus pendula* community is predominant with *Acacia catechu* as the chief associate. But on higher elevations *A. pendula* combines with *Boswellia-serrata*. The density of plants having 15-35 cm. DBH ranges from 200 to 500 plants per ha.

The chief shrub associate in 150-350 mm rainfall zone are *Commiphora wightii, Ziziphus nummularia, Grewia tenax, Euphorbia caducifolia, Mimosa hamata* and *Sarcostemma acidum*. The associated trees that are short with crooked boles include *Salvadora oleoides* and *Maytenus emarginata*. The associates of *A. senegal* community in the medium (350-500 mm) rainfall zone include *Wrightia tinctora, Moringa concanensis, Azadirachta indica, Bauhinia racemosa, Cordia gharaf* and *Acacia leucophloea*. In the higher rainfall regions (500-700 mm) the associate species are *Securinega leucopyrus, Dichrostachys cinerea, Grewia villosa, Barleria prionitis, B. acanthoides, Cassia auriculata, Abutilon indicum* and *Dipteracanthus patulus.*

The ground flora in the low rainfall zone is poor and includes a few species of grasses and forbs such as *Cymbopogon jwarancusa, Aristida funiculata, Eleusine compressa, Aristida hirtigluma, Tragus biflorus, Oropetium thomaeum, Melanocenchris jacquemontii, Enneapogon brachystachys, Indigofera cordifolia, Lepidagathis trinervis, Blepharis sindica, Tephrosia purpurea* and *Tridax procumbens.* In the higher rainfall zone (300-750 mm), some more species are added viz. *Eremopogon foveolatus, Heteropogon contortus, Brachiaria ramosa Bothriochloa pertusa, Hackelochloa granularia, Sehima nervosum, Indigofera tinctoria, Tephrosia petrosa, Boerhavia diffusa, Pupalia lappacea* and *Achyranthes aspera.*

Mixed Xeromorphic Woodlands : This formation largely having spiny species mixed with non-spiny and ever green species, occurs on the flat older alluvial plains and lower piedmont plains with deep depositions of sandy loam or clay loam or clay soils underlain with a hard kankar pan at 25 to 100 cm depth.

The plant communities encountered in the desert plains are 1. *Salvadora oleoides- Prosopis cineraria* 2. *Prosopis cineraria - Ziziphus nummularia - Capparis decidua,* 3. *Salvadora oleoides - Capparis decidua - P. cineraria,* 4. *Salvadora oleoides,* 5. *Capparis decidua - Salvadora oleoides - P. cineraria,* 6. *S. oleoides - C. decidua,* 7. *P. cineraria - S. oleoides - Z. nummularia,* 8. *S. oleoides - Cassia auriculata,* 9. *P. cineraria - C. decidua,* 10. *P. cineraria - Z. nummularia,* 11. *C. decidua,* 12. *Z. nummularia,* 13. *S. oleoides - P. cineraria - Z. nummularia* and 14. *P. cineraria - Acacia nilotica.*

The above plant communities, by the inclusion or exclusion of any one species, affect the association significantly. Therefore, these may be regarded as phases or 'facies' of the climax community, largely indicating the extent of degradation reflected in the preponderance of *Tephrosia purpurea, Crotalaria burhia* and *Indigofera oblongifolia.*

The common shrub associates of all above communities include *Calotropis procera, Balanites aegyptiaca* and *Acacia jacquemontii.* The forbs and grasses are *Aerva persica, Tephrosia purpurea, Crotalaria burhia, Convolvulus microphyllus, Heliotropium subulatum, Pulicaria wightiana, Celosia argentea, Eleusine compressa, Dactyloctenium sindicum, Desmostachya bipinnata, Cenchrus ciliaris, C. setigerus.*

Mixed Xeromorphic Riverine Thorn Forest : The Jawai, the Sukri, the Mitri and the Luni rivers and their tributaries in western Rajasthan form a narrow belt of younger alluvium having deep sandy soils without a hard pan. There is a very good density of trees viz, *Acacia nilotica, A. cupressiformis, Salvadora oleoides, S. persica, Tamarix articulata, Tecomella undulata, Tamarindus indica, Albizia lebbeck, Ailanthus excelsa, Ficus religiosa, F. bengalensis, Moringa oleifera* and *Ziziphus mauritiana.*

Acacia nilotica-Prosopis cineraria community is predominant in the irrigated fields along the river courses and represent the climax of this region. On medium heavy soils, *S. oleoides* and *P. cineraria* dominate. Degradation beyond this stage rapidly gives way to *Tamarix-*

Ziziphus, A. jacquemontii and finally to grasses and sedges viz., *Desmostachya bipinnata, Cyperus arenarius* and *C. biflorus*.

The plant communities on the terraces of the river banks are 1. *Acacia jacquemontii - Cassia auriculata,* 2. *A. jacquemontii-Aerva pseudotomentosa*, 3. *Salvadora persica-Tamarix articulata*, 4. *Salvadora-C. decidua*.

The grasses and forbs in these communities are *Cenchrus ciliaris, C. setigerus, Aristida adscensionis, Digitaria adscendens, Dactyloctenium aegyptium, Chloris virgata, Cynodon dactylon, Crotalaria burhia, Boerhavia diffusa, Digera muricata, Pulicaria wightiana, Volutarella divaricata, Xanthium strumarium* and *Indigofera cordifolia*.

Lithophytic Scrub Desert : Eroded rocky surfaces, gravelly plains and pediment plains with shallow soil deposition in depressional pockets support stunted, multi-stemmed shrubs and trees which are cushion- shaped pillow-forms due to heavy grazing.

Capparis decidua-Ziziphus nummularia is the most prevalent shrub community on eroded rocky surfaces and piedmont plains. Stray plants of *Acacia senegal* and *Prosopis cineraria* also grow along the deep tunnels. Associated shrubs, under shrubs, forbs and grasses are *Leptadenia pyrotechnica, Calotropis procera, Aerva persica, Tephrosia purpurea, Crotalaria burhia, Sericostemma pauciflorum, Bonamia latifolia, Tribulus terrestris, Orygia decumbens, Cleome papillosa, C. brachycarpa, Boerhavia elegans, B. diffusa, Mollugo cerviana, Indigofera cardifolia, Dactyloctenium sindicum, Oropetium thomaeum, Eleusine compressa, Eragrostis* sp., *Aristida hirtigluma*.

Psammophytic Scrub Desert : This formation has woody vegetation predominantly of shrubs, on aeolian deposits viz. stabilised sand dunes, undulating hummocky older alluvial plains and interdunal hummocky plains with very deep loamy sandy often calcareous. Typical psammophillous species are *Aerva persica, A. pseudotomentosa, Crotalaria burhia, Panicum turgidum, Cyperus laevigatus, Calligonum polygonoides, Clerodendron phlomoides, Cenchrus biflorus, Aristida funiculata* and *Citrullus colocynthis, Dipterygium glaucum* and *Haloxylon salicornicum*.

Sand dunes with moderate sand deposition support the following communities: 1. *Calligonum polygonoides - Clerodendron phlomoides*, 2. *C. polygonoides - Panicum turgidum*, 3. *Acacia jacquemontii - Acacia senegal*, 4. *Maytenus emarginatus - Calotropis procera*, 5. *M. emarginatus - A. senegal*, 6. *A. senegal - Calligonum polygonoides*, 7. *Crotalaria burhia - Aerva pseudotomentosa*, 8. *C. burhia - Sericostemma pauciflorum - Leptadenia pyrotechnica*.

The sand dunes in the moderate rainfall zones (250-300 mm) are more stabilised and bear a larger number of small trees and a few shrub species, such as *Prosopis cineraria, Salvadora oleoides, Balanites aegyptiaca, Tecomella undulata, Maytenus emarginatus, Lycium barbarum* and *Acacia jacquemontii*.

The sand dunes in a higher rainfall zone (300-400 mm) are highly stabilised and support mixed xeromorphic woodland instead of Psammophytic scrub desert.

Halophytic Scrub Desert : This formation is localised in low lying saline basins and depressional areas called *rann* or *playa* wherein the salinity decreases towards the periphery and succulent halophytic namo- phanerophytes and chamaephytes, generally of *Chenopodiaceae, Zygophyaceae, Aizoaceae* and *Portulacaceae* grow more towards the periphery.

The plant communities recorded in various *ranns* are: 1. *Suaeda fruticosa-Aeluropus logopaides*. 2. *Haloxylon recurvum-Salsola baryosma-Sporobolus marginatus*, 3. *Sporobolus helvolus-Cyperus rotundus*, 4. *Peganum harmala-Eleusine compressa.*

Other halophytic species common to the above communities are *Zygophyllum simplex, Cressa cretica, Euphorbia granulata, Portulaca oleracea, Fagonia cretica, Trianthema portulacastrum, Echinochloa colonum, Chloris virgata, Schoenfeldia gracilis, Dactyloctenium aegyptium* and *Dichanthium annulatum.*

Growth Pattern and Phenology

The strong monsoonic climate forces vegetation to have a strong periodic growth restricted to rainy season. New vegetative sprout from perennials and germination from annuals takes place immediately after a few showers in June-July. Maximum growth is attained by the end of September followed by flowering and fruiting by the end of October. In arid grazinglands, growth is limited from July to September. In semi-arid parts e.g. at Sagar, five phenological behaviour were identified by (Pandaya, 1964 a & b).

	Species
1. Ephemerals completing life cycle in one monsoon	*Zornia diphylla, Cassia tora, Cleome viscosa, Aristida royleana*
2. Complete life cycle during monsoon but recur in following season	*Paspalum royleanum, Panicum humils*
3. Germination to fruiting in one season but seed maturation in next season	*Volutarella ramosa, Heylandia latebrosa*
4. Showing 2 or more flowering flushes	*Cynodon dactylon, Dichanthium annulatum, Bothriochloea pertusa*
5. Those with one flowering and fruiting flush each year, although period of flowering may cover 2 seasons	*Indigofera linifolia, Evolvulus alsinoides*

Perennial species respond positively with more vegetative growth within a season if rains were more.

Herbage Yield

The herbage yield has been estimated as 3.3 t/ha in *Dichanthium-Cenchrus-Lasiurus* type and 3.5 t/ha in *Sehima-Dichanthium* type. However, these have potential of 5 and 6 t/ha, respectively (Singh, 1988). These estimates however do not include the yield from the ligneous components which often vary due to complexity of factors like soil, biotic factor and uneven nature of the stand.

Ecological Status

It is widely believed that tree shrub savanna are the climax formation in arid and semi-arid zones wherein most of the grasslands or rangelands are in a state of arrested preclimax or disclimax. Bharucha (1975) and Satyanarayan (1964) believed that western Rajasthan has polyclimax. Shreve (1951) demonstrated that each habitat in each division of the desert area has its own climax. While use of the term climax is debatable for the desert vegetation, the phenomenon of progressive and retrogressive succession on different habitats worked out in past 3 decades at the Plant Ecology Section of CAZRI, Jodhpur, India is most well understood aspect (Gupta and Saxena, 1972; Saxena 1977; Kumar, 1994). These are described below:

Changes in Vegetation Upon Degradation

Upon over utilization and degradation, dominant elements are reduced to very low dominance or complete absence. Even associates are also replaced by lower successionals. Their cover and herbage yield declines by 2-8 times and 4-8 times (Table 2) respectively, upon degradation. The percent of climax species may decline much below 40% level. Density may first increase due to spurt in growth of non palatables and thorny species which Dyksterhuis (1949) called invaders. But ultimately the density also declines. Vigour and cover of plants is adversely affected upon degradation. Hedging and browselines are obvious consequences. Dominance diversity relation change upon degradation

Dominance-Diversity Relations : It is well-known that slight degradation increases alpha diversity before it actually declines due to severe degradation. In a study in the Bandi catchment of the upper Luni basin in the Rajasthan desert (Kumar and Shankar, 1987), diversity and equitability of woody perennials in different sites was studied. Sites having degraded grass covers such as *Oropetium- Eragrostis* or *Dactyloctenium-Eleusine* type exhibited a low density and low equitability of woody perennials (Kumar and Shankar 1987). Sites with an optimum cover of *Dichanthium- Desmostachya* showed an intermediate diversity and equitability. This finding was further confirmed by the fact that the dominance-diversity curves of the woody vegetation in degraded sites were geometrical while those of the non-degraded site, log normal in distribution. Similar trends were found in Jaisalmer, too (Kumar, 1990).

Impact on Stability and Equilibrium : Arid ecosystems are more resilient and less stable hence fragile. Vegetational changes upon degradation that are within the bounds of resilience i.e., dynamic equilibrium, should be distinguished from those representing permanent changes due to degradation. To what extent permanent or resilient changes reflect degradation

Table 2. Vegetation cover & yield under degraded and non-degraded condition

Grasscover	Herbage cover (%)		Herbage yield (kg/ha)	
	Non-degraded	Degraded	Non-degraded	Degraded
Dichanthium annulatum Desmostachya bipinnata	4-8	0.5-2	4000	130-1100
Eleusine compress Desmostachya bipinnata	3-9	0.5-2	1200-1500	100-600
Sporobolus marginatus Dichanthium annulatum	4-7	1-3	1400-2600	300-500
Cenchrus ciliaris C. setigerus	4-6	1-2	2000-2500	300-400
Eleusine compressa Dactyloctenium sindicum	3-4	0.5-2	800-1000	175-450
L. sindicus	5-14	2-4	4000	400-500
C. sindicus-P. turgidum	5-8	2-3	1500-2000	300-500
Aristida-Eragrostis-C. biflorus	2-3	0.1-1	500-800	100-200

cannot be determined because we do not know to what extent vegetation changes indicate a disruption of equilibrium. It is therefore, desirable to set up a benchmark as reference with which to compare existing vegetation. This benchmark could only be the potential vegetation that a piece of land can afford to support. Gaussen (1959) called it plesioclimax. The successional status of vegetation with respect to climax obviously reflects its ecological status.

Assessment of Vegetation Degradation : The proportion of decline in the climax vegetation as well as total vegetation compared to the Plesioclimax can be measured through a variety of parameters (Kumar, 1992 a). The exact mathematical relation between the dynamics of each parameter with respect to increase of degradation has not yet been fully understood.

Remote Sensing for Monitoring Vegetation-Degradation : A basic ground radiometric study in this direction has revealed that the spectral response of vegetation in a non-degraded site in Mohangarh (11.7% total cover, 1,162 kg/ha dry matter yield) was different from that of the degraded site near Satyaya (3% total cover, 680 kg/ha of dry matter yield). In fact, the reflectance at 450 mm showed a negative but significant correlation with the total percentage of cover and dry forage yield. Thus, it is possible to monitor vegetation degradation, using inputs in digital image analysis, for the whole region.

Modelling the Degradation : Attempts in this direction have, however, been made by using multivariate techniques of classification and ordination of vegetation of Indian arid lands (Kumar, 1990). Multivariate analysis yielded such site and species groups that are indicators of the degradation status. This was also confirmed by the dominance diversity trends. The species groupings corresponded to the successional status which enabled to predict the degradation stage. Further evidence was supplied from the relative density of spiny species and browse species in these sites (Kumar, 1992 b).

Table 3. : Time sequence of vegetation development on various habitats in arid region

Habitat	Duration of Enclosure (years)	Grass cover	Tree/shrub cover
Hills	7	*Chriysopogon fulvus, Eremopogon foveolatus, Heteropogon contortus*	*Acacia senegal, Maytenus emarginatus, Ziziphus nummularia*
Rocky gravelly	12	*Eleusine compressa Dactyloctenium sindicum*	*Acacia senegal, Balanites aegyptiaca, Maytenus emarginatus, Z nummularia*
Rocky gravelly pediments with contour bunding	6	-do-	-do-
Flat buried pediments (high rainfall, heavy soil)	6	*Dichanthium annulatum*	*Salvadora oleoides, S. persica, P. cineraria, Z. nummularia, C. decidua*
Sandy undulating buried pediments (low rainfall)	6	*Lasiurus sindicus, Panicum antidotale*	*Haloxylon salicornicum, Z. nummularia, Leptadenia pyrotechnica*
Flat aggraded older alluvial plain	4-6	*Cenchrus ciliaris, C. setigerus*	*P. cineraria, A. nilotica, Z. nummularia, C. decidua*
Sandy undulating aggraded older alluvial plain	4-6	-do-	-do-
Sand dunes	18	*Panicum turgidum, Cenchrus prieuri*	*Calligonum polygonoides -sericostoma pauciflorum*
Shallow saline depression	6	*Sporobolus marginatus, Dichanthium annulatum*	*Prosopis juliflora, Acacia nilotica, Capparis decidua*

Vegetation Recovery Through Protection : For studying the impact of protection on the regeneration of depleted vegetation, a large number of areas representative of all desert types of habitat were selected and their vegetation was monitored for as long as twenty years. Analysis of these data revealed (Shankar, 1983) that protection improved the grass cover and promoted the regeneration of shrubs and trees in the exclosures. These habitats acquired the potential vegetation of desired composition and biomass yield rather slowly and the duration required for this development varied from over 5 to 15 years (Table 3). Increase in herbage yield through protection ranged from 3 to 13 times in different habitats (Table 3).

Condition of Grazing Lands

In the extensive survey of range resources in different parts of arid zone, condition classification of grazingland as proposed by USDA was adopted after little modification by Shankar and Kumar (1983) in survey of Luni basin, Jaisalmer and Jalor. The emerging picture is that over 70% of grazinglands have poor to very poor condition class. Of the remaining, nearly 13 per cent belong to the 'Good' class, 14 per cent to the 'fair' class and only 2-3 per cent could be assigned to excellent status. This indicates the severity of biotic degradation by increasing livestock. In a study on recovery of depleted vegetation on different habitats, Shankar (1983) has convincingly demonstrated that desired range condition could be achieved within 5 to 15 years of protection. For accelerating this process, it should be reseeded with the species of higher ecological status. With improvement in range condition, herbage production also increases.

Condition of woody perennials is also not very fair. Not only these browse plants are understocked but are also badly cut and lopped. In a study in Jaisalmer, Shankar and Kumar (1987) estimated that existing forage shrub tree cover was much less, 1.5 to 9.5%, than the desired level (Table 4). Similar situation prevails in entire arid region and leaves much scope for improvement.

Epilogue

Though arid regions of India are constrained by climatic, edaphic and biotic factors, they support a large diversity of grass and browse species. Distribution of these species is habitat specific, the full optimum expression in terms of cover, vigour and herbage yield is attained at particular habitat. However, the potential yield is rarely achieved because of increasing biotic pressure; the increasing livestock which graze the biomass too frequently and at shorter intervals allows only very poor growth. This has also resulted in decline in the grazingland area available per livestock. The range condition is poor. The browse yielding plants are understocked and degraded. An estimate of demand-supply situation revealed that arid zone of north west Rajasthan is highly deficit in respect of forage. Given the protection the yield could be enhanced. Addition of crop residues would further bridge the gap.

In respect of quality, grazing resources in arid region of India are rich in various nutrients and minerals. Quite often deficiency of one element in grass component is compensated by its

Table 4. Forage shrub, tree cover in various grass cover types on different habitats in Jaisalmer (Shankar & Kumar, 1987)

Grass cover type	Habitat	Per cent cover											
		Z. nummularia			*H. salicornicum*			*P. cineraria*			Total		
		Existing	Desirable	Deficit	Existing	Desirable	Deficit	Existing	Desirable	Deficit	Existing	Desirable	Deficit
L. sindicus	Dunes-inter dunes	0.31	1.5	1.19	0.71	6.0	5.29	0.66	2.0	1.34	1.68	9.50	7.82
P. turgidum	Sandy undulating hummocky plains	1.50	3.0	1.50	8.85	10.0	1.15	0.	2.0	2.0	10.35	15.00	4.65
L. sindicus	Interdunal plains	0.91	1.5	0.59	4.64	10.0	5.36	2.41	6.0	3.59	7,69	17.50	9.54
E. compressa	Older alluvial plains	9.02	10.0	0.98	0.23	1.50	1.27	2.74	8.0	5.26	11.99	19.50	7.51
D. sindicus	Buried pediment	1.54	8.0	6.46	1.70	1.7	0.	0.31	2.0	1.69	3.55	11.70	8.15
E. compressa	Runnels and streams	2.88	8.0	5.12	1.44	1.5	0.06	0.	0.	0.	4.32	9.50	5.18
Oropetium thomaeum-Aristida spp.	Piedmonts, hills and intermontane colluvial plains	1.52	8.0	6.48	0.35	0.35	0	1.23	2.0	0.77	3.10	10.35	7.25
Sporobolus marginatus E.compressa	Saline flats	0.79	1.5	0.71	0.	0.	0.	0.21	1.0	0.79	1.00	2.5	1.50

One per cent shrub/tree cover=5,40 and 35 plants per ha of *Prosopis cineraria, Haloxylon salicornicum* and *Ziziphus nummularia*, respectively surplus amount in browse materials. Palatability of different plants varies according to their phenophases and here too, complementarity is seen.

Thus in the existing environmental conditions, grazing resources are rich in diversity, palatability, nutrient and mineral status but poor in vigour and yield. Standardized range management strategies should help in improving the yield.

In the semi-arid zones, the area under natural grasslands is limited and cannot be perhaps increased because of pressure for crop cultivation on good lands. The marginal and degraded lands provide forage to the grazing animals to a limited extent as these are overgrazed. Improvement and grazing management of these rangelands is required. .

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REMOTE SENSING IN THE IDENTIFICATION AND MAPPING OF GRAZING LANDS

Amal Kar and Balak Ram

Introduction

Land for grazing is one of the most neglected and misused natural resources in many arid lands, including those in India. While researchers are engaged in refinement of techniques for improvement of this fragile land, there is growing awareness now that a proper evaluation of the conditions of the grazing lands is possible through viewing these lands on satellite images before, during and after the techniques for improvement are applied. This is especially because of the capabilities of the satellite-borne sensors to look at the earth's land features in different spectral bands and over a large area simultaneously. The synoptic viewing capacity of the satellite sensors, as well as the easy availability of the products, as compared to the aerial photographs, and possibilities of mapping the different thematic boundaries using different spectral bands and band combinations, have led to wider use of satellite remote sensing in the identification, maping, assessment and monitoring of the different earth resources. Vegetation mapping, involving the identification and mapping of crops, forests, pastures and other open grasslands, is one of the major fields in which the remote sensing research is directed to. We shall discuss here the different remote sensing techniques which are used for identification and mapping of grazing lands, with some examples from the arid zone of India.

Remote Sensing: Basic Concepts

Most sensors on the remote sensing satellites record the energy transmitted by the earth features through space in the form of electric and magnetic waves(Star and Estes, 1990). This is also known as the electromagnetic radiation. The sensors in the satellites are built with such specifications that these can record some specific wavelength bands of the electromagnetic spectrum. The wavelength bands are decided on the basis of the reflectance properties in different wavelengths from different earth features which the sensors can 'see' on the earth surface. In the arid region these include terrain features like hills and other rocky/gravelly surfaces like the pediments, pavements and plateaus with different lithology, sandy, non-sandy and salt-affected alluvial/colluvial plains, sand dunes and interdune plains, other small sandy undulating plains, saline depressions, etc., major soil types, vegetation cover including crop fields, pastures and forests, most of the land use categories, including the wastelands, fallow and other culturable wastes, settlements, etc., as also the water bodies. In other words, the sensors can record the reflectance from a host of different earth objects. It is also possible to measure the intensity of reflectance from the tonal gradation, and through it, the subtle changes in the said resource (i.e. changes in water bodies, maturity level of crops and natural vegetation). One of the key factors deciding the utility of a satellite image is its ground resolution, or the capability to identify an object of a particular size. If an image has a resolution of 30 meters then it means that each picture element on the image represents an area of 30m x 30m on the ground. Therefore, usually any object or a group of objects smaller than the size of 30m x 30m is not recorded as a picture element (pixel) on it. Since a pixel is a very small square on the image it is practically impossible to identify an object on a single pixel. A minimum cluster of at least 5-6 pixels is required for proper perception of the object on an image. There are some exceptions to the above rule. In some cases it is possible to identify images even if these are not in the resolution of the pixel, like when a narrow linear feature (a road, a railway track or a structural lineament) with sharp tonal contrast with the surrounding terrain occurs on the image, or when a small water body (a small pond) with deep water exists amidst a barren sandy land. In both the cases the tonal difference between the object in question and its surroundings is so vastly different that it is recognised in spite of its smaller size.

A number of remote sensing satellites are now sending data regularly to a network of earth stations. Among these the Indian Remote Sensing Satellite (IRS) with its two sensors, the LISS I and LISS II, the French satellite, Systeme Pour l'Observation de la Terre (SPOT) with its two sensors (MLA and PLA) and the Landsat satellite of the USA are notable. The Landsat satellite system has, of late become non-functional because of a series of technical snags, but the regular satellite remote sensing of the earth's resources began with the predecessors of the Landsat, the Earth Revolving Technological Satellite (ERTS), in 1972. It carried only one sensor called the Multi-Spectral Scanner (MSS) which recorded the reflectance in four wavelength bands. The ground resolution was about 80m, and hence was a major drawback. The Landsat series from the mid-seventies started carrying two sensors, one for recording data in four spectral bands at 70m ground resolution (MSS) and the other in seven bands at 30m resolution (Thematic Mapper or TM). Some of the useful wavelength bands for different applications are provided in Table 1.

Table 1. Amenability of different remote sensing sensors and wavelength bands to land resources studies

Potential applications	Sensors and band names	Wavelength bands (micrometer)
Soil/ plant discrimination & coastal mapping	LISS I&II band 1 TM band 1	0.45 - 0.52 0.45 - 0.52
Plant vigour assessment & turbidity assessment	LISS I & II band 2 TM band 2 SPOT MLA band 1	0.52 - 0.59 0.52 - 0.60 0.50 - 0.59
Discrimination of vegetation type; Landform & dranage mapping	LISS I & II band 3 TM band 3 SPOT MLA band 2	0.62 - 0.68 0.63 - 0.69 0.61 - 0.68
Delineation of water bodies, shore zone mapping & biomass determination	LISS I & II band 4 TM band 4 SPOT MLA band 3	0.77 - 0.86 0.76 - 0.90 0.79 - 0.89

There are other remote sensing satellites and products also, which are used less frequently and have some specific utilities and limitations. Notable among these are the NOAA weather satellites (AVHRR) with pixel resolutions of 1.1 km (Local Area coverage, LAC) and 8 km (Global Area Coverage, GAC). The images from these satellites are used usually for very broad regional scale mapping of weather and vegetation pattern, especially at 1: 1 million scale or smaller, because of their resolution constraints. Microwave satellite remote sensing with synthetic aperture radar (SAR) has its utility in the mapping of rugged and undulating terrain with dense vegetation cover, like that in the hilly forest areas of the equatorial region where cloud cover persists for most part of the year. The other major application is for estimation of near-surface soil moisture. It also provides very impressive images of the dune-covered areas of the deserts which give low tonal contrasts on the standard colour images. The next generation IRS satellites will carry a microwave payload, along with the usual multispectral scanner. The potentialities of the sensor in characterization of arid grazing lands are being tested (Tueller, 1995).

The sensors transmit the data to a network of earth stations where these are recorded in magnetic tapes. Users have a choice to ask for data in magnetic tapes for display and analysis through a computer, or in the form of paper prints. With so much of information on the land resources, being made available by the satellites almost twice a month, it is necessary to decide about the types of sensors and bands/band combinations for different applications.

It is generally recognised that the band 2 images of Landsat and IRS satellites are more useful for land use mapping, while band 3 images are good for landform and soil mapping. The band 4 images are useful for water bodies mapping and also for discrimination of green vegetation.

Characteristics of Grazing Lands

In order to decide about the appropriate remote sensing products for mapping and monitoring the grazing lands one has to first make an inventory of the different ecosystems in which these resources occur. In the arid lands the grazing lands occur in many different geomorphic or terrain situations. These include the slopes of the hills, the flat pedimented areas with rock outcrops or very shallow and gravelly soils, shallow to moderately deep colluvial plains, sandy plains, alluvial plains, sand dunes and interdunes, margins of the saline depressions (the playas or the ranns), and many other landforms. Reflections from these landforms and the vegetation over them are not recorded separately on the remote sensing data products, but as a complex of the landform-soil-vegetation-moisture complex whose identity is limited by the ground resolution of the image. Visual interpretation of the images, therefore, needs a trained eye to distinguish between the image pattern of such different complexes under different terrain situations. The differentiation is relatively easier in those arid lands where rangelands are contiguous, vast and are well managed (e.g. in Australian and US deserts), but such situations are not found in most of the deserts and other arid lands in the developing nations, where the grazing lands are in moderate to severe degradation states.

In India the national land use classification system puts grazing lands under the head "permanent pastures". A land use classification system has also been proposed by Sen (1978) for the arid zone of India. Almost every village in the arid western part of Rajasthan state (which contains about 61 per cent of the country's total arid lands and is also known as the Thar desert) has a common grazing land whose ownership vests with the elected village council (Panchayat). In local language these lands are called Oran, Gochar, Agor, Beed, etc. All these lands are subjected to unrestricted open grazing, as animal husbandry is a major occupation in this desert (second only to agriculture), and there is very high pressure on these lands. Only a very few permanent pastures, which are owned by the religious trusts, have a better vegetation cover of trees and tall shrubs, but not grasses and under-shrubs.

Various kinds of culturable wastelands on the landforms with poor land capabilities are also used for open grazing, as also the land kept fallow from cropping in some of the year(s). Excepting the fallow lands most other lands where open grazing is practiced are the marginal lands with low carrying capacity. As per the land records available with the Government of Rajasthan, the permanent pastures and the other grazing lands in culturable wastes together occupied 874,000 ha or 4.19 per cent area of western Rajasthan in 1990-91 (Anonymous, 1992). This is about 49 per cent of the total estimated grazing lands in Rajasthan state and 8 per cent of that in India. As grazing pressure on these lands is increasing there is more degradation of the land and at a faster rate. Between 1956-57 and 1990-91 there has been 92.9 per cent increase in the total grazing lands (including permanent pastures and culturable wastes) in western Rajasthan, but the conditions of these lands have not improved. Most of the increases have been reported in the districts receiving an average annual rainfall of less than 350mm, but much less in the wetter districts like Jhunjhunu, Sikar and Jalor (Table 2). This is because of the low potentialities of many lands for rain-fed cropping in the dry west, as compared with those in the wetter eastern part of the desert. Ganganagar district did not have much grazing land because of widespread canal irrigation. So, the figure of 500 per cent increase in the district is not very significant. Moreover, if we look at the area of the grazing lands over the years from 1956-57 to 1990-91 we find a very slight increase from 1959-60 onwards in most districts (Fig. 1). The sudden leap in the area figures in 1959-60 could be due to transferring of some lands from "culturable wastes" and the "barren unculturable wastes" to the category of "permanent

Table 2. Changes in grazing land area in western Rajasthan (1956-57 to 1990-91)

District	Area in '000 Ha Year 1956 - 57*	 Year 1990 - 91*	Change in percentage	Average annual rainfall (mm)
Bikaner	8	84	950.0	259.4
Jaisalmer	52	108	107.7	171.1
Barmer	89	207	132.6	264.9
Gangangar	2	12	500.0	253.7
Jodhpur	44	122	177.3	306.9
Churu	12	46	283.3	325.7
Nagaur	51	73	43.1	372.6
Jalor	47	46	-2.1	421.6
Pali	52	91	75.0	490.4
Jhunjhunu	46	41	-10.9	444.4
Sikar	50	44	-12.0	465.5
Total	453	874	92.9	

*Source: Trends in Land Use Statistics, Rajasthan (1992)

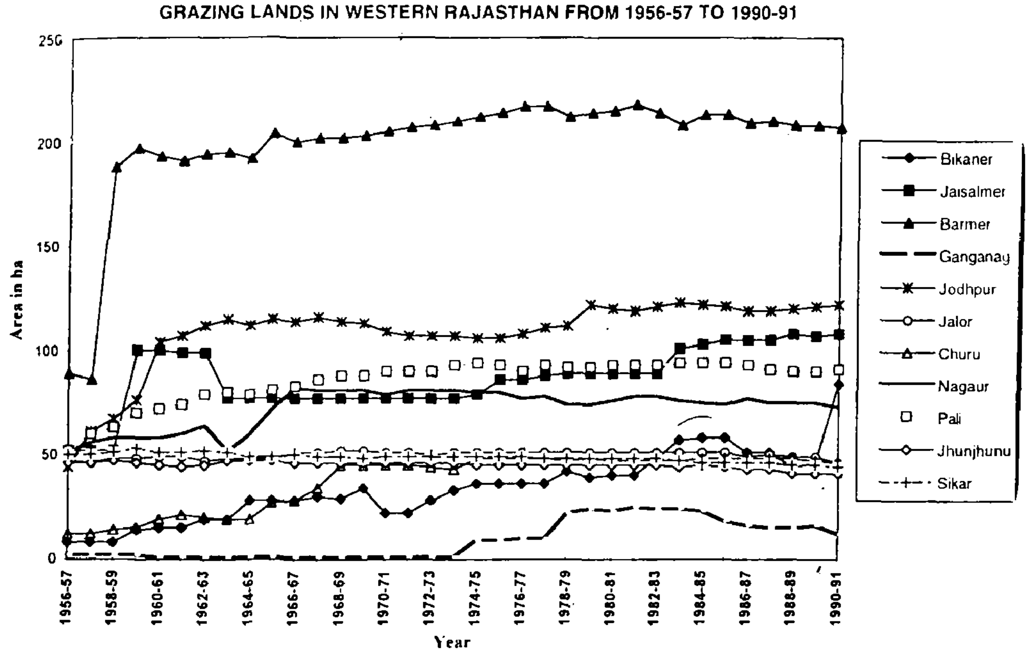

Fig. 1 Grazing lands in western Rajasthan from 1956-57 to 1990-91

pasture" in that year. The trend is not very spectacular since then. Instead, there are field and remote sensing evidence that the classified grazing lands like the orans are now being intruded for cultivation and other non-grazing purposes, and there is widespread degradation.

As land degradation continues regeneration of vegetation becomes a serious problem. Saxena (1992)mapped the broad distribution pattern of plant species in the grasslands of western Rajasthan. The total livestock population in western Rajasthan is 22.6 million as per the 1992 livestock census (Anonymous, 1993). This means that one hectare of grazing land is allotted to 26 animals, consisting mostly of sheep and goats, although the figure will be slightly modified if the animals are converted into Adult Cattle Units (ACUs). Such crowding of animals on the already degraded lands creates more problems of land management.

The spatial pattern of degradation of the grazing lands needs to be understood and periodically monitored on the basis of their total environmental set up for any meaningful action on development. This is now possible to a large extent through satellite remote sensing. Part of the problem in correct estimation of the grazing lands from secondary land records is that the record recognises oran, gochar, agor, beed and other similar lands allocated for permanent pasture as the "permanent pasture and other grazing lands". The record does not recognise the different culturable wastes as grazing lands, although such lands are regularly used for grazing.

While permanent pastures may remain almost unchanged over the years, the area statistics for various culturable wastelands keep changing, depending on the rainfall which is very unpredictable. This creates problem for proper estimation of the land actually put to crops and that kept out of it. Another dimension of the problem is that the land classified as "barren, unculturable wastes" is also used for grazing, as these support some small shrubs and grasses, especially after a good monsoon rain. Satellite images of post-monsoon season show them as carpeted with vegetation, although the quality of vegetation may be poor. As we shall see, satellite remote sensing can provide better answers to some of these questions.

Remote Sensing Applications in Identification and Mapping of Grazing Lands

Visual Remote Sensing : Visual interpretation of remote sensing data products, especially the large scale paper prints of the standared False Colour Composite (FCC), is the simplest way to identify and map the grazing lands and the different types of terrain on which these occur. The most commonly used format is a paper print of the standard FCC of bands 2,3 and 4 of IRS and Landsat images. These products, at a scale of 1: 250,000 or 1. 50,000, provide the application scientists many valuable information on the different land resources, including the grazing land resources. Green vegetation appears on these FCCs in red, but a closer look shows different hues of red, from light brown to reddish brown and dark brown, denoting various phases of maturity and greenness and various types of plant cover. The permanent pastures (orans), which are not so degraded and have a reasonable cover of green vegetation, appear in light brown to reddish brown tone on the FCCs of dry cool season. The National Remote Sensing Agency(NRSA), Hyderabad, has catalogued the tones and textures of the different land use and land cover features on the standard FCCs, and can be used as a guide (NRSA, 1986, 1989). The perimeters of these lands are easily demarcable. Images of mid-September to mid-October (Kharif season) and of mid-January to mid-February (Rabi season) provide better information, the latter having more usefulness in a rain-fed cultivation area, because of the sharp tonal difference bvetween the orans with perennials and some annuals and the harvested fields. Encroachment to the orans can be identified if the boundaries on the FCCs are superimposed on a older map of the oran at the same scale. The types of encroachment can often be interpreted from the tonal variation within the oran. For example, a ploughed land within the oran will usually appear as a rectangular plot with light yellowish tone, while the same plot with crops will appear as a reddish brown to red rectangle. Degraded orans have a mottled appearance where the brownish tone of the vegetation occurs in association with the barren areas having light yellow to creamy white and light blue colours, depending on whether the oran occurs on a sandy plain, salt-affected plain or a rocky surface.

In the case of the open grazing lands there is no defined outer boundary. The mottled appearance then makes it difficult to properly identify the grazing lands. FCCs of images taken just after the monsoon rains, in September or early October, can be difficult to interpret in such cases, because of the uniform reddish tone over the whole scene. Similarly, in the areas having numerous short fallow lands on a light textured soil, interspersed with open grazing lands, the almost similarly reflecting surfaces make it difficult to distinguish between the open pastures and the fallow lands. It is, therefore, necessary to have a knowledge of the terrain conditions before one comes to any conclusion from the image interpretation

Using topographical sheets of 1958 and Landsat TM FCC of 1986, Sharma et al.(1989) mapped and compared some of the orans in Jodhpur district. They found a decline in the area of different orans by 9 to 30 per cent, mainly due to encroachment by the cultivated land and urbanization. The maximum decline was found in the rocky/gravelly pediments with shallow colluvium, where the exploration of ground water encouraged the farmers to reclaim land for cropping. The decline was minimum in the saline alluvial plain due to predominant salinity hazard

In Kachchh district of Gujarat, adjoining the state of Rajasthan, a vast salt-affected plain called the Banni, is considered to be a saline waste with some potentials for grassland development. Cultivation is nowhere practiced in the Banni as the soil is highly saline-alkaline (EC 3-15 mmhos/cm; pH 7.1-9.0). The land has a flat disposition and much of it becomes a vast stretch of water during the rains. Yet, the naturally adapted, coarse-tufted and salt tolerant grasses and other bushes have proved to be a boon for the cattle rearers who move over this plain for good pastures. Field studies suggested some areas of distinct vegetation banding, with denser distribution of grasses and small shrubs, including *Prosopis juliflora*, on relatively higher elevation. The lower segments of the land containing the salt marshes (ranns) are almost devoid of vegetation, except some aquatic weeds. Using paper prints of the single band Landsat TM and IRS images of the dry, cool period (bands 3 and 4), and analysing them through an analogue Image Analyzer, Kar (1993) could highlight the vegetation banding across the Banni and could map them properly. Simulatneously, a digital terrain modelling was carried out for the area, which brought out a structurally controlled undulating surface. Superimposition of the vegetation distribution pattern on the simulated land surfaces, helped in proper mapping of the grasslands on the high level mud flats and in explaining their typical distribution pattern in relation to a neotectonically disturbed terrain. It also explained why the western part of the Banni should have a higher density of *Prosopis juliflora* thickets. The bright red tone of this thicket on the FCC is easier to identify in the absence of crops and can be used to separate it from the grass-cum-woodlands with a lighter tone (Kar,1993).

Ram et al.(1993) reported the mapping of grazing lands in an area of 20,875,000 ha in western Rajasthan from Landsat TM FCCs at 1: 50,000 scale and IRS LISS II FCCs at 1: 250,000 and 1: 50,000 scales (Fig. 2). These were then verified using the field-based information on the type and distribution pattern of permanent pastures and other open grazing lands, as well as the secondary land records on permanent pastures. An area of 952,000 ha, or 4.56 per cent of the total geographical area of western Rajasthan was found to have grazing lands. This included the orans and other permanent pastures, the culturable wastes and the so-called barren unculturable wastes, provided these had an appreciable plant cover at the time of imaging. The land records (Anonymous, 1992) on the other hand, suggested a figure of 874,000 ha (5.19%) under permanent pastures for 1990-91. If we add the area of culturable

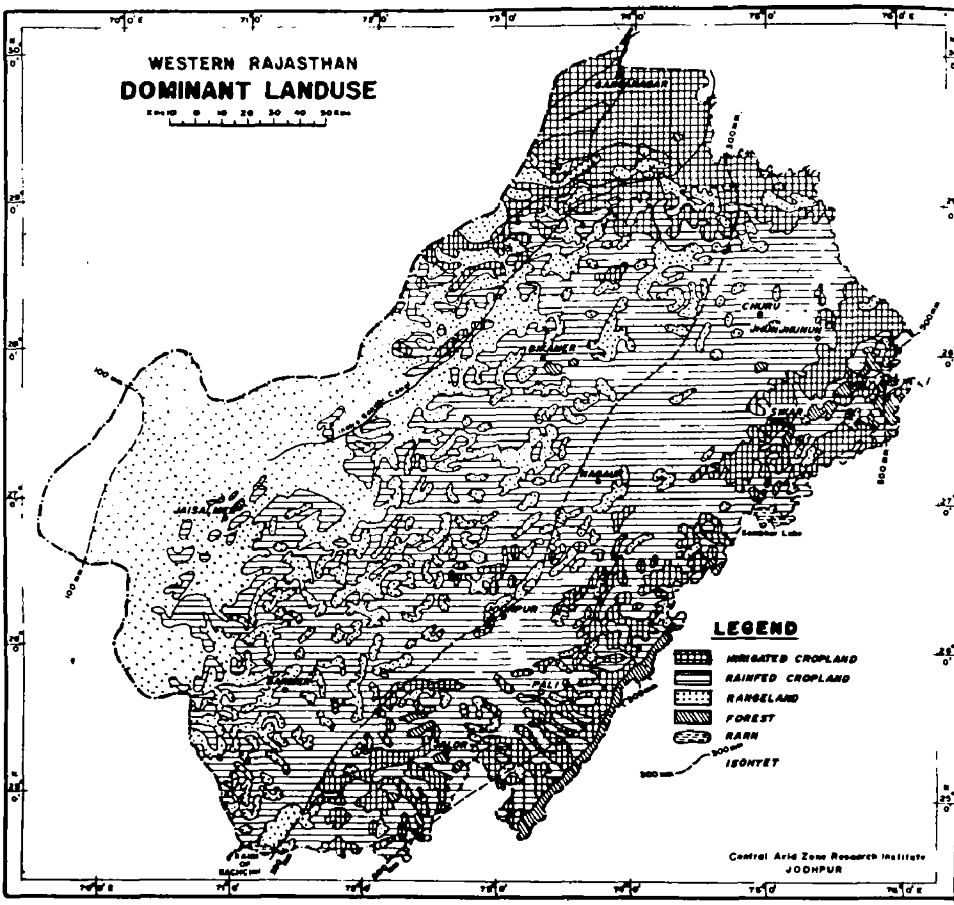

FIG. 2

wastes (4507,000 ha) to the reported area of permanent pastures, we get a staggering figure of 5351,000 ha (25.6% area of western Rajasthan) as grazing lands (Tables 3).

If the tonal signatures of the grazing lands on satellite images are to be believed, then the land records can not be relied on for proper mapping of the grazing lands, even if we allow a small margin of error for visual interpretation of the satellite images and the quality of prints. The difference is too high and can only be explained by degradation and encroachment into the classified lands. Now, considering an area of 952,000 ha available for 22.57 million animals, the density of animals per ha of grazing land is 24, which is too high. The recommended density is 1.3 animals per ha considering the poor conditions of the grazing lands in the arid areas (Bhimaya and Ahuja, 1969).

Using such visual remote sensing methods in association with other available records it is possible to improve our knowledge of the grazing lands, find out the constraints and monitor the changes in them. It is also possible to map the patterns of degradation in these lands, as was found by Singh *et al.* (1992) who mapped western Rajasthan through Landsat TM and IRS LISS II FCCs for desertification, including vegetation degradation.

Digital Remote Sensing: The visual interpretation of the grazing lands is very much dependent on the quality of the paper prints and interpreter's abilities. Some of these factors are

Table 3. Grazing lands in western Rajasthan as per land records and remote sensing (1990-91), in relation to livestock population

	(As per Govt. land records)			Grazing land	Livestock +
			Total land	through	population
	Permanent	Culturable	for grazing	remote	(million)
District	Pastures*	Wastes*	(col.2+3)*	sensing *	
Bikaner	84	1075	1127	67	2.01
Jaisalmer	108	2903	3010	166	0.81
Barmer	207	266	475	224	3.16
Ganganagar	12	76	88	26	2.32
Jodphur	122	67	191	114	2.78
Churu	46	24	70	49	1.69
Nagaur	73	15	88	72	2.80
Jalor	46	26	72	85	1.69
Pali	91	39	129	87	2.73
Jhunjhunu	41	6	47	27	1.07
Sikar	44	10	54	1.52	35.00
Total	874	4507	5351	952	22.57

*Area in '000 ha; +1992 animal census; Source: Statistical Abstracts, Rajasthan (1993)

neutralized when digital techniques are applied to the scenes. As we have noted earlier, the image is an assemblage of many small picture elements or the pixels. The spectral characteristics of these pixels are sought to be understood in the digital image processing and these assume more importance when a proper monitoring is attempted. The reflectance from any single land surface is different in different wavelength bands. The reflectance in the near-infra red band will be different from that in the red, green or blue bands. In digital remote sensing an attempt is made to evaluate and manipulate statistically the spectral response from any land surface, as registered through the digital number (DN) in each pixel in the different bands and band combinations to get the best outputs of the land cover. This far outweighs the standard FCCs in many respects, as it is not dependent on interpreter's bias, but it also needs a detailed background of remote sensing and the terrain.

The most popular digital technique for vegetation mapping is Normalized Difference Vegetation Index (NDVI) which is calculated as (band 4 + band 3)/(band 4 - band 3). The difference increases as the vegetation becomes more green or dense (**Fig.3**). The other simple methods are the Ratio Vegetation Index (RVI; calculated as band 4/ band 3) and Modified Normalized Difference (MND; calculated as band 4-(1.2*band 3))/ (band 4 + band 3). Greenness Vegetation Index (GVI), Perpendicular Vegetation Index (PVI), Soil Adjusted Vegetation Index (SAVI), etc. are the other methods applied to the scenes for extracting information on vegetation condition (Tueller, 1989; 1995).

One of the methods for spectral enhancement is to calculate the greenness index. For IRS LISS II images this is calculated as:

$$-0.1072\, b1 - 0.1219\, b2 - 0.4341\, b3 + 0.8861\, b4;$$

where b1, b2, b3 and b4 are the digital counts in the four bands. Greenness responds to the combination of high absorption in the visible bands and high reflectance in the near-IR band (Sharma et al.,1990).

For the Landsat TM4 and TM5 sensors the Greenness is calculated as:

-0.2848 b1 -0.2435 b2 -0.5436 b3 +0.7243 b4 +0.0840 b5 -0.1800 b7.

When used in association with indices for Brightness and Wetness, a Tasseled Cap transformation is achieved, which attempts to explain the terrain conditions for vegetation and other resource studies in a better way (Crist and Kauth, 1986). Similar algorithms can also be used for IRS LISS II bands. Another spatial enhancement technique is Principal Component (PC) merging which is a complex one and attempts to retain the spectral information of the different bands in different planes. PC1 contains the overall scene luminance, while all other PCs contain interband variations. Usually the first three PCs contain most of the information However, it is still very difficult to interpret the results from PC analysis, and one is never sure what the outcome will be of analysis on the same scene, but for different dates.

The simplest method of digital analysis is to carry out a radiometric enhancement of the different bands of an image, especially through contrast stretching, followed by superimposition of the bands to produce a good FCC (**Fig.4**). Among the spectral classifications, the easiest and the surest one is to attempt supervised classification which involves providing "training sets" to the scene, especially based on a knowledge of the terrain. The scene is then classified by the system into different spectral groups on the basis of the information contained in the training sets. Therefore, more the number of training sets in different tonal regions, the better the results are. In contrast, the unsupervised classification is a poor classifier, as it automatically splits the DNs into some groups with equal intervals.

Digital remote sensing has many possibilities for mapping the grazing lands and for monitoring the changes. Tsunekawa *et al.* (1996) mapped the broad land cover units in Rajasthan, using the NOAA-11/AVHRR LAC mode images of 1989. The study found that NDVI can be used for a macroscopic division of the land cover, but it is essential to use the albedo values with the NDVI for broad, regional scale mapping, inspite of NOAA image's coarse resolution. Potdar et al. (1993) found that the NDVI mapping can simulate the three broad ecological zones in the Thar. In the Banni land of Kachchh Jadhav et al. (1993) monitored the changes in grazing lands using supervised classification technique with maximum likelihood classifier, on the multi-temporal scenes from Landsat MSS and TM, as well as IRS LISS II sensors (1980 to 1988). They reported an increase in the *Prosopis cineraria* thickets and salinity ingress during the period.

Digital remote sensing can also be used to accurately map the changes in the orans and other permanent pastures. For arid Australia Pickup and Chewings (1988) used the Landsat MSS data and a model for grazing cattle distribution on grid cell basis to generate the pattern of movement of the cattle and to calculate the total number of cattle at a particular distance from a water point. Simultaneously, on the MSS band 5 (now 3) they separated the signatures of landscape changes due to different grazing intensities at various distances from the water point and on the basis of vegetation type. This was done through coregistration of two images of an area, acquired in successive passes, followed by calculation of the DN in each pixel of the two

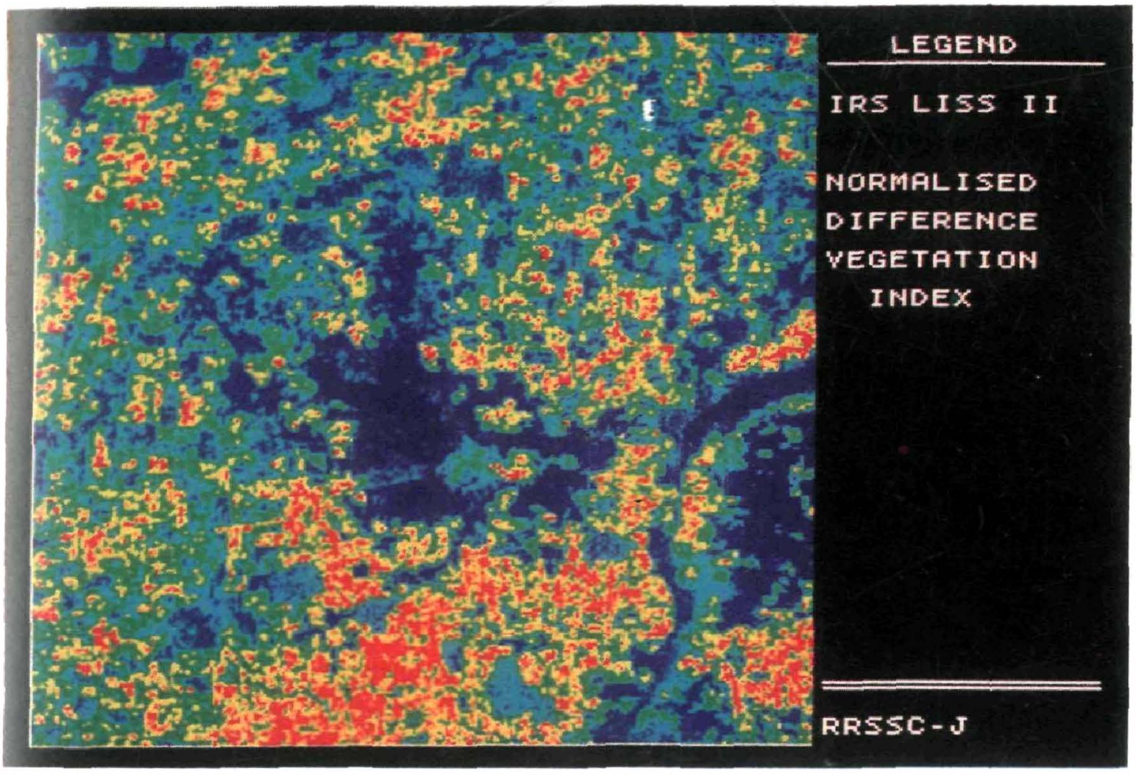

Fig. 3 NDVI output from IRS LISS II subscene of Sikar area for 12 February 1993

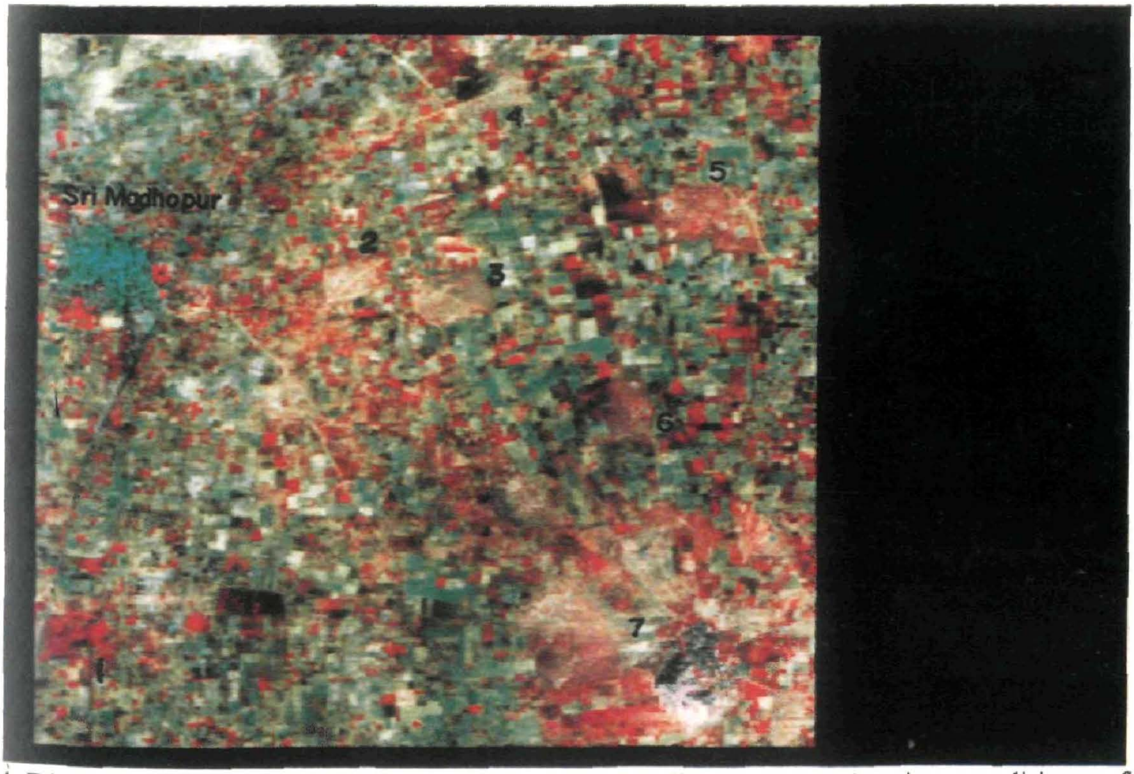

Fig. 4 Digitally enhanced SPOT MLA FCC of Sri Madhopur area, showing conditions of permanent pastures (1-7) on 10 October, 1990. Number 1 and 5 have better plant cover than the others, but there are marks of encroachment for other purposes in 5 and 7. Number 2, 4 and 7 are less vegetated and more degraded

images and remapping the image with the difference between the DN in two images. Using these values in difference band 5 image as signatures of the intensity of grazing in a vegetation type and considering them as a surrogate for cattle pressure (and hence distribution), they could identify the areas which are highly degraded by cattle grazing and need to be protected, as also the sites for possible relocation of the grazing areas. Pickup (1995) also developed a simple model based on the Landsat MSS PD54 transform values in bands 2 and 3 and the bare soil signature to find out the vegetation cover index and intergrating it with the rainfall pattern, predicted the herbage production changes in the rangelands with changes in land conditions and the amount of grazing in arid Australia.

A study undertaken using IRS LISS II subscenes of Luni Development Block of Jodhpur district and Sri Madhopur tehsil of Sikar district for supervised classification and NDVI mapping, and superimposing the results on old topographical maps, found shrinkage in the size of the permanent pasture, especially due to enlargement of cultivation area, settlements, roads and constructions related to public facilities. There are bright prospects of using digital remote sensing in association with Geographic Information System (GIS) for monitoring the different kinds of grazing lands.

Yet, years of research also suggest that the DN values of the sparse vegetation in grazing lands of arid regions are less amenable to digital processing. This is especially because the pixel registers reflectance of far more heterogeneous items, including plants and soil cover, and also because the leaf area index in the desert plants is very low and varies from location to location. As Tueller (1995) mentioned "The real problem with using remote sensing classification tools to map is that the results are difficult to extrapolate to other cases. Often the signatures used to depict a specific plant community do not hold up when attempts are made to use a similar classification during a different season, year..."(p.200).

Conclusion

Remote sensing is useful for vegetation mapping, but it has some limitations also. As the technology advances those limitations which are sensor-based are taken good care of. The result is increasingly better image resolutions and judicious classification of spectral bands for different land resources applications. For many purposes, like finding out the area extent of the grazing lands, their terrain conditions and status of vegetation cover, simple FCC's in paper prints may be useful. However, at times the areas look so similar that the features are difficult to differentiate through visual interpretation. This is when the help of different digital techniques are felt more, as such techniques provide a much better classification, without any bias of the interpreter. However, detailed studies like estimation of plant communities, their densities, or biomass, are difficult propositions and need to be standardized.

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REMOTE SENSING DATA PRODUCTS AND VISUAL INTERPRETATION TOOLS FOR LAND RESOURCES AND GRAZING LAND STUDIES

Amal Kar and Surendra Singh

Introduction

Satellite remote sensing has now become a major source of information for land resources studies,including studies on geomorphology, geology, soil survey, land use and land capability, vegetation cover, water resources (both surface and ground water), natural hazards, desertification and a host of other related fields. Compared to the vertical aerial photographs, which usually have very high resolutions, the satellite imagery has a coarser resolution. Yet the satellite data products are in great demand. Some of the major factors responsible for wide acceptability of the satellite data, even during the initial stages of its application when Landsat I (then known as ERTS 1) was launched by the USA, are its easy availability, wider area covered per scene, synoptic viewing of the area and almost distortion-free mapping of different thematic boundaries from its different spectral bands and band combinations. Vertical aerial photographs are usually restricted in most countries because of their many defence related applications. A number of optical instruments are used for interpretation of the air photo pairs. These include simple stereoscope to advanced zoom stereoscope and other photogrammetric equipment. This article will be restricted to satellite remote sensing only.

Satellite Data Products

In the Indian subcontinent data products from three major satellites are being extensively used. These are: Landsat (US), SPOT (France) and IRS (India). The application potentials of the images in different spectral bands from these satellites are presented in Tables (1 to 3).

Utilities of Single Band and Multi-band Data : It is generally recognised that band 2 images of Landsat and IRS satellites are more useful for land use mapping, while band 3 images are good for landform and soil mapping. Band 4 images are useful for water bodies mapping, as also for detection of subsurface water potential courses. While appreciating the utility of the single band data, it is also to be recognised that much better information on all the land characteristics could be extracted from the False Colour Composites (FCCs) of different bands, especially a combination of band 2+3+4 (the standard FCC). At a scale of 1:250,000 or 1:50,000 these FCCs provide useful information on almost all the aspects of terrain conditions, including vegetation cover.

The MSS and IRS LISS 1 FCCs are useful in broad groupings at 1:250,000 scale. For example, in the geological and geomorphological applications, interpretation of Landsat MSS and TM, and also IRS LISS 1 and 2 FCCs may yield almost the same number of lithological and landform boundaries, but the TM and LISS 2 FCCs will be more helpful because of their higher resolution, leading to quicker interpretation and better accuracy of mapping. The higher resolution of TM and LISS 2 is also very helpful in the delineation of vegetation cover boundaries and in identification of settlements.

Table 1: Landsat spectral bands and their application potentials

Sensor	Spectral band	Wavelength (micrometer)	Applications
Multispectral Scanner (MSS) (Resolution: 80m)	1	0.5-0.6	Regional geological structures and rock units
	2	0.6-0.7	Topographical features and land use mapping; vegetation type discrimination
	3	0.7-0.8	Forest cover mapping; crop identification
	4	0.8-1.1	Shore zone mapping, land & water boundary demarcation; soil moisture zones
Thematic Mapper (TM)(Resolution:30m for bands 1-5 and 7; 120m for band 6)	1	0.45-0.52	Bathymetric mapping in shallow water; soil/vegetation discrimination
	2	0.52-0.60	Plant vigour assessment; turbidity assessment
	3	0.63-0.69	Landform & drainage mapping;vegetation type discrimination
	4	0.76-0.90	Shoreline mapping,water bodies delineation; biomass determination
	5	1.55-1.75	Vegetation/soil moisture content differentiation; snow/cloud differentiation
Thematic Mapper (TM) (Resolution:30m for bands 1-5 and 7; 120m for band 6)	6	10.40-12.50	Thermal mapping; vegetation stress analysis; soil moisture determination
	7	2.08-2.35	Hydrothermal mapping; rock type discrimination

Among the non-standard FCCs a combination of bands 2+4+7 or bands 3+4+7 may be useful for geological mapping, while a combination of bands 3+4+5 may provide better information on drainage network and crop areas.

Standard Paper Prints : For most purposes the standard FCCs of Landsat TM and IRS Liss 2 (at 1:250,000 and 1:50,000) provide the required information in sufficient details. Therefore, it is important to decide, first, about the scale at which one wishes to map the land features, including vegetation. If it is a broad regional scale mapping then a FCC at 1:250,000 scale may serve the purpose. A mosaic prepared from FCCs at 1:1 million scale may also be useful, but this product is better in areas of good tonal contrasts. Incidentally, the full scene standard paper print of the above mentioned satellite data are generally available in either single band (black and white product) or in FCC from the respective national facilities at scales ranging from 1:1 million to 1:250,000 and 1:50,000. Enlarged prints can also be obtained at 1:100,000, 1:25,000 or 1:10,000 scales, or at other user-defined scales. The scale is selected by

Table 2. SPOT spectral bands and their application potentials

Sensor	Spectral band	Wavelength (micrometer)	Applications
High resolution visible (HRV) imaging instrument			
a) MSS (MLA) (Resolution: 20m)	1	0.50-0.59	Assessment of plant vigour
	2	0.61-0.68	Landform and drainage line mapping;discrimination of vegetation types
	3	0.79-0.89	Delineation of water bodies and water courses; shore zone mapping
b) Panchromatic (PLA) (Resolution: 10m)		0.51-0.79	Combination of the above

the user on the basis of his needs and the pixel resolution of the image. For example, a SPOT PLA has a sharper resolution and, hence, can be used without problem at 1:10,000 scale. For IRS LISS 2 and Landsat TM the largest scale which can be used without pixel blurring is 1:50,000

Standard Film Negatives and Positives : The film negatives and film positives (transparencies) are available for single bands and also for the FCCs at 1:1 million scale for Landsat MSS and TM, as also for IRS LISS 1. For LISS 2 the smallest standard size is 1:500,000, while for SPOT the smallest standard size is 1:400,000. The negatives can be ordered if the user wishes to generate images at his own, while the small transparencies are generally ordered for the FCCs and enlarged optically at the desired scale to overlay the image pattern on a base map, although single band black and white transparencies (including those of SPOT PLA) are also used for specific purposes.

Geocoded FCCs are very useful for repeated monitoring of changes in land cover and land uses, and especially for land degradation mapping. These products could be easily superimposed

Table 3. IRS spectral bands and their application potentials

Sensor	Spectral band	Wavelength (micrometer)	Applications
a) LISS-I (Resolution : 72m) and	1	0.45-0.52	Coastal mapping; shallow water bathymetric mapping; soil/plant discrimination
b) LISS-II (Resolution : 36.25m)	2	0.52-0.59	Turbidity assessment; plant vigour assessment
	3	0.62-0.68	Landform and drainage mapping; discrimination of vegetation types
	4	0.77-0.86	delineation of water bodies and water courses; shore zone mapping; biomass determination

on the topographical sheets without any significant distortion across the printed area. Otherwise, the standard products are known to have slight distortions which may not affect one time unit delineation, but may be crucial in mapping the changes. An user can also ask for the geocoded products of the different satellites. However, these are usually consulted for some critical areas and at a scale of 1:50,000 or larger, because of the high cost of the products. Geocoded products of SPOT, Landsat TM and LISS 2 are very useful for visual interpretation of mapping.

Some Simple Equipments For Visual Interpretation

There are several simple, easy to handle equipments for visual interpretation of satellite date products. Some of these are useful for proper viewing of the paper prints, while some others help in viewing the transparencies and negatives. A few of the products are described below.

Light Tracing Tables : The photographic prints of the FCCs and single band black and white images are usually viewed under normal light for recognition of the features. Sometimes the tonal contrasts become poor, either because of processing defects or inherent properties of the features. The interpreter then needs an additional tool for proper visualization of the features The problem can be solved if the image is viewed on a light tracing table. These tables are fitted with tube lights under an opaque glass top. The defused light passing through the glass brightens the objects without any glaring effects on the eyes and, thus, helps in easy identification of different units on the basis of their tonal differences, and also for mapping of those units directly on a tracing sheet. Some of the tables are additionally fitted with magnifying glasses for identification and mapping of very small units. These tables are easy to manufacture and, therefore, the users can interact with local furniture makers to either modify some existing tables or to manufacture new ones according to the required size, height and other specifications.

Optical Enlargers : Two kinds of optical enlarger are very useful for visual interpretation and mapping. These are as follows.

Optical Pantographs: Where the scale of imagery does not match with the scale of the base map, the imagery needs to be enlarged or reduced to the scale of the base map. An optical enlarger is used for this purpose. The one that has been recommended by the Department of Space (Govt. of India) and is available in the Indian market, is Optical Pantograph which can carry any film negative, film positive (transparency), or photographic print up to 9" x9"size (240 mm) in its copy holder for continuous enlargement to 4x size, or reduction to 1/4th the original size. The light source is below the copy holder for the transparencies and negatives, and above it for paper prints. The illuminated image is seen at the desired scale vertically above the copy holder, and on a glass top. The movement of the copy holder up and down is motorised, so the user can easily match the scales and features of the original as it is enlarged or reduced to the scale of the base map or image. By putting a standard glass top over the viewing desk one can enlarge the features from 4x to 5x. For example, the standard film negatives and transparencies of Landsat images (including those of FCCs) are now available in 9" x 9" (240 mm) format, corresponding to the scale of 1:1 million . The 4x magnification of these products yield images at 1:250,000 scale. Since topographical sheets are also available at 1:250,000 scale, the details can easily be transferred from the magnified image to the topographical sheet at that scale or any other base map at 1:250,000 scale. Transferring the features from a 1:250,000 scale photographic print to a base map at 1:50,000 scale, however, involves 5x enlargement. This requires the help of an extra glass top. The instrument's carriage can also be tilted in X and Y directions through push buttons. This helps in correction of minor spatial distortions in the image while transferring the details on the above maps.

Optical Enlarger (Procom 2): For large scale mapping from the 9"x 9" (240 mm) format transparencies and negatives (1:1 million scale images for Landsat and LISS I; 1:500,000 scale images for LISS 2 images), the best results are achieved when the data products are put in the holder of an optical enlarger. The instrument is called Procom 2. It allows light to pass through a 2"x2" window. An enlarging lens system then enlarges the lightened area on to a platform. The images could thus be effectively enlarged up to about 50 times or more, depending on the lens system used and the resolution of the image. When the 1: 1 million transparency is enlarged to 1: 50,000 scale, the enlargement factor is 20x. Landsat TM and IRS LISS 2 transparencies are particularly suitable for enlargement through this equipment to the scale of 1: 50,000, especially because of their higher resolution compared to the MSS and LISS 1 images. The instrument is also helpful for mapping at cadastral scale, provided the resolution of the image is still better, as is found in the case of SPOT MLA and PLA images. There are other useful models of optical enlarger also.

Image Analyser : Sometimes the satellite data products are available to an user in the form of a single band BW print or negative. Characterisation of the land surface under such circumstances is to be carried out on the basis of one's ability to interpret the subtle tonal variation in the BW images. An analogue image processor, called the Image Analyser, can be useful in deciphering the details in areas of very low tonal variation. The TV camera of the equipment first senses the BW image (at 9" x 9" format or smaller), either in transparency form, or as a paper print, and reproduces it on the monitor. The video processor unit then allows the operator to alter the contrast and also to density slice the gray shades of the image on the basis of information supplied for small "training sets". The ultimate product on the monitor is a colour coded image. The area under each colour within the displayed total area can be found out, using the equipment's digital meter, as also the assigned value for each colour. Recent improvements suggest attaching the Image Analyser with a small IBM compatible computer having a VGA card, enough memory and disk space as well as good pixel resolution. A software called Frame Grabber records the image seen on the screen of the Image Analyser and saves it in a computer language. This allows the interpreter to carry out many statistical analyses on the scene, to saveit on computer for future use and also to take print of the analysed scene at desired scale and time.

Additive Colour Viewer : We have noted earlier that standard FCC of band 2+3+4 is very useful for land resources mapping. However, if the FCC prints are not readily available, but the film negatives/positives of individual bands are, then FCCs could be prepared through the use of an Additive Colour viewer. The instrument's carriage can hold four transparencies of 70 mm size on a single plane. Between the light source and the transparency holder is a set of three filters in blue, green and red. The operator can put these filters on any three bands and co-register them on the screen or the viewing desk and see the final output of the three-band images in colour. The operator is, thus, at a liberty to create his own colour composites, providing any colour to any band. The standard FCC, on the other hand, assigns blue, green and red filters on band 2, 3 and 4, respectively, Although this equipment was in great demand during the early phase of satellite remote sensing, it is not very popular now.

Diazo Printer : Apart from viewing the colour composites we can also prepare the diazo colour prints, using a Diazo printer and diazochrome film. To produce a standard FCC, the transparency of band 2 is first put face to face with a yellow film and kept inside the printer. A mercury vapour lamp then exposes the film. The film is then moved into an ammonia chamber where it is developed. Subsequently the band 3 transparency is placed face to face with a magenta film, and the band 4 transparency with a cyan film for exposure and development in the manner stated above. The three films are then co-registered to produce a FCC. The quality of the product is, however, not very high. In a colour photographic enlarger, on the other hand, light is passed through blue, green and red filters over the negatives and a colour composite print is produced.

Digital Image Processing

The visual interpretation of the images in print is, sometimes, constrained by the poor quality of the print and/or some inherent characteristics of the raw data. Under such circumstances several digital image processing techniques are very useful. However, digital image processing is a costly affair and, hence, needs to be carried out with clear objectives in mind and in areas with specific problems. We shall discuss some basic features of this technique.

Digital image processing is a powerful tool and does not depend on the bias and/or limitations of the interpreter. In this technique the interpreter uses the Computer Compatible Tapes (CCTs) of the desired scenes and run them through a host computer. Therefore, it requires a robust computer hardware system, including a good digital computer with enough disk space and memory, as well as peripherals like a tape drive, a digitizer, a plotter, a printer and, if possible an in-built camera and a photo-write system. It also needs a software package to perform different kinds of processing on the image, so that the desired patterns emerge from the raw scene. The basic processing techniques for enhancing the vegetation features have been mentioned earlier (Kar and Ram, this volume).

There are several good software in the market. These include ERDAS, ISROGIS, PAMAP, EASYPACE, SPANS, etc., which can be used in any IBM-compatible machine, especially using the UNIX or SUN working environment. Most software are raster-based, but some can also handle vector data structure (e.g. PAMAP). Remote sensing software are now increasingly used in conjunction with GIS capabilities. Most remote sensing software have, therefore, either simultaneous GIS capabilities, or are compatible with some GIS, so that the user can transfer his results from image interpretation to the mapping platform with a greater degree of accuracy. It also helps the interpreter in creating appropriate database for modelling the past, present and future of the resource he analyses. ERDAS software is compatible with ARC INFO GIS. Software are also available for use in Macintosh and Intergraph machines.

There are many functions which can be carried out with the remote sensing software. These include rectification of errors in the image, like radiometric and geometric rectifications, which is a basic requirement in any image processing. It is also possible to perform enhancement of the features in the image, especially through contrast stretching. There are three major types of stretching. These are linear stretching, non-linear stretching and density slicing. The latter one includes many complicated statistical algorithms for feature enhancement. Other capabilities include band combination, filtering (low pass and high pass), as well as supervised and unsupervised classification.

Further details on different aspects of remote sensing and its application potentials are available in Lillesand and Kiefer (1979), Colwell (1983), Sabins (1986), Patel and Singh (1992), Bonham-Carter (1994) and Rao et al. (1994).

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AMELIORATION OF PROBLEMATIC ARID SOILS THROUGH SILVIPASTORAL SYSTEM

D.C. Joshi

Introduction

Silvipasture involves growing grasses between trees or planting trees on the grassland. The term has been scientifically defined recently, but the concept is in practice in India since long. In silvipasture system trees, shrubs and grasses are grown simultaneously on a piece of land, which are complementary to each other. It offers a sustainable land management system which increases overall productivity of the land, conserves soil resources, improves environment, offers an efficient system for utilisation of rainfall and stored soil moisture and recycling of the nutrients.

Establishment of such a multistorey system on the degraded arid areas is not an easy task. It requires a holistic approach keeping in consideration the low erratic rainfall, sandy shallow saline soils with low fertility, uneven and sloping topography, scarce saline ground water, large livestock population and sometimes the apathetic attitude of local residents.

Soils, which form the foundation of the 'multistorey system', vary widely in terms of their potentials and limitations. Therefore, a successful silvipasture programme should have a good appraisal of soil resources. Based on the knowledge of soil characteristics, selection of proper plant species and appropriate soil moisture conservation techniques can be made. This is discussed through a brief appraisal of the problematic soils of arid Rajasthan. The relevant physico-chemical characteristics and the available water holding capacity of soils are reported in Table 1 and 2 respectively.

Problematic Soils

Dune Complex Soils: The sand dunes in arid Rajasthan are mostly of parabolic shape, but longitudinal, transverse and barchan dunes also occur. These dunes are associated with narrow interdunes. The dune-interdune association has been termed dune complex and is the largest single unit occupying 30-40% area in arid Rajasthan. These occur in less than 250 mm rainfall zone and also in the 300-400 mm rainfall zone. Due to intense biotic activities, these are under severe degradation and need immediate attention.

The soils associated with dune complex are uniformly fine sand, pale brown to yellowish brown (10 YR 6/3-6/4) and 150 cm deep. The silt and clay contents are 0.4-1.3% and 1.8 to 4.5%, respectively. The $CaCO_3$ (0.6-5%) content is mostly in diffuse form. The interdune soils are similar in colour but have slightly more silt, clay and $CaCO_3$. These soils have been classified as mixed, hyperthermic Torripsamments.

The surface of dune complex is uneven. Besides the slopy and uneven dune swales the interdunes are also filled with thick sand sheets, hummocks and barchanoides. The available

Table 1. Physico-chemical characteristics of the problematic soils

Depth (cm)	Particle size distribution (%)				CaCO3 (%)	Moisture equivalent (%)	pH (1:2)	Electrical Conductivity(EC, dSm -1)
	Clay	Silt	Fine sand	Coarse sand				
Dune complex								
0-25	1.9	1.1	96.0	4.5	1.5	2.0	8.04	0.16
25-50	4.8	1.5	86.9	4.3	1.4	3.5	8.01	0.16
50-75	4.2	1.4	89.9	3.5	1.5	3.0	8.04	0.16
75- 100	5.5	1.5	88.8	3.5	1.3	4.5	8.10	0.16
Light brown sandy								
0-20	3.8	3.8	88.6	10.0	0.8	4.8	9.80	0.24
20-40	*9.6*	*16.3*	*64.3*	*50.0*	*4.9*	*15.8*	7.45	*0.66*
40-60	13.0	14.1	58.2	76.2	8.3	17.1	7.54	0.26
Hard pan soils								
0-10	7.2	6.8	74.7	11.3	-	7.8	8.21	0.11
10-30	9.3	8.3	69.3	12.6	0.2	10.3	8.24	0.13
30-50	10.4	9.2	67.1	12.0	1.3	10.5	8.20	0.15
Below 50	13.2	11.6	22.1	14.3	38.6	-	8.30	0.30
Gravelly uplands								
0-8	5.9	3.3	74.1	11.9	4.1	17.3	8.20	0.24
8-15	7.6	6.7	54.9	15.4	14.2	21.3	8.50	0.25
below 15 Gravelly layer								
Salt affected								
0-20	28.7	29.1	30.3	0.5	11.3	30.1	7.07	28.6
20-50	16.4	24.9	49.0	0.6	8.5	27.5	7.23	19.9
50-70	16.6	24.9	51.0	0.8	6.7	28.6	7.44	21.3
70- 100	24.6	28.3	40.0	0.4	6.8	36.1	7.30	26.1

water capacity is low (50-80 mm/metre). The surface soil dry quickly but in subsoil moisture is available for deep rooted plants.

Light Brown Sandy Soils

These are soils of sandy plain. Scattered sand hummocks and occasional sand dunes occur on these plains. The soils are brown to yellowish brown (10 YR 5/3-5/4), loamy fine sand/fine sand and weakly aggregated. The silt and clay content ranges are 3.6 to 6.2% and 1.8 to 3 2%, respectively. The subsoil is loamy sand, weak subangular blocky with some what more of silt

Table 2. Moisture retention capacity of some typical arid soils

Soil group/series	Available moisture capacity (%)	(mm/m)
Dune complex	3.8-5.4	52-78
Light brown sandy soil		
Thar	4.7-6.8	53-84
Chiral	5.8-7.4	72-86
Grayish brown loam soil		
Pipar	10.3-17.2	75-125
Gajsingpura	14.3-17.2	160-190
Asop	12.3-15.2	140-165
Shallow hard/gravelly soil		
Kolu	5.6-7.2	35-68
Bher	6.8-9.7	48-78
Kumparabas	7.4-9.4	63-84

and clay. Below 60-90 cm depth lime concretionary layer occurs. This concretionary layer is pervious to roots and water. These soils are members of coarse loamy, mixed, hyperthermic Cambids/Calcids.

Hard Pan Soils

These are generally 30-40 cm deep sandy soils, underlain by a compact lime concretionary strata. The soils are pale brown to yellowish brown (10 YR 6/2, 5/4), fine sand to loamy sand and weakly aggregated. Clay and silt contents are in the range of 6.1 to 8.4% and 4.0 to 5.5%, respectively. The substrata is compact due to lime and silica and is impervious to roots and water These have been classified as coarse loamy, mixed, hyperthermic, Lithic Petrocalcids.

These soils have root zone limitation. The available water capacity is also very low (39-50 mm/50 cm depth). Because of these limitations the soils do not support perennial and deep rooted plants.

Gravelly Uplands

In arid region of Rajasthan such soils occur in two situations: i) associated with sandy plain and ii) in the pediment zone. The gravelly upland soils associated with sandy plain have thin veneer of fine sand/loamy fine sand, underlain by a thick zone of loose lime concretionary material. These soils have severe root zone limitations, very low available water capacity and are moderately prone to wind and water erosion.

The gravelly soils associated with pediments may vary in texture from fine sand to sandy loam and loam. The solum has appreciable mixture of rock fragments. Moderate slope, moderate to severe water erosion, low available water capacity and appreciable mixture of gravels in the soil mass are the constraints of these soils. However, frequent runoff from the adjoining hills and protection against hot wind are favourable conditions for silvipastoral management.

Salt Affected Soils

In arid and semi-arid regions, high salinity in soils and ground water assumes unusual proportion and poses a problem to reckon with. Natural saline flats, saline depressions, relict saline and secondary salinised lands due to high water table are common. Such lands are better suited for silvipastures than arable cropping.

Natural salt affected soils are scattered as small patches throughout the arid Rajasthan, but their major occurrences are in the flood plains of Gaggar river in Hanumangarh, Bikaner and Shri Ganganagar districts and in the south-eastern part in Jodhpur, Pali, Nagaur and Jalor districts. The soils are grayish brown to dark grayish brown (10 YR 5/2, 4/2), loam to clay loam and silty clay loam. These are 60-150 cm deep. The soil profile is highly saline (EC 20- 80 dSm^{-1}). Salinity in the surface soil is high and gradually decreases with depth. The soil profile is very compact with prismatic/columnar structure. Water infiltration and permeability in the profile are restricted. During rainy season water remains ponded on the surface. Relict saline soils have high salinity in the substrata. The waterlogged soils associated with high salinity are common in canal command areas. Seepage from main canal and high water table in the irrigated fields have resulted in the development of this problem. Such lands have gone out of cultivation in the IGNP area and in other small irrigation projects in south-eastern arid Rajasthan.

Inherent Fertility Status

The degraded problematic soils are generally low in the available nutrient (Tables 3 and 4). The sandy soils contain low organic carbon (less than 0.1%), 10-15 $kg\ ha^{-1}$ available phosphorus and 140 to 200 $kg\ ha^{-1}$ available potassium. With slight increase in the silt and clay content there is increase in the available nutrients. The loam and clay loam soils contain 0.3 to 0.4%

Table 3. Major nutrient status of the problematic soils

Soils	Organic carbon (%)	Available phosphorus (kg ha -1)	Available potassium (kg ha^{-1})
Dune complex	0.10-0.16	10-15	116-392
Light brown sandy	0.12-0.15	9-15	78-482
Hard pan/gravelly upland	0.15-0.25	15-20	300-890
Salt affected	0.08-0.73	9-25	67-400

organic carbon, 15-20 kg/ha phosphorus and 200-700 kg/ha potassium in available form. The available iron, manganese, zinc and copper content of these soils vary widely (Table 4). All the soils are well supplied with the available Fe and Zn but Mn and Cu is marginal to low in dune complex and other sandy soils. The salt affected soils have been found to contain adequate amount of micronutrients to meet the requirement for silvipastoral management (Joshi *et al.*, 1981, 1983). Micronutrients are well distributed in the profile which can meet the requirement of deep rooted trees and shrubs.

Table 4. Micronutrient status (ppm) of the problematic soils

Soils	Fe	Mn	Zn	Cu
Dune complex	3.5-27.5 (7.8)	1.1-16.0 (6.1)	0.27-1.91 (0.80)	0.12-1.52 (0.44)
Light brown sandy	3.4-8.6 (6.2)	4.0-13.4 (8.0)	0.41-1.32 (0.85)	0.36-0-89 (0.50)
Hard pan/gravelly upland	2.5-7.6 (4.5)	3.0-12.0 (6.0)	0.30-1.21 (0.70)	0.25-0.75 (0.40)
Salt affected	2.6-16.0 (6.07)	6-29 (12)	0.56-3.37 (1.10)	0.55-2.08 (1.10)

Data in parenthesis indicate mean values

Land Capability Classification

Land capability is the inherent capacity of land to perform at a given level for general landuse. The major factors which govern land capability classification are inherent soil characteristics, landscape features and the climatic factors. Under this system the agricultural use of land is confined to class I to IV, while the alternate uses are recommended for lands with capability classes VI to VII. The land capability classification also identifies the constraints that limit the landuse viz. the climates (c); soil depth (d); texture (s); wind erosion (ea); water erosion (ew); salinity/alkalinity (sa); topography (t) and drainage (d). Landuse capability surveys for some of the arid zone district (Table 5) revealed that in Jaisalmer and Barmer districts, receiving <100-250 mm rainfall, the majority of the area qualified for class VI and VII and thus recommended for silvipasture.

Silvipasture: Alternate Landuse for Problem Soils

In the arid region low and erratic rainfall, high temperature and dust storms in summer impose severe restrictions on the use of land for arable cropping. In the rainfall zone of less than 250 mm, silvipasture rather than arable cropping has been regarded as sustainable landuse irrespective of the soil type and terrain characteristics. In the rainfall zone of 250-500 mm the dune complex, hard pan, shallow gravelly uplands and salt affected soils qualify for landuse capability class VI and VII which suggest that these areas are mainly suited for silvipastoral land uses. However, because of socio-economic constraints, the dune complex are being cultivated for rainfed crops. The crop yields are meagre and this practice of cultivation inflicts damage to soil. Silvipasture is a better alternative for such lands.

Table 5. Land capability classification of typical arid zone district

District	Rainfall	Land capability classes (Area km^2)				
	(mm)	III	IV	VI	VII	VIII
Barmer	200-300	1673	5844	7555	10698	2043
Jaisalmer	<100-250	280	2492	16389	13671	5568
Jalor	400-500	5376	2623	406	1471	764
Nagaur	300-500	9555	3425	3540	190	1020

The swales of sand dunes and uneven topography of the interdunes impose restriction on soil working. The dune complex soils have low moisture retention capacity and high infiltration rate. The rain water received during good/normal rainfall years reaches to lower horizons. Because of low capillary movement of water in sandy soil, the moisture remains localised at some depth. The shrubs, grasses and trees feeding in different zones can utilise this moisture. The vegetation canopy also protects the sandy soils from erosion. The leaves shed by the vegetation enrich the soil.

The dune complex soils are most susceptible to wind erosion. Therefore the first step is to create micro wind break. This can be achieved by using locally available materials like dried twigs of the bushes and trees. In Indian desert the twigs of *Prosopis cineraria, Zizyphus nummularia* and *Calotropis procera* and whole plant of *Crotolaria burhia, Aerva persica* and *Calligonum polygonoides* are used. In Iran and China twigs of *Haloxylon* sp. and *Tamarix* sp. are used. The trees, shrubs and grasses suitable for dune complex are listed in (Table 6). After establishment of microwind break these plant species can be grown. The runoff water should be conserved in situ.

On vast stretches of sandy plain, particularly in the rainfall zone below 250 mm, frequent droughts lead to failure of the rainfed crops. The tree species can be planted at 4m x 5m or 5m x 5m interval and grasses can be grown in between. Here the soil/moisture conservation measures like revegetation mulching and vegetative barriers should be adopted.

Hard pan soils are recommended for silvipasture because of their severe root zone limitations and droughtiness. On these soils *Prosopis juliflora*, and *Acacia tortilis* can be grown by breaking the compact lime concretionary strata. The shrubs like *Aerva tomentosa, Crotolaria burhia* and *Calotropis procera* naturally come up on these lands. The grasses like *Sehima nervosum* and *Dichanthium annulatum* can be grown. Contour bunding and field bunding are essential to conserve the rain water.

On gravelly uplands it is difficult to establish trees. However *Acacia senegal, Acacia tortilis, Prosopis juliflora* can be grown by following soil and moisture conservation measures. The shrubs like *Capparis decidua* and *Ziziphus nummularia* are well suited for these lands. The grass cover including *Aristida funiculata* and herbs like *Indigofera cordifolia* also do well on these lands. The sheetwash should be checked by providing contour trenching, contour furrowing and staggered contour trenching.

For saline flats, the plant species are selected according to the salinity level and physico-chemical characteristics of the soils (Table 7). For establishment of tree saplings the

pits are dug and the saline soil is replaced by good soil. Ridges of 0.8 to 1m height are created in east-west direction and the grass seeds are sown on ridges in between the tree rows on sodic soils. Application of gypsum @ 50% soil gypsum requirement is essential. For planting trees the compact subsoil layer should be broken and gypsum mixed with the soil should be refilled in the hole Gypsum can also be uniformly applied in the fields, mixed with soil and then rain water allowed to be ponded. This will improve the soil physico-chemical properties.

Table 6. Plant species, suitable for dune complex

Trees	Shrubs	Grasses
Rain fall 150-250 mm		
Acacia tortilis	*Calligonum polygonoides*	*Lasiurus sindicus*
Acacia senegal	*Zizyphus nummularia*	*Panicum antidotale*
Acacia jacquemontii	*Zizyphus rotundifolia*	
Rain fall 250-400 mm		
Prosopis cineraria	*Calligonum polygonoides*	*Cenchrus ciliaris*
Tecomella undulata	*Zizyphus mauritiana*	*Cenchrus setigerus*
Acacia tortilis		*Saccharum munja*
Acacia senegal		
Rainfall 400 mm and above		
Prosopis cineraria		
Albizzia lebbek		*Panicum turgidum*
Colophospermum mopane	*Ziziphus mauritiana*	*Saccharum munja*
Acacia senegal		*Cenchrus ciliaris*
Pongamia glabra		*Cenchrus setigerus*
Pongamia pinnata		
Azadirachta indica		
Ailanthus excelsa		
Cassia siamea		
Dalbergia sissoo		

Harsh, L.N. (1996)

Treatment of 5 t ha^{-1} gypsum progressively increase the infiltration rate over the years (Anonymous, 1980). In medium black soil with alkali problems, gypsum treatment does not improve the forage yield. However, different soil and moisture conservation measures like bunding, corrugation and tied ridge planting have some positive effect on forage yield. At Gudda (Haryana) Grewal and Abrol (1986) from an alkali soil, reported the fresh foliage yield of 7.7 to 16.5 t ha^{-1} of Karnal grass (*Diplachne fusca*) grown in association with *A. nilotica* in flat surface planting. Higher forage production was recorded under ridge planting. Abrol and Gill (1988) suggested planting tree seedlings in auger holes filled with a mixture of original soil, 2- 3 kg gypsum and 7-8 kg farm yard manure in sodic soils for afforestation. The auger holes of 15 cm diameter and 180 cm depth have given better performance of plant species than shallow (60 cm) auger holes.

In arid regions, soil are also severely degraded due to irrigation with high residual sodium carbon (RSC) water. After 10-15 years irrigation such lands are turned unfit for cultivation. In cases of water containing high RSC (15-20 me L^{-1}) the soils become very compact, water infiltration restricted and nutrient availability also becomes limited (Joshi 1988, 1989). Amelioration of such soils has been attempted by application of gypsum @ 100% of the soil gypsum requirement + quantity of gypsum required to neutralise RSC in excess of 4 me L^{-1}

Table 7. Plant species suitable for salt affected soils

Species	Soil EC (dSm^{-1})		
	High (more than 16)	Medium (8-16)	Low (4-8)
Tree/shrubs	*Prosopis juliflora* *Tamarix articulata* *Prosopis pallida* *Prosopis tamarugo* *Prosopis chilensis* *Salvadora sp.* *Casurina equisetifolia* *Atriplex sp.* *Haloxylon recurvum* *Suaeda fruticosa*	*Acacia leucocephala* *Dichrostachys nutans* *Acacia nilotica*	*Azadirachta indica* *Acacia aneura* *Colophospermum mopane* *Eucalyptus camaldulensis*
Grasses	*Sporobolus marginatus* *Eleusine compressa* *Dactyloctenium sindicum* *Karnal grass*		*Heteropogon contortus* *Cenchrus setigerus*

(Joshi and Dhir 1990, 1994). Gypsum application decreased the pH of the surface soil by 0.3-0.4 units and SAR. The accumulated infiltration rate was higher in the gypsum-treated fields.

During 1979, unprecedented flash flood in the river Luni deposited 40-100 cm thick saline sediments on the most productive lands. These lands turned barren and even a blade of grass was difficult to grow. Gypsum application as per 100% soil requirement followed by leaching was effective in reducing salinity (Joshi and Dhir 1990). Higher level of gypsum was more effective in lowering SAR. Increased infiltration due to gypsum application further helped in lowering the salinity Such reclaimed lands can be brought under silvipastoral land use, because of paucity of good quality water for irrigation of arable cropping.

The silvipastoral systems and their various facets when compared with traditional land use have been found to yield more than 7 times with year round forage availability and also very high protein and nutrition for animals. The multitier system has been found highly economic compared to other forms of land use. Gupta and Mohan (1982) found the silvipastoral system to be more remunerative than the rainfed farming in arid and semi-arid climates.

Under poor soil, water and nutrient situations of problematic soils, where cropping is not possible, the silvipasture serves the twin purpose of forage and wood production. In addition it also conserves the eco-system. By following the silvipasture techniques based on soil characteristics a holistic development of the area can be achieved

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WIND EROSION AND ITS CONTROL IN ARID REGIONS

J.P.Gupta

Introduction

Movement and deposition of sand is an important factor for degradation of otherwise productive lands. Out of 175 million ha area suffering from degradation in the country, about 60 million ha is due to wind erosion alone. As much as 58% area of western Rajasthan is occupied by sand and semi-stabilized sand dunes. Wind erosion is one of the main problem of the region and is doubly harmful as both areas from where the soil is removed and where it is deposited, lose their productivity. Moreover, sand transported and deposited by aeolian process do not remain stationary but move further along the wind direction causing damages to crops, economic establishment and communication channels, etc. Degradation of land through wind erosion is major threat to agriculture and allied activities.

Wind Erosion Process

The wind erosion process may be divided into three distinct phases:(i) initiation of sand movement, (ii) transportation, and (iii) deposition. Initiation of soil movement results from turbulence and velocity of wind. Wind velocity near the smooth ground surface is zero, some distance above this is smooth and laminar but above this it is turbulent. If the soil particles are attached to each other strongly, they can resist the force of wind and do not move. The initiation of soil movement thus depends upon the force of turbulent wind, the surface roughness and the size of soil grains. The amount of sand moved depends upon particle size, wind velocity and the distance across the eroded area The quantity of soil moved varies as the cube of excess wind velocity above the constant threshold velocity, the square root of particle diameter and gradation of soil. Deposition of sand occurs when the gravitation force is greater than the forces holding the particles in the air The process generally occurs when there is a decrease in wind velocity caused by vegetation or other physical barriers such as fencing, ditches, etc.

Types of Sand Movement

(i) *Surface creep*: It is the rolling or creep of the larger particles over the surface. The soil particles are generally too heavy to be lifted by wind. They move primarily by the impact of particles in saltation and not direct force of wind.

(ii) *Saltation*: It is the bounding or jumping of soil particles mostly in the range of 0.05 to 0.5 mm. The movement of particles due to wind erosion is predominantly by this process.

(iii) *Suspension*: It is the floating of small sized particles in the air stream. Fine dust is picked up by bigger particles in saltation. Once entered in the turbulent air layers are lifted high into air by upward eddy currents Fine sand, silt, clay and organic matter are generally, eroded by this process.

Causes And Factors of Wind Erosion / Deposition

Natural Factors : High wind velocity, scanty rainfall, structureless sandy soil, extreme variation of diurnal and annual temperatures and high evaporative demand of the atmosphere are the main factors responsible for wind erosion in arid regions The wind regime builds up from April onwards and the strongest winds are observed in the months of April to June During dust storms activity wind speed often reaches 60 to 80 km hr^{-1} (Ramakrishna, 1992) Drought conditions result in sparse vegetation This along with excessive biotic interference deteriorates fast and causes soil to blow off more vigorously The observations made by Krishnan (1977) show that in arid regions the dust blows up to 20,000 to 30,000 ft

Measurements of dust blowing from the surface to a height of 3 metres indicate that the average amount of dust blowing on the day of dust storms varies from 0 50 to 4 2 q ha^{-1} in Jodhpur In case of Jaisalmer, however, where the wind speeds are high, an average of 5 11q ha^{-1} was recorded Removal of grass cover in an area of about 2000 m^2 at Chandan (Jaisalmer) resulted in soil removal of 1 065 m^3 within three years The climatic wind erosion indices for some stations of arid Rajasthan are presented in Table 1.

Table 1: Climatic wind erosion indices (%) for some stations of Indian desert.

Station	Climatic (a)	Wind erosion (b)	Index category
Jaisalmer	32 59	73 78	High
Jodhpur	3 71	6 81	Very low
Nagaur	2 30	4 58	Very low
Jaipur	1 94	2 44	Very low

(a) Based on mean annual wind velocity
(b) Based on mean wind velocity of summer months (March-Sept)

Minimal threshold velocity for initiating wind erosion was found to be 5 km hr^{-1} for Bikaner and 10 km ha^{-1} for Jaisalmer (Gupta *et al* , 1981) The critical wind velocities for the above two sites were 15 and 25 km hr^{-1}, respectively Much of the wind action is confined to summer months April to June It is during the summers that the ground vegetation cover is minimum, facilitating severe wind erosion

Besides the wind speed, the major soil factors affecting erodibility are soil texture , state and stability condition of soil particles Soil texture plays an important role in determining the erodibility of particular soil to wind erosion (Table 2) The soils of the arid zone are predominantly formed of coarse particles i e sand Fine to medium sand predominated in their fabrics with little silt and clay, the quantity of latter two particles seldom exceeds 25% together Thus, while the sandy components predominate in particles size (80-95%), organic matter is low Such soils are generally structureless and single grained to weakly subangular blocky This makes these soils prone to wind erosion The data presented in Table 3 shows a relative

Table 2. Wind erodibility indices for different soil textures.

Predominant soil texture	Soil erodibility index (mg ha^{-1} year^{-1})
Loamy sand and sparic material	360-700
Loamy sands	300
Sandy loam	200
Clay and clay loam	200
Calcareous loam	200
Non-calcareous loam, silt loam 2%clay, and organic soil	125
Non-calcareous and silt loam 20% clay	100

loss due to wind erosion from different soil types in Rajasthan. Irrespective of wind velocity, soil loss was found to be higher from Bikaner than from Chandan and Jodhpur. Grain size distribution in a particular soil is also related with erodibility. Soil samples from Bikaner and Chandan showed higher percentage of grains in the range of 0.1 to 0.25 mm in the eroded samples showing thereby higher susceptibility of this fraction to wind erosion (Table 4).

Anthropogenic Factors : In arid regions, besides climatic vagaries and erratic monsoon the escalation of human and animal population are major factors causing deterioration in the ecosystem The arid region at present has an average density of about 90 persons per km^2 and is one of the most thickly populated in the world. During the last few decades, the human and animal population has registered a substantial increase in the area consequently more and more marginal lands are put under cultivation. Thus, the increasing activities of human and animal, cultivation particularly on duny complex, over exploitation of trees for fodder and fuel and indiscriminate grazing have accentuated the erosion/deposition process. The magnitude, however,depends upon factors such as soil type, slope and land use, etc. Dhir (1989) and Raina (1992) have also reported an acceleration of wind erosion due to human activities in arid zone

Table 3. Soil loss due to wind erosion in western Rajasthan.

Mean wind velocity (km hr^{-1})	Soil loss (kg ha^{-1})		
	Chandan Sand	Bikaner Sand	Jodhpur loamy Sand
5	1.0	0.5	0.3
10	8.0	120.8	1.4
20	76.7	273.7	15.6
40	1276.0	1605.2	-

Impact of Wind Erosion/Deposition

Soil Loss : Gupta and Aggarwal (1980) recorded a loss of 9.6 cm and 0.2 cm top soil layer from a bare and stubble covered sandy plains, respectively during April to June 1977 The

Table 4. Grain size distribution in the field soil and eroded samples from two sites in western Rajasthan.

Site	Soil description	% distribution of soil grain (mm)		
		0.25	0.1 to 0.25	0.05
Bikaner	Field soil	12.8	62.0	0.5
	Eroded soil	12.8	69.4	0.6
Chandan	Field soil	16.0	66.6	1.5
	Eroded soil	14.8	73.5	0.4

pasture land remained free of erosion. During stormy days of 1973 to 1975, the sediment load up to 3 m above the land surface at Jodhpur and Jaisalmer was 0.5 to 4.2 q ha^{-1} and 5.1 q ha^{-1} respectively. The removal of grass cover from 2.0 km^2 caused soil loss of 1065 m^3 in three years with a loss of 0.53 m soil depth. The grain size distribution in these sediment included fine sand (55-75%), clay (6-15%) and silt (14-39%). During an unusual strong wind regime in the year 1985, characteristics of aeolian sediments from three different land forms were studied by Ramachandra *et al.* (1992). Thick sand sheets (40-100 cm) were a common feature in interdune, while in sandy plain the magnitude of sand features was much less (20-50 cm). Shallow gravelly area generally escaped sand deposition. During the same stormy period, acceleration in wind erosion due to cultural practices was also observed (Dhir, 1989). The sandy plains deep ploughed with tractors lost 2630 to 3160 t ha^{-1} soil while the fallow lands with 2-4 per cent vegetation cover lost 207-283 t ha^{-1} soil. The loss from pasture with 8-12 per cent vegetation cover was negligible.

Loss of Nutrients : The removal of top soil by wind erosion also causes loss of plant nutrients and thus productive lands are turned unproductive. A mean of 192.4, 101.2 and 103.9 kg ha^{-1} N, P and K was found to be lost in two months under arid zone conditions (Gupta and Aggarwal, 1980). The concentration of nutrients was maximum in soil grains having diameter less than 0.05 mm, the total nutrient loss was highest from bare soil having higher percentage of grain of diameter greater than 0.1 mm. .The content of nutrients in fence line deposition was higher than the field proper (Dhir, 1987). The effect of wind erosion on the fertility status of different land uses showed (Raina, 1992) that a decrease in organic carbon at degraded site was more in oran (50.7%) followed by cultivated (50.3%) and pasture (39.4%). In case of K, the decrease was 55% in cultivated 35.2% in oran and 12% in pasture lands. The decrease in P was maximum in pasture land. Thompson (1952) reported loss of 27 kg available N, 12 kg available P and 158 kg available K per hectare annually.

Loss of Crop Yields : It is a common belief that the crop yields in severely eroded lands is half to two third of that from uneroded field. Bittu (1989) recorded 30% loss in crop yield due to soil deterioration through wind erosion in 40 years.

Control Measures

The control measures are broadly of two types viz., (i) Sheltering the soil from wind erosion, and (ii) Creating soil condition resistant to wind action. The control practices may include the following-

Table 5. Yield of dryland crops

Crop	Yield kg ha-1	
	1942	1982
Pearl millet	1000	700
Moth bean	800	500

Plantation of Wind Breaks and Shelterbelts : Wind break is any type of barrier used for protection from winds-while shelter belt is a barrier longer than wind break usually consisting of trees and shrubs. The importance and utility of shelterbelts in checking the wind erosion has been well recognized. Considerable work has been done on the plantation of trees as wind breaks and shelterbelts. The effectiveness of shelterbelts in reducing the wind velocity depends on velocity and direction of wind and also on canopy growth, design and geometry of shelterbelts *Prosopis juliflora*, *Azadirachta indica* and *Albizzia lebbek* as three row shelterbelt along the highways in pyramidal shape were found suitable in desert areas (Kaul, 1985).

The percent reduction in mean wind speed of 8 years old 5 m tall shelterbelts of *Prosopis juliflora*, *Cassia siamea* and *Acacia tortilis* was maximum at 2H distance (Gupta, 1993) The reduction in wind speed by all the three types of shelterbelt during monsoon was higher than summer possibly due to better canopy growth. The use of shelterbelt also brought about 50% reduction in wind erosion. A mean loss of 548.8 kg ha^{-1} soil from bare field reduced to 351, 300 and 184 kg ha^{-1} by shelterbelts of *Prosopis juliflora*, *Acacia tortilis* and *Cassia siamea*, respectively. The total nutrient loss was also found to be maximum from bare soil without shelterbelts followed by *P. juliflora*, *A. tortilis* and *C. siamea* showing thereby the conservation of soil fertility by the shelterbelts. Ganguli and Kaul (1969) and Bhimaya *et al.* (1958) reported that shelterbelt when planted across and on boundaries of agricultural fields, effectively control sand drift and protect crops.

Sand Dune Stabilization : The sand dunes and their movement is a menace to productive agricultural fields and other economic establishments and therefore deserve stabilization. Water balance studies in arid zone has revealed considerable moisture (2-5 per cent) stored in lower depths of unstabilized dunes even in the peak evaporation months of May-June (Gupta, 1979). The reason is low capillarity. This shows that there is considerable scope for the stabilization of such areas. Techniques have been developed for fixing and afforestation of sand dunes by CAZRI. These have been used by the state agriculture and forest departments for arresting the movement of sand dunes.

Stubble Mulching : Close growing crops are generally more effective for erosion control than are inter tilled crops. Experiences have shown that close growing crops protect soil, but inter tilled crops lose soil by wind erosion. The practice of planting the crops normal to prevailing wind direction is useful. Under stubble mulch farming, crop stubbles are left in the field and the next crop is planted with minimum tillage. In mid west dust bowl of United states, large scale mechanised stubble mulch farming is practised as a measure of protection to the cultivated farm land from wind erosion. In arid zone of India, Mishra (1974) reported a decrease in soil loss by 28.6, 46.5, 54.6 and 63.5 per cent after 15,30,45 cm and whole stalk pearl millet stubbles left in the field. In western Rajasthan (Bikaner), total soil loss occurred in 75 days was 1449 t ha^{-1} from bare fields but reduced to 22.5 t ha^{-1} from the field covered with 10-15 cm stubbles of pearl millet (Gupta and Aggarwal, 1980). Crops stubbles also reduced surface evaporation and eventually helped in growth of vegetation. This practice, however, has limitations to its adoption on large scale because the farmers are reluctant to leave stubbles in the field because they are useful as animal feed.

Wind Strip Cropping : Strip cropping consists of growing alternate strips of cultivated crops and close growing crops in the same field. The main advantage of this practice are (1) Physical protection against blowing of sand provided by vegetation, (ii) soil removal limited to a distance equal to the width of strip, (iii) greater conservation of water, and (iv) possibility of earlier harvest. Field strip cropping of grass strips to legumes (mung bean and moth) in a ratio of 6:1 has been found useful for the control of wind erosion and higher crop production Strips of perennial grass of *Lasiurus sindicus* and *Ricinus communis* at right angle to the prevailing wind direction reduced the impact and threshold velocity of wind to the minimum and thus checked the wind erosion and increased the production of crops in between protective strips (Mishra, 1971). Wind strip cropping as recommended in USA and Canada may not be feasible because of Indian land tenure system and small scattered holdings. However, the field strip cropping system of grain legumes or cereals in grass strips seems promising, for it can be applied to individual fields and holdings.

Primary and Secondary Tillage : The objective of proper tillage is to produce rough cloddy surface. for wind erosion control Excessive tillage of land when it is dry breaks clods and exposes it to wind action. The results of a study showed that clods greater than 5 mm size in the disked field were 42% but when disked and planked they reduced to 12.7% (Table 6)

Wind erosion in 5 days period in disked and planked field was 42 t ha^{-1} in contrast to only 0.5 t/ha in disked field (Gupta and Gupta, 1981). The sandy soil ploughed with tractor were found to lose 2630 to 3160 t ha^{-1} soil but fallow land having 2-4% vegetation cover lost only 207 to 283 t ha^{-1} soil (Dhir, 1989). Direct seeding by tractor operated drill without prior seed-bed preparation has been observed to yield as much pearl millet as with seeding after preparatory tillage

Conclusion

To conclude it may be mentioned that wind erosion/movement of sand is a menace seriously affecting the productivity of agricultural lands and other economic establishments and therefore need conservation. Various technologies like minimum tillage, shelterbelt plantation, sand dunes stabilization, wind strip cropping, pasture development and silvipasture system suiting to different agro-ecological zones have been developed and need wider adoption.

Table 6. Soil loss from cultivated field.

Soil treatment	Soil condition (clods >5mm)				Wind velocity (km hr^{-1})		Soil eroded
	Clods (%)	Mean wt.(g)	Mean dimension Length	Width	Max.	Min.	(t ha^{-1})
Ploughed and Planked	12.7	1.75	2.1	1.2	29.1	26.0	40.1
Ploughed	12.4	111.80	7.9	6.5	29.1	26.0	0.50

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SAND DUNE STABILIZATION AND SHELTERBELT PLANTATION TECHNIQUE FOR ARID REGIONS

L.N. Harsh and J.C. Tewari

Introduction

About 5.2 billion ha area of land mass is classified under drylands. Of these 3.97 or 75% of drylands are atleast moderately degraded. Nearly 216 million ha of rainfed croplands or about 47% of their total area in the world drylands (457 million ha) are affected by various processes of degradation, mainly wind and water erosion of soil, depletion of nutrients, and physical deterioration (Dregne et al. 1991,. The largest area of degraded rangelands occurs in Asia, followed by Africa (Table 1). More than 100 countries are either moderately or severely affected with the problem of soil erosion. In India 53 per cent of the land is subject to various

Table 1. Global status of desertification/land degradations in agriculturally used drylands

Continent	Irrigated land			Rainfed croplands			Rangelands			Total agriculturally		
	Total (m/ha)	Degraded (m/ha)	%	Total (m/ha)	Degrade dm/ha	%	Total (m/ha)	Degrade dm/ha	%	Total (m/ha)	Degrade dm/ha	%
Africa	10.42	1.90	18	79.82	48.86	61	1342.35	995.08	74	1432.59	1045.84	73.0
Asia	92.02	31.81	35	218.17	122.28	56	1571.24	1187.61	76	1881.43	1311.70	69.7
Australia	1.87	0.25	13	42.12	14.32	34	657.22	361.35	55	701.21	375.92	53.6
Europe	11.90	1.91	16	22.11	11.85	54	111.57	80.52	72	145.58	94.28	64.8
N. America	20.87	5.86	28	74.17	11.61	16	483.14	411.15	85	578.18	428.62	74.1
S. America	8.42	1.42	17	21.35	6.64	31	390.90	297.75	76	420.67	305.81	72.7
Total	145.50	43.15	30	457.74	215.56	47	4556.42	3338.46	73	5159.66	3562.17	69.0

forms of land degradation(Singh, 1989). Keeping in view of severe problem of desertification, United Nations have launched a programme to combat Desertification (Plan of Action to Combat Desertification - PACD) in 1977 in almost all the countries. In that, soil conservation was one of the major activities. Since then most of the countries have developed or standardised the technologies for sand dune stabilization and shelterbelt plantation. The present paper briefly describe the sand dune stabilization techniques are being used in different countries.

Sand Dune Stabilization

Winds are dynamic force which cause soil erosion. Not all the winds causes soil erosion, but only the air currents which are able to blow the transport sand grains, can modify the surface pattern of sandy areas. The threshold of wind velocity at which sand can be transported differs according to grain size of sand particles to be moved and it is for grain size of 0.10-0.25 mm, 5.6m/sec. for grain size 0.25-0.50, 6.0 m/sec. for grain size of 0.5-1.0 and 7.0 m/sec. for grain size of more than 1.0 mm in diameter.(Baghold,1941)

Sand particles are deposited behind ridges, clumps of plant residue and other barriers or are carried off the field. The surface is gradually becomes drifted with hummocks of sand. These sand hummocks ultimately leads to formation of different types of dunes viz., Barchans, Parabolic, Coalesced parabolic, longitudinal, transverse and obstacle dunes. These dunes are further grouped into two major groups i.e. old and new formations. Old dunes are established, but due to over exploitation their margins became loose and sand drift starts whereas new dunes are active and also mobile. Therefore, more emphasis is required to stabilise the second type of dunes. The technologies developed for sand dune stabilization by different countries are described here.

India and Pakistan : About 58 per cent region of arid western Rajasthan is being covered with different types of dunes with different intensities. Since 1961 CAZRI has developed the sand dune stabilization techniques and with that technology Forest Department of Rajasthan has stabilised more than 90,000 ha area. The steps used in sand dune stabilization are: (i) protection from biotic interferences, (ii) erection of micro wind breaks in form of checker board or parallel strips (iii) establishment of a vegetation cover through direct seeding or by transplanting of adapted species and (iv) after care of newly established dune. In almost all the countries these steps are being followed with some minor modifications in mulch materials and using of different species which are suited to their conditions.

i) *Protection against biotic interferences*: Different fencings were tried to see their efficiency but results revealed that on the sand dunes Barbed-wire with iron post are most effective. Recently live fencing has also been found economical and viable because of accelerated cost of steel.

ii)*Mulching*: Affected dunes must be treated by fixing micro wind breaks across the wind direction in parallel strips or in checker board design at the spacing of 2 m apart on the crest and, 5 m apart on the middle and heel of sand dunes to save the seedlings from the over deposition of moving sands or from the exposure of roots. For erecting the micro-wind breaks the locally available bushes like *Zizyphus nummularia, Crotolaria burhia, Leptadenia pyrotechnica, Calotropis procera*, etc. are used.

iii) *Afforestation of treated dunes*: Afforestation of dunes can be done by any of the two methods: (a) by direct seeding and (b) by transplanting.

(a) *Direct seeding*: The success in afforestation on dunes through direct sowing could not be achieved because of erratic rainfall, long dry spells and deposition of moving sands over the seedlings. Further, during high wind velocity, seed of tree and grasses are blown away. Some efforts were made to stabilise the dunes through aerial seeding. (Kumar and Shankarnarayan, 1988) recorded about 8.14 per cent germination on the aerial seeded dunes. Among trees and grasses maximum germination was found in *Colophospermum mopane* (51.4%) followed by *Acacia tortilis* (9.0%), *Citrullus colocynthis* (7.25%), *Ziziphus rotundifolia* (4.84%), *Prosopis cineraria* (3.8%) and *Lasiurus sindicus* (0.03%). But after three years there was sharp decline in the survival of tree species except in *Lasiurus sindicus* grass which infact showed the increase in its total population. Hence, success through direct sowing is not satisfactory. Recently, seeds broadcasting of different tree species were done in the sandy soils of CAZRI, Jodhpur Research Farm. The seeds were treated with Jalshakti, a polymer, @ 2 kg/100 kg seeds. The results revealed that even after 3 years, the survival was 25 per cent in *Colophospermum mopane* followed by *Acacia tortilis* (20%) and *Acacia bivenosa* (15%). In contrast, all other species showed only 5-10 per cent establishment (Harsh et al. 1989). The seeds of *C. mopane* treated with Jalshakti were also broadcasted in other areas near village Salawas and their survival ranged between 25% to 30%. For massive afforestation aerial seedling seems to be the only answer at present with repeated seeding on the same area.

(b) *Through transplanting*: Better results are achieved by planting the nursery raised seedlings. Normally the seedlings are raised in perforated poly bags of 10" x 4" size or in the sun dried bricks prepared from the mixture of sand, clay and farmyard manure in equal ratio. The deep planting is preferred to facilitate the root systems to get in contact with the moist zone, which happens to be in the depth of 50-60 cm below the surface. The tree species suited for sand dune stabilization are *Acacia tortilis, Prosopis juliflora, Acacia nubica, Calligonum polygonoides, Colophospermum mopane, Acacia bivenosa, Prosopis cineraria, Ziziphus nummularia, Parkinsonia aculeata* and *Cordia rothii*. In grass and creepers, *Lasiurus sindicus, Cenchrus ciliaris, Panicum antidotale* and *Citrullus colocynthis*. For the semi-stabilized sand dunes or stabilized dunes, some other species are also found suitable. They are *Acacia salicina, Hardwickia binata, Albizia lebbeck, Azadirachta indica, Maytenus emarginata, Balanites roxburghii* and *Tecomella undulata*.

Iran : About one-fourth of Iran is desert and dunes have developed in many parts of the desert. These dunes became a serious menace to communication system, village settlements, and agricultural fields. Because of seriousness of the sand dunes problem in terms of the physical damage caused by moving sand, atmospheric pollution and human discomfort caused by air born dust, sand dune stabilization has been the major priority of soil conservation service of Ministry of Natural Resources, Islamic Republic of Iran. They have followed the same steps as described in Indian context but, recently they have used bitumen mulch, which has proved to be an effective means of stopping sand movement. It has been reported that more than 75,000 ha of active dunes, have stabilised. The species used for stabilization and found most successful are presented in Table 2.

Country has also attempted to use aircraft for mass seeding in duny areas, but still it is at experimental stages. Similar technology and plant materials are being used in Saudi Arabia.

China: About 33% area of China is desert which is located in desert steppe and steppe zones in the east part of Helan mountain and in the east regions of Wushar Ling Mountain. In order to control land and desertification Chinese Government has set up some organs, including the National Sand Control Co-ordinating Group and local desertification control organs. In the past 40 years these organs played an important role in desertification control. Since 1978, 91,000,000 ha of land have been afforested and the forest cover increased from 5.05% in 1950's to 7.09% in 1994.

In Naiman County and Dayijian Fang in Zhanggoutai of Zhangwu County in Harquin Steep and dune establishments are the living example. Along the railway tracks in Naiman the desertified land composed of mobile dunes is mainly stabilized with plants and engineering measures (sand barriers). In Tree plantations viz. *Pinus sylvestris*, var. Mangolica, *Artemisia*

Table 2. Suitable species for sand dune stabilization in Iran

Species	Distribution
Haloxylon ammodendron	Turkestan, Khorassan, western and middle eastern Iran
H. aphyllum	Turkestan and foothills of Khorassan
H. recurvum	Baluchistan
H. multiflorum	Baluchistan
H. salicornicum	Baluchistan
H. articulata	South-west Iran
Suaeda resomarinus	Throughout Iran
Calligonum persicum	Throughout Iran
Tamarix stricta	Saline soils where water table is nearer the surface
Aristida pennata	Throughout Iran
Panicum sp.	Throughout Iran

halodendron, *Salix flavida* and *Caragana microphyla* are commonly used. By this way mobile dunes are fixed and railways are guaranteed to pass unimpeded. Vegetation cover increased about 30-50% from 10%. The sand erosion reduced about 60-70%. The organic matter increased to 600-800%.

Central Asia: About 15 per cent area of the Central Asia is occupied by *barchan* dunes and other patches of natural deflation. The sand dune stabilization also includes the same steps as mentioned in Indian context. But recently emphasis on new technologies have been given viz., development of new concepts of sand stabilization, improvement of physical features of sandy soils, application of gel and new substances for improving soil structure, testing of new chemicals for sand dune fixation, improvement of techniques for establishment of forest plantation, etc.

Sand drift and sand dune problems are not only in South Asia or Central Asia, but also very common in Coastal areas of many countries, in African continents and Australia.

North Africa: In Tunisia, about 188000 ha of sand dunes have been fixed with different tree species, of which 70,000 ha are now productive forest. In Libya since 1952 extensive programme of sand dune fixation have been undertaken. The national programme aims to create a green belt 50 km wide extending along the entire length of Libyan coast from Tunisia to Egypt. Some 83,000 ha of dunes in this belt have been stabilised and planted. In Algeria, main programme is to develop a green belt measuring 1,500 km long and between 20-40 km wide to protect an area of some 3.5 million ha against encroachment of desert from the south. In Tahrer (Egypt), which was originally covered with sand dunes, has now been stabilised. About 60,000 ha land now planted with fruits and fodder. In Mauritania since 1980, about 2000 ha have been reafforested and stabilized the dunes (Skoupy 1991).

In other countries like Senegal, Mali, Burkino Faso, Chad, Niger, Nigeria and Sudan, the major emphasis has been given on the sand dune stabilization and development of wind breaks. In all the countries it was realised that biological fixation costs half as much as mechanized stabilization. It has added advantage of involving the local community in transforming their own environment as well as to get the employment.

All above mentioned countries have also followed the same sand dune stabilization techniques which have been described in Indian context.

Shelterbelt Plantations

The areas which are not covered by sand dunes but are highly vulnerable to soil erosion or soil drifting also need attention. On these land dryland farming are the common practices, and due to high desiccating winds, the crop production declines steadily. Therefore, to protect the top fertile soils, shelterbelt plantation/wind breaks around the farm is an important measures. The shelterbelts are strips of tree species planted in staggered way against the wind direction.

Design and Establishment of Shelterbelt : *Design:* Depending on wind velocity, shelterbelt design type and layout differs from site to site. The shape of shelterbelts should be triangular in cross section of pyramidal in structure, i.e. the tallest trees should be in the centre row followed by flank rows of medium height trees and lateral row should be of bushy plants. All these should be planted in staggered or zig-zag way to avoid any tunnelling effect. To have protection from the wind throughout the year, it is necessary to include both evergreen and deciduous trees in the shelterbelt. There should be adequate space between fast and slow growing trees to avoid suppression.

Spacing (i) There should be a minimum spacing of 2.4 m and a maximum of 7.6-9.1 m between the two rows and (ii) within the row spacing should be a minimum of 0.9 metre for shrubs and a maximum of 6.1 m for tall trees.

Species selection: (i) Tree species should be adapted to the site, (ii) the height and crown density should be sufficient to provide adequate protection, (iii) species should be drought tolerant, salt and wind resistant, (iv) they should have deep tap-root system, and (v) should also have a tendency to develop erect or drooping branches to discourage bird perching.

For arid region of western Rajasthan, the following tree/shrub species are most suitable for shelterbelt plantations. For flank or lateral rows *Prosopis juliflora, Acacia bivenosa, Ziziphus nummularia, A. tortilis, Cassia siamea, Calligonum polygonoides, Acacia senegal, Colophospermum mopane* and *Tamarix articulata* are suitable.

For central rows *Albizia lebbek, Azadirachta indica, Acacia nilotica var. indica, A. nilotica var. cupressiformis, Dalbergia sissoo, Hardwickia binata, Eucalyptus camaldulensis, and Tamarix articulata* are suitable.

Establishment of Shelterbelts: Shelterbelts are generally planted at right angles to the prevailing wind direction. Successful shelterbelts of *Acacia nilotica* var. *indica* and *Dalbergia sissoo* over a length of 1-2 km were established at the Central Mechanised Farm, Suratgarh, in Bikaner district, in early sixties by Arid Zone Research Institute, Jodhpur. Again in the seventies 3 rows constituting *Acacia tortilis, Cassia siamea* and *Prosopis juliflora* as flank row and *Albizia lebbeck* as central row were established at CAZRI, Jodhpur.

For successful plantation of tree species shelterbelts, planting pits of 60 x 60 x 60 cm should be dug out and half filled with loose weathered soil. Six to nine-month-old seedlings should be planted in the pits provided around with saucer-shaped depression. The planting should be done after the first effective monsoon rain.

Function of Shelterbelts: Effect of shelterbelts (eight-year-old) on wind speed, evaporation rate, soil moisture, wind erosion, soil fertility and crop production were monitored at Jodhpur (Gupta *et al.*, 1984; Muthana *et al.*, 1984).

Effect on wind speed: The wind directions in the Indira Gandhi Nahar Project area are north-east to north in winter, whereas during the rest of year they are mostly south-westerlies. A narrow belt, passing through Jaisalmer-Phalodi in the eastern part, records the highest wind speed during the summer season. The maximum wind velocity that can be expected normally in the area is about 30-40 km/hr but occasionally reaches as high as 100 km/hr resulting in severe dust storm. Observations on daily wind speed during summer and monsoon season at 2H (H=height of shelterbelt) distances in the windward side and at different distances (2H, 5H and 10H) in the leeward side with different tree combination were recorded from the experimental field (Table 3). The frequency analysis of wind direction revealed that the wind break planted against the wind direction was very effective on 92% of days. Wind speed reduction was higher during monsoon season than in summer, due to better canopy growth. The wind reduction in *Cassia siamea-Albizia lebbeck* type shelterbelt was maximum at 2H and 5H distances which was followed by *Acacia tortilis - A. lebbeck* type shelterbelt (Table 3).

Table 3. Reduction of mean wind speed (%) at different distances in the leeward side of different shelterbelts

Shelterbelt types	Summer			Monsoon		
	Distance from the shelterbelt					
	2H	5H	10H	2H	5H	10H
P. juliflora - A. lebbek	33	17	12	38	26	21
C. siamea - A. lebbek	36	17	13	46	36	24
A. tortilis - A. lebbek	36	25	13	46	36	20

Source: Gupta *et al* (1984)

Effect on evaporation: The evapo-transpiration is maximum in arid region which is greatly influenced by wind speed. The study revealed that there is a decrease of 5-14% in pan evaporation values in the leeward side at 2H distance (Table 4).

Effect on soil moisture: Soil moisture content was higher at 0-15 cm and 15-30 cm depths in shelterbelt plantation consisting of *C. siamea - A. lebbek* than the other combinations of tree species used for shelterbelts (Table 5). This indicated that shelterbelts delayed the soils from the drying and moisture loss was less when compared with bare field.

Effect on soil erosion and fertility: Constitution of shelterbelts has varying effect on soil erosion. Among 3 combinations used in shelterbelts, maximum reduction in soil loss was

Table 4. Effect of *C. siamea - A. lebbek* shelterbelts on pan evaporation values during 1978

Sites	Pan evaporation (mm dug)			
	April	May	June	July
Windward side	11.0	14.5	13.4	6.0
Leeward side	9.5	13.8	12.4	5.7
% decrease in pan evaporation	14.0	8.0	8.0	5.0

Source: Gupta *et al* (1984)

recorded (184 kg/ha) with *C. siamea - A. lebbek* followed by *P. juliflora - A. lebbeck* (351 kg/ha). In unsheltered area the soil loss was 547 kg/ha. The minimum soil erosion in case of *C. siamea - A. lebbeck* type shelterbelt was due to dense canopy cover compared to *Acacia tortilis - Prosopis juliflora* type of shelterbelt (Table 6).

The maximum nitrogen loss was in bare soil (191 g/ha) while it was lowest in case of *C. siamea - A. lebbeck* (64.5 g/ha). The phosphorus loss was 101.0 g/ha from bare field while in *C. siamea - A. lebbeck* type shelterbelt plantation, it was 34 g/ha. The potassium loss recorded from bare soil was 1039.0 g/ha, while with *C. siamea - A. lebbeck* type shelterbelt it was only 350 g/ha. The nutrient loss was maximum in bare field, followed by shelterbelts with *P. juliflora - A. tortilis* and *C. siamea - A. lebbeck.*

Water-use-efficiency and grain production: The water-use efficiency in plots at distances of 5H, 10H, 15H, 20H, 25H and 30H under the shelterbelts was in order of 1.5, 1.51, 3.09, 3.79, 5.62 and 2.65 kg/ha/mm, respectively, with a grain yield (bajra) of 3.7, 6.1, 6.3, 8.8, 9.8 and 5.9 q/ha, respectively. The average yield with and without the sheltered area was 6.8 q/ha and 4.8 q/ha, respectively. Hence, by providing shelter to bajra crop the grain yield increased by 42% over control. Effect of shelterbelts on grain, fruits and vegetables in different countries have been reviewed by Chandrasekharaiah (1987).

Performance of shelterbelt tree species: Muthana *et al.* (1984) recorded the height and per cent survival of trees planted in shelterbelts. The study revealed that after 7 years (1973-80)

Table 5. Effect of different types of shelterbelts on moisture status of soil

Type of shelterbelts	Soil depth	Moisture status of soil (w/w)% days after irrigation				
		1	2	3	4	5
P. juliflora - A. lebbeck	0-15	10.8	7.5	7.4	5.2	4.1
	15-30	12.1	9.5	9.2	7.0	6.1
C. siamea - A. Lebbeck	0-15	11.4	8.1	7.1	5.7	4.3
	15-30	12.2	9.9	9.2	7.8	7.2
A. tortilis - A. Lebbeck	0-15	9.2	6.8	5.6	4.5	3.4
	15-30	10.3	8.4	7.4	6.4	4.4
Bare soil (Without shelterbelt)	0-15	10.1	7.8	6.5	4.7	4.1
	15-30	11.3	8.5	7.9	6.4	-

Source: Gupta *et al.*(1984)

Table 6. Effect of different types of shelterbelts on soil erosion and nutrient loss due to wind erosion

Shelterbelt types	Total amount of soil loss (kg/ha) (20 April-26 June)	Nutrient loss due to wind erosion g/ha		
		Nitrogen	Phosphorus	Potassium
P. juliflora- A. lebbeck	351.2	123.0	65.0	664.4
C. siamea- A. lebbeck	184.3	64.5	34.1	350.1
A. tortilis- A. lebbeck	300.0	113.0	45.5	570.0
Bare soil (without shelterbelt)	546.8	191.4	101.2	1039.0

Source: Gupta et al. (1984)

among the 4 species, *C. siamea* attained the maximum height (649 cm/tree) with 79% survival. The lowest height was attained by *P. juliflora* (543 cm/tree) with 87% establishment (Table 7).

Other Types of Shelterbelts: In addition to perennial tree shelterbelts, some other types of shelterbelts are also in use. These are: (i) micro-shelterbelts (planted by annual tall crops), and (ii) artificial shelterbelts (Netlyon).

Micro-shelterbelts: Micro-shelterbelts, also known as 'Annual shelterbelts', are made up of tall-growing annual plant species which provide shelter to low-growing plants like vegetable crops, as perennial tree species in shelterbelts take long time to be effective (5-7 years). The studies conducted at Central Arid Zone Research Institute, Jodhpur from 1976-1981 by Gupta *et al.* (1984) revealed that 3 rows of pearl millet as shelterbelt has increased the yield of cowpea and okra crops in order of 21 and 44% over unsheltered crop in summer season (Table 8). In addition to an increase in vegetable yield, the sheltered field provide an additional remuneration from bajra fodder which come to about Rs. 1,600 per hectare.

Artificial shelterbelts: In New Zealand, recently artificial shelterbelts were used for protecting kiwi fruits (Richard, 1986). The artificial windbreaks or shelterbelts are constructed from a porous (typically 30-35%) plastic woven or knitted cloth. Typical fence heights are between 4.5 and 7.0 m. The study revealed that rows of kiwi plants adjacent to woody shelterbelts produce only 13 flowers/cane as compared to 32 flowers/cane for rows adjacent to artificial shelterbelt. The woody shelterbelts have root and moisture competition with the sheltered crop. It was estimated that 30% of orchard area is lost in natural shelterbelts whereas in artificial shelterbelts whole area can be used in crop production. In India, artificial shelterbelts have however not been tried so far.

Table 7. Mean growth in height and establishment of tree species in shelterbelts

Tree species	Mean growth in height (cm) (1982)	Establishment (%)
Cassia siamea	649	79
Acacia tortilis	624	94
Prosopis juliflora	543	87
Albizia lebbek	564	96

Source: Muthana *et al.* (1984)

Table 8. Vegetable yield (q/ha) of ladyfinger and cowpea vegetable crops as influenced by micro-shelterbelt

Treatment	1976	1977	1978	1979	1980	1981	Mean yield	Percentage increase over unsheltered
Lady's finger crop (1976 - 78)								
Unsheltered	24.3	17.6	28.6	-	-	-	23.5	41.0
Sheltered	48.2	22.2	29.3				33.8	
Cowpea vegetable crop (1976-81)								
Unsheltered	30.2	14.8	52.0	15.5	23.4	35.8	28.6	21.0
Sheltered	41.1	24.7	56.4	17.9	26.9	40.8	34.6	

Source: Gupta *et al* (1984)

Management and Renewal of Shelterbelts : Several kinds of trees with different growth characteristics are normally required to provide foliage for optimum structure of a shelterbelt over a period of years. The structure, however, is not static one, even when the right species were selected. Once a shelterbelt is established, the relationship among the species changes. The height, density, cross sections of the shelterbelt changes with time. These changes greatly affect the structure and efficiency of the shelterbelt. Therefore, management practices are required to develop and maintain a shelterbelt at a state of maximum effectiveness. Following methods are used to manage a shelterbelt.

Pruning: Pruning of innermost rows of tree species facing the leeward side is essential to facilitate cultivation of crops. The pruning should be employed to trees damaged by wind, insects or other reasons. Many trees develop multiple stem and leaders and individual branches that suppress more desirable species should be removed. It also provides adequate porosity.

Thinning: During the dense thicket stage, trees begin to compete with their neighbours for light, moisture and nutrition. Thinning is necessary to increase the area for tree to provide space for crown expansion. The thinning can be accomplished by complete removal of one or more rows or removal of individual trees on the basis of their conditions. The removal of individual or entire row is feasible upon the growing conditions and their role in the shelterbelts. These can be done by two types, viz. low thinning, and (b) crown thinning.

Renewal of shelterbelts: Preferably before they reach the stage, when trees start declining in their growth or dying off, the shelterbelts should be renewed. This can be done by two means, namely, (a) by removing the half of shelterbelts and replanting the new seedlings or planting new belts midway between the existing plantation. The older belts would then be removed when the younger ones become effective.

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REHABILITATION OF DEGRADED GRAZING LANDS

S.K. Saxena and Surendra Singh

Introduction

There is an increasing demand for food, fodder, fuel and fibre with the escalation of human and livestock population. Man and domestic animals activities have reduced or destroyed the biological potential of the land which ultimately lead to imbalance of a fragile desert ecosystem. Major natural resources have been degraded to an unbelievable low level with amazing rapidity. Loss of plant cover causes the loss of soil by way of wind and water erosion leading to desertification. In Rajasthan much of the area due to human interference in many ways has created the degraded lands or wastelands which at present have negligible productive potential. The land degradation due to soil salinity, erosion, waterlogging, deforestation, overgrazing and unscientific methods of agriculture practices, is causing serious concern. To halt this process, the Govt. of India established, the National Wasteland Development Board (NWDB)in the year 1985. Its sole object was to bring five million hectare of land every year under fuelwood, forage and fodder plantation. This was only possible by initialling a massive programme of rehabilitating the degraded land/ wasteland by planting trees, shrubs and grasses to increase the availability of fuel, fodder, forage.

Category of Wasteland/degraded Lands

The NWDB initiated the process to know the extent of degraded lands in the country and their present status of degradation, limitation and physical potential as it is essential pre-requisite for carrying out the rehabilitation work. A technical task group was constituted to define various wastelands occurring in the country. According to task group the wastelands are defined as "The land which is degraded and is presently lying underutilized except the current fallow due to different constraints". (Anonymous 1988). Different categories of wastelands are defined by the task group and following discussion is based on the land categorization (waste lands) of this task group. In arid and semi-arid parts of Rajasthan we come across mostly eleven degraded/wasteland areas barring of glacial, steep sloping and shifting cultivation. The wastelands with the help of remote sensing techniques (TM data) have been mapped at 1:50,000 scale in 182 districts of 19 states of the country having more than 16% of wasteland area.

Degradation of Grazing Land

Livestock holders make use of almost all the available habitats except the cultivated lands, (till crop is there) constituting nearly 62% area for grazing their animals. Due to continuous grazing with heavy livestock pressure the botanical composition of grassland/grazing lands gets modified. High yielding perennial grasses like *Cenchrus*, *Lasiurus*, *Dichanthium* and *Panicum* etc. are the first victim of overgrazing. Continuous grazing leads to complete extermination of all these grasses. Almost all the village commons, wastelands, and long fallows, could be seen with extreme degradation. Here only pioneer species of colonization like *Aristida funiculata*, *Cenchrus biflorus*, *Eragrostis poaoides*, *Tephrosia purpurea* and *Indigofera cordifolia* are encountered. Gupta and Saxena (1972) in their successional studies of grasslands have indicated these species as initial colonizer. Bare soil experience quick runoff and less moisture status (Saxena and Prakash 1992). The degraded vegetation mentioned above is generally less productive and non-palatable but under stress this is also consumed by livestock.

Rehabilitation of Different Type of Degraded Grazing Lands

The main objective of wasteland/grazing land rehabilitation should be to provide a vegetation cover that is functional, ecologically suitable and acceptable to the local people. It should also give an aesthetic look. One has to plan and design the revegetation strategies which should give positive growth impact and establish quickly (Saxena *et al.* 1994). It shall be an ideal situation if species suiting to the habitat as well as for fulfilling the requirement of grazing animals are selected. Local vegetation surrounding the rehabilitation site can be taken as an indicator for selection of suitable species. The following discussion essentially deals with rehabilitation of different type of degraded lands.

Gullied and/or Ravinous Lands : These are formed as a result of localized surface runoff affecting the friable soil material (deep alluvium) and causing land dissection which on ramification leads to the ravinous land formation. Ravinous degraded lands are concentrated in the south-east of Rajasthan through the Yamuna and the Chambal rivers courses. In eastern and western parts of Aravalli, due to faulty agricultural practices, much of the area is converted into dissected gullied land. In 12 states of India, about 4 m ha of table land are affected by such problem whereas 4 to 6 m ha are likely to be threatened (Bali 1985). Reclamation measures for such lands include, gully control and water conservation in the form of gully plugs, check dams and drop structures. Gully plugging by growing grasses like *Cynodon dactylon, Desmostachya bipinnata* on gully floors should be taken as the first measure. Trees and shrubs species like *Acacia nilotica, A. senegal, A. leucophloea, Balanites aegyptiaca, Capparis decidua, P. juliflora, C. sepiaria, Dichrostachys cinerea, D. nutans, Azadirachta indica, Pongamia pinnata* may be planted on the bank of the gullies (See also Table 1,1a,1b & 1c). Ravinous uneven beds may be planted with *A. tortilis* and *P. juliflora.* Close planting of *Saccharum bengalense* especially on the bank of gullies will provide higher order of soil protection.

Trees with good crowns like *A. nilotica, Albizzia lebbek, P. juliflora* (tree form), *P. cineraria* may be utilized in revegetating the catchment areas. It shall reduce the intensity of runoff and cutting of the bank (Table 2). A composite check dam of earth/brick masonry is necessarily required for large catchments (7.5-15.0 m wide). Bench terracing in shallow ravines area for agriculture. Drop structure may be built at the erosion spots like gully heads to lower down the water current/speed. Development of water storage structures on suitable site will help in developing good crop/horticultural trees/forest trees etc.. These above approaches are warranted in different areas to fit.

Uplands with or without Scrub : They are largely undulating rocky or gravelly areas with small rills. Here the slope ranges from steep to moderate. There is a thin soil cover with distinct water erosion hazards. In many cases the lower slopes are covered by rocks debris. In

Table 1. Suitable tree species for rehabilitating degraded lands

Botanical name	Local name	Degraded habitat	Palatability to animal	Suitable rainfall zone (mm)	Remark
Indigenous Tees					
Acacia catechu	Kaith	Rocky, gravelly	Less palatable	450 +	Economic sp.
Acacia nilotica ssp. *indica*	Desi babool	Moderately saline plain	Cattle, camel, goat	350 +	A top feed sp.
Acacia nilotica ssp. *cupressiformis*	Khajoor bawli	Moderately saline plain	Cattle, camel, goat	350 +	A top feed sp.
A. leucophloea	Rheonja	Moderately saline plain, semi-rocky	Non -palatable	250 - 450	
Acacia senegal	Kumut	Rocky, gravelly, piedmont	Goat, camel	250 - 450	Top feed sp.
		Rocky, semi-rocky & plain	Palatable to cattle	350 +	Economic sp.
Ailanthus excelsa	Maharukh, Arru	Alluvial Plains	Goat, sheep	400 +	Top feed sp.
Albizia lebbeck	Siris	Alluvial Plains	Cattle	400 +	- do -
A. amara	Chota siris	Semi-rocky & plains	Cattle	350 + 500	- do -
Anogeissus pendula	Dhokra	Rocky, semi-rocky	Less platable	250 - 500	Economic sp.
A. rotundifolia	Endhruk	Moderately saline plain	Least platable	350 - 500	-
Azadirachta indica	Neem	Almost all habitats	Goat, camel & cattle	350 +	Top feed & medicinal
Bauhinia racemosa	Jhinjni	Rocky, semi-rocky, plains	Goat, camel & cattle	250 - 450	Top feed sp.
Dalbergia sissoo	Shisham	Alluvial plains	Cattle	400 +	Top feed
Emblica officinalis	Anwla	Semi-rocky & plains	Cattle	350 +	Economic sp.
Holoptelia integrifolia	Papri, kanju	Semi-rocky & sandy plain	Less palatable	350 +	-
Melia azadirachta	Bakain	Semi rocky & alluvial plain	Less palatable	350 +	-
Prosopis cineraria	Khejri	Alluvial plains	Highly palatable to all	250 - 500	Good top feed
Salvadora oleoides	Jal	Saline lands	Camel & wild life	350 - 600	Camel feed
S. persica	Pillu	Saline lands	Camel & wild life	400 - 700	- do -
Tamarix aphylla	Jhau	Saline lands	Non-palatable	200 - 450	Easy to multiply
Ziziphus mauritiana	Ber	Semi-rocky, plains	Highly palatable	350 - 550	Good top feed

Table 1-a. Exotic tree species suitable for degraded lands

Botanical name	Local name	Degraded habitat	Palatability to animals	Suitable rainfall zone (mm)	Remark
Exotic Trees					
Acacia tortilis	Israeli babool	Majority of degraded land	Goat & camel	150 - 500	Very hardy
A tortilis ssp *spirocarpa*	Australian babool	Grazing lands	Goat & camel	150 - 500	Very hardy
Acacia aneura	Maulga	Grazing land , gullied land	Goat & camel	250 - 400	Less prefered by livestock
A salicina	Sanjay braksh	Flat plains, Gullied land	Non -palatable	250 - 400	Good for avenue
Eucalyptus cameldulensis	Safeda	Strip lands	Noi -palatable	350 +	Fast growing
Leucaena leucocephala	Soo-babool	Moderately salt affected alluvial plains	Hightly palatable to . livestock	350 +	High regeneration capacity
Populus deltoides	Popular	Moderately salt affected alluvial plains	Less palatable	350 +	Fast growing

Table 1-b. Suitable shrub species for degraded lands

Botanical name	Local name	Degraded habitat	Planting spacing (m)	Palatability to animals	Suitable rainfall zone (mm)	Remark
Indigenous Shrubs						
Acacia jacquemontii	Bawli	Duny,sandy	3x3	Goat browse well	150 - 350	Dune slope, hummocky
Calligonum polygonoides	Phog	Duny,sandy	3x3	Camel, goat, sheep browse well	150 - 350	Dune slope, hummocky
Clerodendrum phlomoidis	Arni	Duny,sandy	3x3	Non palatable	150 - 350	Leaves bad smelling, easy to multiply
Cordia gharaf	Gundi	Rocky, Semi-rocky	3x3 or 5x5	Goat, camel prefer	250 - 400	Fruits palatable
Dichrostachys cinerea	Kolai	sandy	3x3 or 5x5	Wildlife, cattle & goat	250 - 500	Prefers upland, plateau
Dandrocalamus strictus	Bans	Piedmont, pediment,	5x5	Cattle	400 +	Fallen leaves preferred
Grewia tenex	Gangaren	Rocky rocky	3x3	Wild life, buffalo & camel	300 - 600	Fruits edible
Haloxylon salicornicum	Lana	Saline lands	2x2	Wild life, buffalo & camel	200 - 500	A feed of lean period
Leptadenia pyrotechnica	khemp	Sandy plains & sand dune	2x2	Non -palatable	150 - 350	Light green & non leafy
Lycium barbarum	Murali	Sandy plains & sand dune	3x3	Goat browse well	150 - 350	Very hardy
Mimosa hamata	Jhujni	Sandy plains & sand dune	3x3	Goat browse well	150 - 350	Very hardy
Morus serrata	Kartoos	Semi rocky & alluvial plains	3x3	Palatable	350 - 600	Leaves good for silkworm
Salsola baryosma	Jerio -lana	Saline lands	3x3	Camel browse	150 - 400	-
Suaeda fruticosa	Kala-lana	Saline lands	2x2	Buffalo & camel browse	150 - 400	Leaves succulent
Ziziphus nummularia	Bordi	Rocky, semi-rocky	3x3	Leaves palatable to all	150 - 400	Leaves shed after December

Table 1-C. Suitable exotic shrub species for rehabilitating degraded lands

Botanical name	Local name	Degraded habitat	Planting spacing (m)	Palatability rating	Suitable rainfall (mm)	Remark
Exotic Shrubs						
Acacia farnesiana	Angrezi kikar	Sandy to semi-rocky	3x3	Moderately	250 - 500	Pods & seed well preserved
Acacia nubica	Noobika	Calcium rich, sandy soil	3x3	Unpalatable	250-400	Highly thorny
Cercidium floridum	Cercedum	Sandy, gravelly	3x3	Slightly	250-500	Seed very hard
Colophospermum mopane	Mopane	Sandy, semi-rocky	3x3 or 5x5	Slightly	250-500	Regenerate well
Dichrostachys nutans	Nootan	Sandy, semi-rocky,rocky	3x3	Well browsed by wild life	250-450	Throw root suckers
Parkinsonia aculeata	Angrezi babool	Sandy plains	5x5	Non - palatable	150-450	Thorny but showy
Prosopis juliflora	Vilayti babool	Almost all habitats	3x3 or 5x5	Non - palatable but pod palatable	200-700	Aggressive in establishment
Salicornia bigvolii	Salicornia	Saline lands	2x2	Camel browse	150-400	Seed bear oil
Ziziphus spina-cristii	Vilayti bor	Rocky, gravelly pediment & piedmont	5x5 or 3x3	Highly palatable	150-450	Highly spiny, hardy

Table 2. Rehabilitation of grazinglands in arid region of Indian desert

Habitat	Protection	Measures of reclamation			
		Conservation measures	Method of reseeding	Suitable grasses	Suitable top feed species
Ravinous land Gullied and/or live hedge Upland with or without scrub					
a) Piedmont	Stone wall	Contour terracing, contour trenching	Along contour	*Cenchrus Dichanthium Sehima*	*Prosopis, Acacia Salwadora, Dichrostachys*
b) Gravelly, rocky pediments	Stone wall/live hedge	Bunding, trenching and contour furrow	In contour furrows	*Cenchrus, Lasiurus*	*Prosopis, Tecomella*
Degraded grazing lands – Flat plains					
a) Light tetured soil	Barbed wire frencing/livehedge	Lavelling, bunding inter-row water harvesting	Direct sowing/pelleted seeds	*Cenchrus, Lasiurus*	*Prosopis, Tecomella*
b) Medium testured soil	Barbed wire fencing/livehedge	Lavelling, bunding, inter - row water harvesting	Direct sowing/pelleted seeds	*Cenchrus, Dichanthium*	*Acacia, Prosopis, Ziziphus*
c) Heavy textured soil	Barbed wire fencing/live hedge	Lavelling, bunding, inter - row water harvesting	Direct sowing/pelleted seeds	*Dichanthium, Brachiaria*	*Prosopis, Acacia*
Salt affected lands	Bunding/live fencing	Raised bed, trenching	Seeding on bunds	*Sporobolus Chloris Dichanthium*	*Capparis, Haloxylon Suaeda , Salicornia*
Strip lands	-	-	Rooted slips or dibbling of seeds /pellets	*Saccharum Desmostachya*	*Pongamia, Cassia siamea, A. tortilis, Azadirachta indica*
Mining/industrial wastelands	Live fencing /core wall	Micro-catchment, half-moon, contour terracing	Rooted slips & pellets dibbling	*Cenchrus, Lasiurus Panicum*	*A. tortilis, Ziziyphus, A.indica, A. senegal, A. nilotica*

order to spread the water evenly and allow it to penetrate at lower depth the sloppy lands need the soil conservation measures.

Contour furrow and trenching at a regular interval of 3-5 m may be carried out on moderately sloping land. It will allow to increase the moisture regime and help in gathering the soil as well. During monsoon, natural vegetation whose seeds have accumulated by air dispersal along the contour line shall grow extensively. In order to hasten the process of succession, the reseeding with desirable grasses like *Cenchrus ciliaris, C. setigerus, Cymbopogon jwarancusa, Eremopogon foveolatus, Heteropogon contortus and Sehima nervosum* may be carried out by dibling just after first shower. Pelleted seeds or rooted slips of the above grasses may be transplanted after effective monsoon shower. On steep sloping land, terracing should be practised. To check the biotic disturbances live hedges of *Euphorbia caducifolia* of and *Acacia senegal* may be developed (Table 3).

Water Logged and Marshy Lands : The marshy lands, though of less value, support good biological diversity than the adjoining land. Marshy areas are quite difficult areas for rehabilitation. These are partly controlled by the process of aquatic ecosystem and surrounding hydrology (Loucks 1996) and partly by the activity or process on the adjacent uplands. The water in the marshy lands, generally derived from the adjacent upland, brings lot of soil along with organic carbon and phosphorus.

Waterlogged areas which get colonized by mesophytic species, mostly tall grasses, become the reproductive habitat for many a birds. Though majority of birds are highly mobile but these land provide some support in various phases of their life cycle.

(i) In arid areas like Indira Gandhi Nahar Pariyojana many a waterlogged and marshy lands have been developed along the main canal and its tributaries (Saxena 1991). During summer months the marshy land comparatively become partially dry and serve as grazing ground for wild life as well as bovine population. During drought and famine period the partially palatable/unpalatable species like *Typha angustata, Saccharum bengalense, S. spontanium* provide cut fodder for livestock and dried out lands become grazing ground to livestock, as new growth and tender foliage material become available. Outer fringes of marshy lands may be rehabilitated by *Cynodon dactylon* which can provide grazing material for almost whole year.

(ii) In coastal marshy land, Mangrove patches along sea coast support good top feed species like *Rhizophora* sp. and *Avicinia* sp. These species are much exploited for fodder and fuel purpose. Large scale plantation of these two species to restore the ecological balance of such area may be undertaken.

Saline/Alkaline Lands : In desert areas there are natural saline affected lands locally called as *Ranns*. These are low lying areas where the water along with sodium salts accumulate from surrounding uplands. Continuous accumulation of salt in the form of white encrustation does not permit any vegetation to grow. They are quite flat areas with heavy textured saline/alkaline soils During summer the hard surface provide typical cracking pattern in the ground. In desert tract majority of the *ranns* are surrounded by high stabilized dunes. The peripheral zone of these

Table 3. Suitable grasses for rehabilitating degraded lands

Botanical name	Local name	Degraded habitat	Planting spacing (m)	Palatability	Suitable zone rainfall (mm)
Arundo donax	Kalam ghas	Marshy land		Non -palatable	400+
Cenchrus ciliaris	Dhaman, Anjam	Sandy plains, sand dunes	1x1	Highly palatable	200-400
C. setigerus	Moda dhaman	Rocky, semi-rocky, sandy	0.75 x 0.75	Highly palatable	150-350
Cymbopogon jwarancusa	Bur ghas	Rocky, semi-rocky & sandy	0.75 x 0.75	Partially palatable	150-300
Dichanthium annulatum	Karad	Plains with heavy soil	1 x 1	Highly palatable	300-700
Lasiurus sindicus	Sewan	Sand dunes & Interdune plains	1 x 1	Palatable	150-350
Panicum antidotale	Gramna	Sandy plains, Interdune plains & sand dunes	1 x 1	Palatable	250-500
P. turgidum	Murut	Sand dunes	1 x 1	Less palatable	150-350
Saccharum bengalense	Munja	Dissected gullied land, sandy area	2 x 2	Palatable when young	400+
Sporobolus marginatus	Khari ghas	Saline land	0.75 x 0.75	Less palatable	150-400
Typha angustata	Patera	Marshy land	-	Non -palatable	400+

ranns support halophytic species like *Suaeda fruticosa, Sporobolus marginatus and Prosopis juliflora. Tamarix aphylla, Salvadora oleoides, S. persica* occur quite sparsely.

Some treatments are needed to increase the production potential of grazing material in this habitat. Bunding may be carried out at a regular interval of 5-6 m apart. The process will help in leaching out the salt of the raised bunds where salt tolerant species of grasses like *Dichanthium annulatum, Chloris virgata, Cenchrus setigerus* and *Sporobolus marginatus* etc. may be grown through pelleted seeds or rooted slips. The portion between the two bunds species like *Suaeda fruticosa, Salicornia sp. Atriplex nummularia, Haloxylon salicornicum, Salsola sp.*, all being good halophytes, may be tried through broadcasting of seeds (Table 4). Few top feed species like *S. oleoides, C. decidua, Dichrostachys nutans* may be grown on bunds or along margin of the saline depression.

Degraded Forest Land : Degraded forest areas are mostly on hilly and undulating terrain, pediments and piedmont plains which have steep slopes at places. In Thar desert most of these areas are in highly degraded state and require rehabilitation to check erosion of skeletal soil. Species common on them are *Acacia senegal, A. leucophloea, A. catechu, Anogeissus pendula, Boswelia serrata, Azadirachta indica, Moringa concanensis, Butea monosperma, Wrightia tinctoria, Grewia tenax, Rhus mysorensis, Commiphora wightii, Maytenus emarginata, Euphorbia caducifolia* and *Dichrostachys cinerea*. All these species are well adapted to the terrain but exist in small nucleus due to degradation. Hence the poly bags raised seedlings of these species may be transplanted on rocky site.

In this case soil conservation measures like contour furrowing at 8-10 m interval with 20-30 cm deep furrow, 60 cm wide contour trenching, bunding are required to be developed for improving the soil moisture status. Even with plantation the existing germules of annual species shall be first to colonize along the trenches with significant forage production (Ahuja 1975).

In order to have good ground forage material species like *Bothriochloa pertusa, C. setigerus, Apluda mutica, Sehima nervosum, H. contortus, Cymbopogon jwarancusa* may be sown between the tree/shrub rows (3 to 5 m spacing) by dibbling the pelleted seeds or rooted slips transplantation. Brick wall (1m high) may initially be raised all around the treated area and a live hedge of *A. senegal, E. caducifolia* may be developed (refer Table 3).

Degraded Pasture/Grazing Lands : Continuous heavy grazing modify the botanical composition of the grasslands. Palatable perennials with high forage potential like *Cenchrus ciliaris, C. setigerus, Lasiurus sindicus, Dichanthium annulatum, Panicum antidotale* etc. are the first victim of overgrazing. Continuous grazing of these species together with prevailing drought and famines result in their complete extermination. At present almost all grazing lands especially village commons, "Orans & Beers" do not support these productive species. Pioneer species like *Aristida funiculata, A. mutabilis, C. biflorus, Eragrostis poaoides and Indigofera cordifolia* may be seen. Gupta and Saxena (1972) in their successional studies have shown these pioneer species as indicator of overexploitation. Loss of ground cover has a bearing on runoff and moisture status. Higher soil bulk density lead to lower infiltration rate causing low moisture

Table 4. Suitable effective live hedge material for degraded lands

Botanical Name	Local name	Habitat	Characteristics	Suitable height (m)	Time of propagation	Suitable rainfall zone (mm)	Remark
Acacia jacquemontii	Bawli	Sandy, duny	Thorny	3	Oct.	150-250	Hardy
Acacia nubica	Noobica	Sandy, duny	Spreading, very thorny	3	Monsoon	150-250	Highly effective
Acacia senegal	Kumut	Semi-rocky, plains	Thorny	3	Oct., Monsoon	300-400	Very effective
Cassia auriculata	Anwal	Plains, semi-rocky	Non -palatable, flowering	2.5	Feb.	350-500	Very effective
Colophospermum mopane	Mopain	Sandy, semi-rocky	Non-thorny, less palatable	3	Monsoon	150-350	Very effective
Clerodendrum phlomidis	Arni	Sand dunes, sandy plains	Unpalatable	2.5	Monsoon	250-400	Effective
Dichrostachys cinerea	Kolai	Rocky,semi- rocky	Thorny, fine leaved	2.5	Monsoon	250-400	Effective
Dichrostachys nutans	Nootan	Rocky,semi- rocky	Thorny, fine leaved	2.5	Feb.,Monsoon	250-400	Effective
Euphorbia caducifolia	Danda Thor	Rocky, piedmont, pediment	Thorny, no leaves	2.5-3.0	Oct., Feb.	200-400	Time taking
Lycium barbarum	Murali	Sandy plains	Thorny	2.5	May-June	150-350	Effective
Opuntia delinii	Hatha thor	Sandy plains	Thorny	2-3	Oct.-Feb.	200-350	Time taking
Parkinsonia aculeata	Agrezi bawal	Sandy plains	Thorny	3-4	Feb., Monsoon	150-350	Effective
Prosopis juliflora	Vilyati babool	Almost all habitats	Thorny, leafy	3-4	Feb.-Oct.	150-400	Highly effective
Pithecellobium dulce	Jangal jalebi	Alluvial plains	Thorny, leafy	4-5	Oct., Monsoon	250-400	Highly effective
Zizyphus rotundifolia	Bordi	Piedmont, pediment, graveily land	Thorny, leafy	3-4	March-April	200-450	Effective

storage in soil profile. Village commons need priority for rehabilitation. It can be achieved only with the co-operation and active participation of local people.

Being in the vicinity of the village it becomes essential to check the movement of grazing animals. Several methods may be adopted.

(i) Barbed wire fencing with 4 strings and different posts like angle iron, stone slabs, wooden posts may be tried.

(ii) Ditch digging and bund formation is another method. It is labour intensive and needs continuous maintenance. Live fencing of desirable species should be raised along the bunds which will become effective in 5-7 years period. *Euphorbia, Parkinsonia, A. senegal, P juliflora, A. tortilis* are preferred species (Table 3).

(iii) Planting of multipurpose leguminous species of topfeed value should be selected for plantation in the grassland area (Table 1, 1a, 1b & 1c).

(iv) The area in question for rehabilitation should be divided into four to six compartments and one part may be taken up each year.

(v) Forage cutting should be preferred overgrazing. It will allow sustainable forage production from the rehabilitated sites. It is difficult to have managed grazing.

(vi) The reseeding is needed to enhance the annual forage production because under natural conditions the progress of succession is quite slow (Shanker, 1983). High yielding species like *C. ciliaris, C. setigerus, D. annulatum, P. antidotale, and Lasiurus sindicus* (Table 3) depending on the soil type may be sown through 1-2 years old seeds or rooted slips or dibbled along the rows in the furrow at 10 mm depth.

(vii) Introduction of top feed species like *A. tortilis, A. nilotica, Prosopis cineraria, Salvadora oleoides, A senegal, Dichrostachys nutans, Ziziphus nummularia, Calligonum polygonoides, Capparis decidua* may be transplanted. The sapling should be raised in polyethylene bags and must gain 6-9 months age. A density of 30-50 trees/ha is quite desirable.

Sand Dunes : In desert tract large area is covered under stabilized and unstabilized sand dunes of various types. These are largely utilized as grazing ground for the livestock. Excessive grazing and removal of grasses and scrub vegetation lead to loosening of sand structure. With high wind velocity (above 12 kmph) the sand piles on the dune crest and leeward side. It creeps down to the adjoining fields. Cultivation of the stabilized dunes also accelerate the process of soil erosion *Prosopis cineraria, A. senegal, M. emarginatus, Calligonum polygonoides, L. pyrotechnica, Clerodendrum phlomoides* and *Lycium barbarum* are the common species which occur with poor plant density. The ground vegetation include *Cenchrus and Aristida* species. Few may witness *Lasiurus* and *Panicum* species as well.

Simple protection: Indian desert has a good seed nucleus of desertic forage species which have the capacity to regenerate and establish themselves very well on dune complex, if not utilized before seed dispersal. In this context the foremost criteria for the stabilization of moving sand is to stop any cultural operation and animal grazing. Simple protection of the dunes for 4-6 years period enable the forage vegetation to grow and establish well and check the sand movement completely. Areas or part of the dunes which remain uncovered by forage species need the introduction of seeds of such species during monsoon season through dibbling or broad casting. On such dunes introduction of top feed species with 30 trees/ha and/or 100 shrubs/ha may be transplanted. Here shrub species or small trees like *Calligonum*, *Maytenus*, *A. jacquemontii*, *Ziziphus nummularia*, *Colophospermum mopane*, *Capparis decidua* may be given preference. Here the non-palatable species like *Clerodendrum phlomoides* may be utilized to develop as live hedge through vegetative propagation (Table 1,1a,1b & 1c).

Specialized Techniques : Moving dunes like barchans and active part of the stabilized dune with much sand piling should be taken up first for stabilization/rehabilitation through standard technique developed by CAZRI. To check fast movement of sand a chess-board of 1-3 metre size should be laid out with the help of available brush wood like *Tephrosia purpurea*, *Aerva persica*, *A. pseudotomentosa*, *Calligonum polygonoides*, *Leptadenia pyrotechnica* and *Calotropis procera* etc. Here these plants should be cut above the ground, leaving a part to regenerate back. This process is to be carried out before monsoon. Desirable trees and shrub species (table 1,1a,1b & 1c) with 3-6 m spacing may be transplanted during monsoon period, after an effective shower. Live-hedge of species like *Calotropis procera*, *Clerodendrum phlomoides*, *Acacia jacquemontii*, *Leptadenia pyrotechnica* and *Lycium barbarum* should be raised all around the rehabilitated site. *Cenchrus* and *Lasiurus* grass seed, rooted slip or pelleted seeds may be sown between the plant rows.

Mined Wastelands : Rajasthan is quite rich in its mineral wealth. Arid ecosystem of western Rajasthan is much disturbed by mining activities causing many hazards. Abandoned mining sites convey the sad story of the area. Largely the pre-mined sites used to be the grazing ground for livestock. Mining creates complete loss of woody perennials and forage species. Site of destruction through excavation and piling of mining muck make the tract unsuitable for plant life to establish. Thus these areas need to be rehabilitated which should provide a protective and productive plant cover by trees, shrubs and grasses.

For rehabilitation each mining site has its own peculiarity and need separate treatments for successful rehabilitation work. Before taking up the rehabilitation work, the site characteristics like soil, pH, EC, nutrient status, dumps slope, compactness and many allied characteristics should be undertaken. Vegetation adjacent to the mining area should be studied. All this will give an insight to develop the plan of work for systematic rehabilitation. Some of the following steps are given below:

- Surface configuration, land levelling, soil compaction,stabilizing the piles, bunding, contour furrowing, terracing etc. are required.
- Many sites may need the transport of soil for reclamation purpose.
- Addition of farm yard manure, tank silt/bentonite/chemical fertilizer.
- Select suitable plant material, mostly multipurpose leguminous species.
- Creation of suitable pit size 30 cm^3 to 60 cm^3.
- Developing a water storage structure for summer watering.
- Grass seed broadcasting/pelleted seed or rooted slips.
- 6-9 months old tree/shrubs transplanting during monsoon.

- Pits weeding and hay/stone mulching in the pit.
- Fortnightly or monthly summer watering @ 10 litre/pit for first 3 years.
- Live hedge of suitable plant species like *P. juliflora, Parkinsonia, Tamarix* (table 3) may be raised. Out of the live hedge thorn fencing of *P. juliflora* or any other thorny sp. available in the area may be carried out. Stone wall of 1m height may also be erected in a rocky situation.
- Local people co-operation and co-ordination is essential for successful rehabilitation work

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ROLE OF CONSERVATION METHODS IN ESTABLISHMENT OF TREES AND HIGHER PRODUCTION OF FORAGE SPECIES IN SILVIPASTORAL SYSTEM

N.S.Vangani

Introduction

Indiscriminate exploitation of natural resources for meeting the ever increasing demand for food, fodder and fuel have caused land degradation. The continuous degradation has led to imbalance in land-water-plant and human-animal systems.

The land capability classes V to VIII are categorised as degraded lands; have one or more limitations of slope, erosion,stoniness, rockiness, shallow soils, wetness, climate, etc. Such parameters generally make these lands unsuited to cultivated agricultural crops and limit their use largely for pasture, forest and wildlife and are mostly Government lands or common lands in denuded conditions. Some of the lands may be beyond management and as such are worth writting off. Reduction in Range production due to erosion have been reported by Lowdermilk, (1951), Sampson (1952) and Stoddart and smith (1955). However, most of these lands have a great potential for producing fodder, fuel, fibre and low quality timber by adopting existing technologies for restoration. The technologies could be such as soil and water conservation measures supplemented with proper silvipastoral; combination of afforestation and grassland development. Increased in forage due to soil erosion control have been reported by .'ample (1957) and Nixon (1957) but the definite benefits in the terms of production from grasslands have not been reported.

Rain water in the form of runoff is basic soils erosion agent. If the runoff is appropriately managed within the limits, erosion could be checked. Thus, twin objectives of conservation of resources and their efficient utilization will lead to a better vegetative cover and there by reducing the soils erosion hazard.

A suitable Soil and Water conservation measures adopted and the results of the experiments conducted by the scientists of CAZRI on effectiveness, forage production and tree plantation are being highlighted.

Before drawout the achievements on forage production through conservation measures, it will be worthwhile to have discussion on tree plantation; essential component in silivipastoral system.

Micro catchment water harvesting (MCWH): A micro-catchment is a very small watershed, varying from 100 to 300 m^2, designed to collect runoff for the consumptive use of a single tree (Evenari *et al.*, 1971; National Academy of Sciences, 1978).

It is a well known fact that the percentage of runoff increases with decreasing catchment size. The practical significance of this fact is that a tree having a catchment of its own gets relatively more runoff water than a comparable tree on the terrace of runoff farm. This is illustrated in Fig. 1. and is based on the results of experiments in the Indian desert (Sharma, 1986). It has been found that small watershed are efficient producers of runoff water, being able to harvest ten to fifteen per cent of the annual runoff.

Micro-catchments are very simple to construct. A large, gently sloping plain is subdivided into micro-catchment of various sizes, with a border check about 15 cm high raised around each catchment. At the lowest point of each catchment, an infiltration basin, 30-40 cm deep, is made and a tree is planted in it. After heavy rainfall the whole micro-catchment is flooded, but a light shower causes ponding only in the basin.

MCWH is practised in North Africa, Afghanistan, India, Israel, Mexico and Pakistan (National Academy of Science, 1978; Sharma *et al.*, 1986). It was also found that salinity in the profile of infiltration basins decreased considerably, even to a point where it no longer presented a hazard to the growth of moderately salt sensitive crops (Evenari *et al.*, 1971).

The advantages of MCWH are: (1) construction is inexpensive compared with other water harvesting methods, (2) vast areas can be used for plantation solely on the basis of local water, (3) the relative water harvest is higher than that of larger catchments, and (4) there are no conveyance losses.

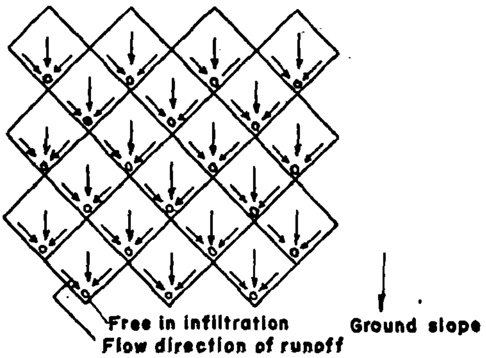
A modification of MCWH is desert strip farming or contour catchment water harvesting (CCWH) (Fig.2). This method uses a series of strips, which are created by grading the soil to form a series of ridges behind which the water infiltrates. CCWH is regarded as a modification of MCWH this is not necessarily so. CCWH was tested in the Arizona (Morin and Matlock, 1975) over an area of 40 ha, and in Israel in Wadi Mashah and Sede Boquer over similar areas (Boers and Ben-Asher, 1979).

Roaded catchment water harvesting (RCWH): RCWH is widely practised in western Australia. Roaded catchments consists of series of parallel compacted roads with exaggerated camber which adjoin to make V-shaped channels that discharge into a collector drain at the lower end (Fig. 3). The roaded catchment was developed from field experience, from which design rules-of-thumb were produced for the gradients of roads and collecting channels to ensure that no serious erosion would occur. The size and shape of the roads and the catchment layout have evolved mainly through intuition and by taking into consideration the construction equipment. Individual roads vary from 50 to 300 m long and 5 to 12 m wide; the catchment area can very up to about 10 ha (Hollick, 1975).

Water Conservation

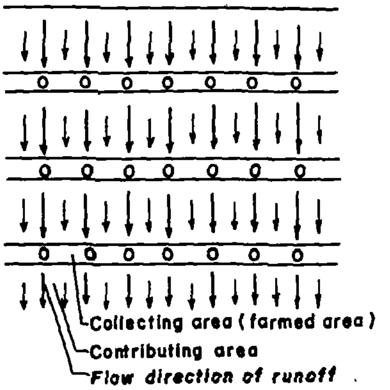
Contour trenching

Sloping lands, steeper than 1 to 10% with shallow depth of soils would result in a very open degraded type of vegetation. Such areas are treated by digging trenches strictly along the contours. Tree seedlings suitable to the locality and fast growing are introduced or seeds of tree species are sown on the berms formed of the excavated material on the down slope edge of the trench.



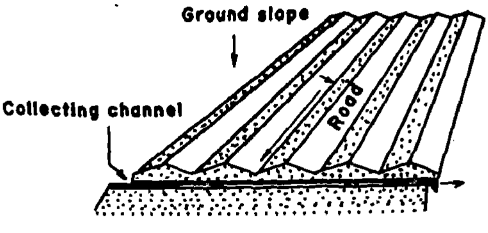
Micro Catchment Water Harvesting System

Fig. 1



Contour Catchment Water Harvesting System

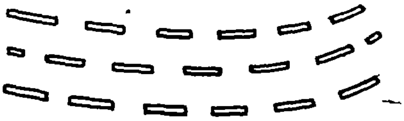
Fig. 2



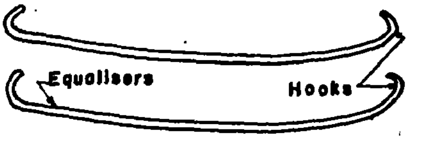
Roaded Catchment Water Harvesting System

Fig. 3

Staggered Trenches



Contour Trenches



Trenches

Fig. 4

Contour trenching consists of excavated trenches and forming bunds at trenches along a uniform level or at a particular contour across the slope of uncultivated wastelands. The main objectives of contour trenches are to reduce the amount and intensity of runoff, conserve moisture and soil, thus help in the establishment and accelerating the growth of trees in afforestation programme. The runoff collected in trenches which ultimately percolated through the soil and travel down and benefits the slopy lands in middle and lower parts of the catchment

Contour trenches are excavated at suitable vertical interval depending on the slope of land. Their cross sections are designed to collected and convey the runoff expected from interspace between the successive trenches. The side slopes of the trenches are 1:1 or 1/2:1 according to the nature of soil. Trenches are continuous or staggered type. Normally continuous trenches are 15 m long with cross section rarely exceeding 0.3 x 0.3 m. A common practice is to have 4 m long trench at an interval of 4 along the contour line. The staggered trenches are shorter lengths and occur in a row along the contour with interspacing between them. In the alternate row, the trenches will be located directly below one another. The trenches in successive rows will be staggered with the trenches in upper row and the interspace in the lower row being directly below each other (Fig.4). The length of the trench and interspace between the trenches in the same row may be suitably arrived at so that there will not be long unprotected sloping lands. In arid areas, trenches of 1.5 m x 45 cm x 45 cm are dug at 3 m space staggered on contour. The excavated soil is piledup on the down hill slope along the trench length. The seeds are either sown on berm of the trenches on in diagonally half filled trenches. The following equation is used to calculate the capacity of the trenches.

$$Q_{Runoff} = (W \times D)/[100\ HI\ (1 + X/L)]$$

where,

Q_{Runoff} = depth of runoff from area in cm (considering intense storms at recurrence intervalof 5-10 years)
W = Width of trench in cm
D = depth of trench in cm
HI = horizontal interval in metres
L = length of trench in metres
X = gap in between the trenches in metres.

Surface mulchng : The practice of surface mulching has a role in reducing evaporation in dryland areas. Mulches of plastic films and organic wastes have proved useful. Plastic mulch is a costly input. Often the advantages are not commensurate to the achievable benefits. Moreover, the application of such mulch is quite cumbersome and in case of organic wastes, the quantity required to cover the field is a constraint. Further, in very sandy soil situations, since the soils are self mulching, the practice may not be of much advantage in drylands cropping. But mulch application can certainly be advantageous in reducing the supplemental irrigation requirement during the initial establishment of tree crops in Agro-horticulture and Agri- silviculture systems (Singh, and Vangani 1989). Since the surface soils will be wet more frequently in such cases, the mulch will substantially reduce the surface evaporation following irrigation. Quantity of mulch material required will be small and its application is easy for only the planting basins need to be mulched and not the entire field which will be required for field crops. Mulches of gravel if available from digging of planting pits and organic wastes can conveniently used for such conditions.

Use of sub-surface barriers for water and nutrient conservation : It has been estimated that about 40% of the total rainfall s lost as deep percolation in sandy soils. Field trials with three sub-surface barriers i.e. asphalt, bentonte clay and pond silt, each placed at 60 cm depth in 2-5 mm thickness allowed 80-85%, 60-70%,50-60%, retention of the total rainfall, in the root zone, respectively (Anonymous, 1988). These barriers, reduced the leaching losses of nitrogen

Bentonite as sub-surface moisture barrier: Bentonite clay is a natural resource of western Rajasthan. As sub-surface moisture barrier, it has been found to reduce deep percolation of moisture from the root zone. In pits the bentonite can be placed laterally too, thus creating a buried pot like structure, which in particular is suitable for initial establishment of tree plantation (Anonymous, 1988)

Effect of sub-surface barrier and mulches on soil moisture retention: Both bentonite barrier

Table 1. Effect of bentonite barrier and mulch on moisture retention and growth in date palm

Treatment	Moisture storage (mm) in 60 cm soil profile on		Increment in height of plant (cm) between
	27-10-87	2-11-87	24-4-86 to 4-11-87
Control	46	49	43
Mulch	51	53	55
Barrier	67	70	62
Barrier + mulch	85	87	79

Source . Anonymous, 1987

and surface mulch of plant residue showed higher moisture storage than the control treatment (Table 1). This was caused by reduced losses of moisture in evaporation and deep percolation

The arid region of Rajathan, experiments conducted on soil and water conservation measures at Range management areas; Jadan, Jaisalmer, Bhopalgarh and Palsana reveals that there could be substantial increase in forage production with this technology. The soils and rainfall characteristics and also initial vegetative cover were variable at all the four sites

Jadan Range Management Area (76.89ha) had rolling topography and primarly the soils were gravelly to sandy loam to fine loam, eroded to a large extent, thereby exposing stones and boulders at various locations, with average slope of 1 to 2 per cent. Due to rolling topography and long length of slopes, the area was subjected to severe sheet and rill erosion. During experiment (1961-72) the rainfall varied from 119.2 to 789.0 mm. The following are the details of soil and water conservation treatments.

- Contour furrows 23 cm deep and 61 cm wide forming a cross section 929 sq.cm. (1 sq.ft.) were dug and excavated earth was formed into the mound on the down slope side. These were spaced 8 to 10 metre apart.
- Contour bunds of 0.56 m^2 cross sectional area were consturcted at vertical interval (V.I) of 60 cm. across the slope. The bunds were provided with one random rubble dry stone masonry spillway, for excess storm water.
- Contour trenches of 0.18 m^2 cross section (0.6x0.3m), were dug at 0.6 m V.I. After every 60 m length 1.5 m space was left unexcavated to serve as spilling section during heavy rainfall

In order to compare the effectiveness and economics of these soil conservation structures constructed within the fenced area, a pair of plots of 0.0081 ha was laid in between the structures. Also a pair of same size plots were laidout in the untreated areas which were also fenced. While selecting the sample plots care was taken to see that the botanical composition of sample plots in treated and untreated areas and slope was also identical, as far as possible. The vegetation of these plots was harvested in the beginning of November every year.

The data from contour furrows revealed that there was highly significant increase in forage yield from treated plots over its control. An average increased forage yield per year was 638 7 per cent (230.8 to 2012.5 per cent), i.e. 1.354 tonnes/ha. irrespective of rainfall amount received in the year. The increase in forage yield during first year was 230.8 per cent and there after very remarkable increase in next five years was recorded.

The effect of contour bunding on forage yield was also significant. An average increase in yield as a result of treatment was 168.8 percent. (15.2 to 2689 per cent). The increase was remarkable during first year, there after it showed downward trend in subsequent years.

Forage yield as a result of contour trenches were significantly higher over their control The increase in forage yield was of the order of 181 per cent during first three year and also in subsequent two years but latter on it showed decline. However, an average increase in forage yield as a result of contour trenching treatment was 165 per cent over the control. Over all increase in forage yield from all the three treatments over the untreated area in presented in the Table 2.

It is revealed from Table 2 that within the three treatment there is significant difference in forage production. Probably because; the distance between two successive contour bund and contour trenches was large as compared to the contour furrows. Hence there was more uniform spread of water in the later, thus, enhancing the soil moisture regime (Morth, et al, 1971, Wasivlah *et al.*, 1972) and resulting in better growth of grasses.

In the treated area of contour trenches, the increase in forage yield was low, because most of the runoff was traped in the trenches. Thus, limiting the spread of water to lesser area and less moisture regime. However, in the case of contour bunds, the spread of water was on large area resulted in better vegetative cover, as compared to contour trenches.

From this experiment it was concluded that on rangelands in western Rajasthan with shallow soils and rolling topography, contour furrows of cross section , 929 Cm^2 horizontally

Table 2. Increase in forage yield (per cent) as a result of soil and water conservation measures.

Year	Rainfall (mm)	Contour furrows		Contour bunds		Contour trenches	
		Yield (t/ha)	Per cent	Yield (t/ha)	Per - cent	Yield (t/ha)	Per cent
1961	544.9	0.54	230.8	2.24	2689.0	0.47	181.0
1962	279.9	2.09	983.4	1.78	410.6	1.19	434.7
1963	250.4	0.58	888.4	1.26	436.4	0.68	369.1
1964	394.0	1.84	1673.6	1.47	295.5	1.24	207.3
1965	477.6	2.06	878.7	0.65	60.6	0.64	70.9
1966	446.2	0.07	811.9	0.22	15.2	0.88	79.2
1967	789.0	1.31	300.8	0.28	33.7	0.42	49.2
1968	126.2	0.35	2012.5	0.04	207.2	0.05	281.4
1970	586.0	1.34	408.8	1.23	159.6	1.82	386.7
Mean	432.7	1.35	638.7	1.02	168.8	0.82	165.0

Source : Field date

spaced at 8-10 metre apart is the most useful soil and water conservation measure to improve the forage production.

This was not the end of soil and water conservation measures tried on the rangeland for more forage production. In another experiment tried at the four centres (Jaisalmer, Bhopalgarh,Palsana and Jadan) western Rajasthan. Eight plots (30 m wide, 130-160 m length)were treated with contour furrows and contour bunds of the following specification seperately and combination against one plot as control.

Contour furrows	
X. section (height or depth)	Vertical spacing
15 cm	12.5 cm
10 cm	10.0 cm
Contour bunds	
75 cm	80.0 cm
70 cm	60.0 cm

In order to evaluate the combined effect of furrows and bunds, the above sections were tried in four possible combination in four plots. The remaining four plots were provided seperately with series of bunds and furrows having above specification. The control plot and the two plots with furrows were equipped with H. flume and stage level recorder for measuring excessive runoff. But during the study period no significant runoff water was recorded from these plots.

Monthly observation on soil moisture revealed that moisture percentage attains a peak by the end of July or sometimes in August depending upon the distribution of rainfall. Percentage increase in soil moisture over the control plot is presented in Table 3.

From the above Table 2 it s revealed that bunding of 75 cm high and 80 cm vertical spacing combined with contour furrowing 10-15 cm depth and 100-125 cm vertical spacing seems to be better for soil and water conservation in different types of rangelands of the arid zone.

Table 3. Per cent increase in soil moisture from treated plots over the control plot

Location	Depth (cm)	1966				1967			
		Contour furrow	Contour bund	Contour furrow and bund I	Contour furrow and bund II	Contour furrow	Contour bund	Contour furrow and bund I	Contour furrow and bund II
Jaisalmer	0-5	100.4	45.6	129.5	83.4	130.2	127.7	154.6	105.7
	5-15	75.4	18.9	90.9	58.5	70.5	75.0	59.0	46.9
	15-25	40.0	23.6	47.2	49.1	88.1	49.6	25.8	33.3
Bhopalgarh	0-5	25.0	26.3	27.2	9.1	-29.1	-17.1	8.1	-2.3
	5-15	32.0	30.8	30.0	14.4	6.9	9.1	4.5	13.2
	15-25	43.1	21.0	17.9	13.5	81.0	46.3	9.3	13.2
Palsana	0-5	5.0	-5.5	-1.8	-3.7	3.1	0.5	14.0	3.1
	5-15	5.1	0.5	1.9	-6.2	7.8	7.4	12.5	2.6
	15-25	11.2	2.7	4.3	0.76	28.5	24.0	16.6	16.5
Jadan	0-5	43.6	39.2	19.1	10.0	18.3	19.4	11.6	0.97
	5-15	53.8	35.3	8.8	57.2	8.6	18.1	14.6	0.20
	15-25	77.1	34.7	40.0	56.2	2.1	21.3	20.7	17.9
I	Contour bunds & furrow			bunds 80 cm V I & 75 cm lugh			Furrows 10 cm V.I. 10cm deep 12.5 cm V I 15 cm deep		
II	Contour bunds & furrow			bunds 60 cm V.I. & 70 cm high			Furrows 12.5 cm V.I. 15cm deep 10 cm V.I 10 cm deep		

Source: Wasiullah et. al, 1972.

Further Wasiullah *et al.* (1972) reported the perennial grass species such as *Lasiurus sindicus*, *Cenchrus ciliaris*, *Cenchrus setigerus* and *Eleusine compressa* were benefited by soil conservation measures at Jaisalmer, Bhopalgarh and Jadan where the soils were shallow, but in deep sandy soils at Palsana, the perennials were adversely affected and *Aristida* and *cyperus spp.* increased in their number. This tally with observations on increase in moisture percentage.

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DEVELOPMENT OF WATER BODIES IN OPEN PASTURE LANDS

M.A. Khan

Introduction

Water is a scarce commodity in the arid zones of India which covers about 12% of the country's geographical area. The most acute water shortages in India occur within the hot arid belt of Rajasthan. This region accounts for 61% of the area classified as arid within India and is spread over eleven western districts of the State. The terrain within this region is dominantly sandy and has a disorganised drainage network. In addition, much of the area is underlain by deep and often saline groundwater aquifer. In this region rainfall is low and erratic and generally occurs in the monsoon months from mid-June to mid-September. Meagre water supply, high seepage and evaporation demand restrict the activities to support the land management systems and to increase total biomass production in the region. The relatively higher rate of infiltration and permeability lead to reduced surface runoff which is generally expected as a result of high magnitude storms.

The river Luni and its tributaries originating from the Aravalli hills are the only rivers with defined drainage network which drain into the saline *Rann* of Kutch. This drainage system too is ephemeral in nature and flows during rainy months, making the problem of water bodies development extremely different. The drainage system in the rest of the area which occupy more than two third of the total area is undefined and the streams originating from the isolated hills disappear under sand. These streams can be tapped and utilised for conjunctive usage. They can also be utilized for diverting and spreading over large areas for improving moisture regime in open pasture lands. Development of water bodies through utilization of rain runoff remains the major source to develop silvi-pastoral systems, improved crop production and for domestic purposes.

Rainwater Harvesting Structures

Nadi : Nadi is constructed for storing water available from adjoining natural catchment during the rainy season. In arid Rajasthan, construction of *nadi* is one of the oldest practice and is still the common source of water for conjunctive uses. The capacity of *nadis* generally ranges from 1200 to 15000 m^3, depending upon physiographic conditions and rainfall pattern. At present most villages in the region have one or more *nadis*. According to the 1982 census, the number of *nadi* in Nagaur, Barmer and Jaisalmer districts were found to be 1436, 592 and 1822, respectively.

Traditional *nadi* has the limitation of high evaporation losses from free water surface, seepage losses through porous sides and bottom and heavy sedimentation due to degradation in the catchment. Depending upon the physiographic setting and wetted area, the contribution to ground water recharge from these structures ranges from 0.06 m in rocky pediments to 1.58 m sandy plains. A study conducted by the Central Ground Water Board using the recharge pits has indicated that a pit of 3m x 3m x 3m, was sufficient to divert 6500 m^3/year to the ground water reservoir (NDWM, 1988). Recharge from a pond of 2.25 hectare area and storage capacity of 15,000 m^3 in north Gujarat alluvial area could, therefore, be induced to create ground water recharge of 10,000 m^3 in one rainy season.

Nadi should be located in areas with lowest elevation to have the benefit of natural drainage and need of minimum excavation of earth. Surface of the catchment area should preferably be impermeable. If necessary, the catchment area may be structured artificially by soil conditioning and guide bunds to divert runoff in the *nadi* from other adjoining areas. The surface to volume ratio should be kept minimum possible (less than 0.3) for reducing the evaporation losses. Silt trap should be provided at the inlet point to prevent sediment load entry in the structure. The inlet should be stone pitched to prevent soil erosion. In order to prevent seepage losses through sides and bottom, these should be lined with either LDPE sheeting or stone masonry. In case of LDPE lining it should be embedded properly in the soil. An exploitation well should be constructed at a suitable point of *nadi* with water lifting device to facilitate the withdrawal of water from the *nadi*. The stored *nadi*'s water may be utilized for taking up silvipastoral activities and improving the range management which will help in environmental improvement and meeting demand of fuel and fodder. Central Arid Zone Research Institute (CAZRI), Jodhpur, developed the improved design of *nadi* with LDPE lining for maximising surface water availability in water-scarce areas.

In Barmer district, improved design of Jasder *nadi* for a capacity of 18,100 m^3 was developed. In the command area of *nadi*, plantation of suitable species of trees and grasses were taken up during 1987-88, utilising *nadi* water. Tree species of *Colophospermum mopane, Acacia. tortilis, Dichrostachys nutans* and *Ziziphus nummularia* were planted in rows at a distance of 5m x 5m in each case. In between tree rows, *Cenchrus ciliaris* grass was sown in July, 1988. The grass production in 1989 was around 500 kg/ha. The survival of woody plants (trees) was over 60% and growth was very encouraging. The trees now have gained 3-4 m height and 0.3 to 0.5 m girth. The development of trees with the supplemental irrigation from the *nadi* has improved the environment, beside providing fodder and fuel.

Tanka : Tanka is a small circular or square underground tank constructed with lime mortar or cement plaster. It is constructed normally on fallow ground where surface runoff can be diverted to the *tank* by creating a clean catchment all around. This system is an ancient practice and still very common in western Rajasthan.

Tanka is constructed in different sizes depending upon water requirement. Smaller *tanka* is, however, generally better managed and conserved water is used more judiciously than the bigger *tanka*. A *tanka* constructed utilising traditional method is not strong and is generally subjected to leakage from sides and bottom. In addition, sediment entry with runoff is not protected and some evaporation takes place from the top as the structure is covered only with thorn.

In order to overcome problems encountered in a traditional *tanka*, CAZRI, has developed improved designs of this structure for capacities ranging from 10,000 to 6,00,000 litres (Khan, 1992). Vertical surfaces in improved *tanka* are made of stone masonry with cement plaster and the base is made with 10-15 cm thick cement concrete layer. Inlets and an outlet are protected with iron bars and gratings to protect waste materials entry into the *tanka*. Silt entry in the structure is restricted by providing silt traps at inlet points. Top of the structure is covered with stone slabs with cement plaster, leaving only an opening for the withdrawal of water. In western Rajasthan a large number of improved *tankas* have been constructed for conjunctive uses.

With the construction of 1,42,000 litres capacity *tanka* in Sar watershed, plantation of trees like *Acacia tortilis, Acacia senegal, Acacia nilotica, Prosopis juliflora, Prosopis cineraria* and *Colophospermum mopane* was taken up during the year 1991, 1992 and 1993. In the 6 hectare silvipastoral block, spacing between the rows and the plants were kept at 10 m and 5 m, respectively. In the 4 hectare block, where only trees were planted, 3m spacing between the rows and the plants were maintained. The plant density in the silvipastoral block was 200 per ha, while in the tree block it was 1000 per ha. Trees established utilizing *tanka* water were 1,500 in 1991, 1,300 in 1992 and in 1993. In the village, 15 *tankas* of 10,000 litres capacity each were also constructed for raising forest nursery and for the establishment of fruit orchards. In recent time a large number of *tankas* have also been constructed for sand dune stabilization and for afforestation in western Rajasthan.

Khadin: Khadin is a unique practice of water harvesting and moisture conservation in suitable deep soil plots surrounded by some sort of natural catchment zone. In this system, runoff from uplands and rocky surfaces is collected in the adjoining lower valley segments. The plots are vigorously built and managed to make the entire system a self-contained unit for cultivation. On the earthen bund, trees and grasses are established for increasing fodder and fuel availability. Grass also helps in stabilization of bund, whereas, tree works as a wind break and thus reduces the evaporation losses from free water surface in the *khadin* bed. Under the condition of evaporation, soil moisture and fertility are maintained in the deposits behind the earthen bunds. The total energy input of rainwater, sand-silt-clay accumulation and cultivators' own activities are interwoven into a complete production system. In this system, there is a progressive increase in crop yield every year due to the deposition of fresh silt and clay in the *khadin* bed. There is also fast gain in the tree height due to the continuous supply of moisture from the system.

The depth of water trapped in a *khadin* varies from 50 to 125 cm, depending upon the catchment characteristics, rainfall pattern and storage capacity of the *khadin* bed. This gradually depleted through seepage and evaporation, leaving the surface soil moist and fit for sowing. Data on salinity in soil profile (0-120 cm) shows that average EC in Rupsi *Khadin* in Jaisalmer district was 2.2 mmhos/cm, whereas, outside it was 36.2 mmhos/cm (Kolarkar *et al.* 1983).

The *khadin* system of cultivation has witnessed a fluctuating fortune. During the nineteenth century due to the rivalry among the local inhabitants, *khadins* were completely neglected and fell into disrepair. It was only during the second half of the twentieth century that the Government again recognised the need of the *khadin* cultivation. Old *khadins* were repaired and new farms were constructed. Since 1965 the government has repaired 66 *khadins* in Jaisalmer district. At present more than 500 *khadin* farms have been revived, covering an area of 12,150 hectares of farm lands. CAZRI, has developed the improved designs of *khadin* to optimise the process of infiltration, runoff generation and routing, as well as soil and water storage capacity.

Anicut : Anicut is a structure constructed across a stream. It is an earth fill section with a spillway and is designed to hold sufficient water to submerge a substantial upstream area during the rainy season. The retained water sinks into soil profile and then seeps down to replenish adjacent wells. These wells are used for irrigating small patches of land for the establishment of forest trees and for other uses. Water retained behind the anicut is used for lift irrigation in the adjoining area. Anicut can support intensive silvipastoral activities in the areas where rainfall is unreliable. It is also useful for reclamation of a gully through bank stabilization and sedimentation, regeneration and improvement of overall environment.

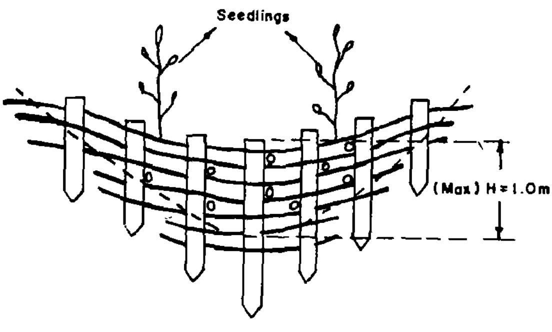
With the construction of anicuts in Jhanwar watershed (Jodhpur district) static water levels in wells located downstream increased from 1.8 to 2.2 m as compared to increase of only 0.5 m in wells located in adjoining areas. It has also helped in regeneration of plants of different species and grasses in the upstream area which has improved substantially the availability of fodder and fuel. Studies conducted for two years in Pali district have shown that the presence of anicuts increased aquifer recharge from 5.2% to 38.5%. Also in the vicinity of anicuts, a thick forest has come up which has improved the economic condition of people in the area.

Gully Plugging : About 4 million hectare land in India is affected by gully and ravines which threaten another 4-6 million hectare of productive table lands. Much of these areas are in semi-arid regions and the rest in the drought affected parts of soil conservation region in eastern red soils (Das, 1977). However, with the proper management the runoff through gullies can be harvested for groundwater recharge, for the improvement of silvipastoral lands and for other uses. In western countries the gully control works started as back as 1900 AD. However, in India such works were taken up on extensive scale since 1960.

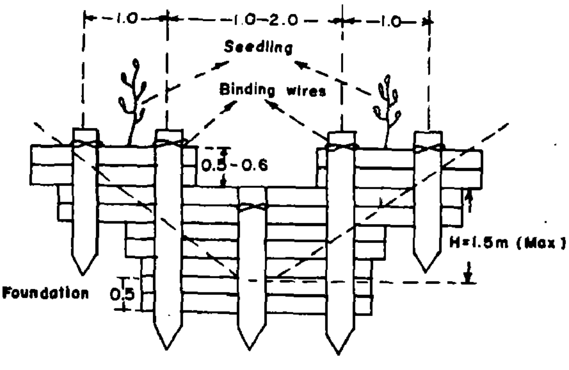
The gully plugs may be of brush wood, wooden logs (Fig.1), Where gully problems are present, drop spillway with earthen extension walls can be constructed to intercept and divert runoff in the adjoining areas for irrigation while checking erosion. The projects help to restore some of the degraded lands and recharge ground water. Alternately, streams can be barricaded by low channel sills to increase water depth so that water can be lifted for irrigation along upstream sides. These lands could otherwise lie fallow due to long dry spells and drought. The specification and spacing of gully plugs are given in Table 1.

Water Harvesting Dams : In ravines or heavily gullied lands, small earthen dams with drop inlet spillways are often constructed. These create a small storage to increase ground water recharge, promote better vegetative growth and provide water for irrigation during monsoon as well as winter season. The optimum size of these structures with regard to catchment area and potential command varies greatly and is dependent on site characteristics.

Water Spreading : Water spreading is a practice where flood water is deliberately collected from a large area or from stream sources and diverted into a smaller area. It improves the rangeland through irrigation or overall improvement of moisture condition in degraded lands, so



Front view of Brushwood gully check



Front view of log gully check

Fig. 1. Gully control structure

that natural and artificial regeneration of vegetation are accelerated. It is also adopted to recharge groundwater for various future uses.

Surface runoff can be intercepted by constructing long dykes and then led along to spread over the receiving area through a staggered system of dykes and ditches. Generally water from 4 to 12 ha area can be spread over 1 ha. Alternately, an earth fill is put across the stream with extension diversion dyke to lead water for spreading. The method adopted are syrup pan system of spreader and spur dykes, pondage bank of spreaders only, and short spreader and ditch system. In between the spreader dykes, shallow furrows could be provided to facilitate quick and uniform absorption of water. To permit outflow from spreader dyke, stone pitched rock weep holes are provided.

For recharging groundwater, basin method is followed, particularly on irregular topography. On the river beds shallow furrow ditch system is followed. Meadow flooding over extensive

Table 1.Specification of materi: ls and location of gully plugs in gullies

Stope of gully bed (%)	Width of gully bed (m)	Location	Type of gully plug	Vertical interval (m)
0-5	4.5	Gully bed	Brush wood	3.0
	4.5 -10.5	Gully bed and side branch		2.25 - 3.0
	7.5 - 15.0	At theconfluence of two gullies	Sand bag	-
	7.5 - 15.0	At the confluence of all branches of compound gully	Brick masonry	-
5-10	4.5	Gully bed	Brush wood	3.0
	4.5-6.0	Gully bed and side branch	Earthen	1.5-3.0

area is followed in gently sloping areas which are free from gullying (Rao, 1972; NAS, 1974; UNEP, 1983).

Percolation Tank : Technological development in pumping method and well construction, high water demand for domestic and crop husbandry uses have resulted in large scale exploitation of groundwater. In the arid and semi-arid regions where rainfall is scanty, replenishment of ground water is not in proportional to its utilisation. Under such situation, artificial groundwater recharge through water harvesting method may be recommended.

Percolation tanks are generally constructed on the small streams or rivulets with adequate catchment for impounding surface runoff. These tanks will have no surplus weirs as these are used entirely for recharging the aquifers through percolation. Construction of this structure takes into account the catchment area, likely runoff, designed storage at the site as well as the area of benefit of the structure. The construction of such structure is considered to be very useful as means of water conservation and to strengthen the drinking and irrigation water sources.

Limitations

- Percolation tanks are effective in deep and pervious soils.
- Desiltation of percolation tank is essential otherwise fine sediments may reduce the soil porosity, resulting in less percolation.
- The catchment and bed of the percolation tank must be free from salinity, otherwise it will deteriorate the groundwater quality.

Subsurface Barriers : In desert, ground water recharge, whether direct from rainfall or through stream flow, is not regular but discontinuous, reflecting the variable nature of rainfall and runoff. The response of river flow on the replenishment of wells located along the banks is immediate. However, meagre recharge during runoff period does not sustain the wells for a sufficiently long time due to which scarcity of water is felt. To some extent the yield of such wells can be improved by abstracting the sub-surface flow of sandy bed streams through construction of subsurface barriers across the stream beds.

Subsurface barrier is the most suitable structure as it is safe from flood havocs, does not need elaborate overflow arrangement and periodic desilting. The silt from surface area at upstream side of barrier is flushed away during flash floods whereas entire storage of water being underground, evaporation losses are also insignificant. The construction needs a 30 to 60 cm wide concrete or brick masonry wall extending down to the impermeable basement or compact foundation. Subsurface barrier may also be constructed with angular rock pieces arranged in the form of dry masonry 100 cm wide wall or with a 250 micron polyethylene sheeting, properly embedded in the soil. Construction of two-sub surface barriers of 10 m length each, within 300 m from the water supply well, is enough to store water required for a village with population of 500 (NDWM, 1988). As the domestic wells are located in the village, there is need for constructing these structures close to the village only. One of the structures should be in the upstream side whereas the other should be downstream. If only one structure is constructed, it should be downstream of the wells to intercept the basin subsurface outflow of ground water from around the wells. During dry season, when the pumping water level in the well is low, the hydraulic gradient is reversed and the water is drawn from the ground water mound downstream.

Study conducted for 3 years at Kalāwas, Jodhpur district, revealed that with the construction of a sub-surface barrier the rate of depletion of ground water was reduced from average 1.0 m to 0.3 m per year (Table 2 and Fig. 2).

Sand-Filled Dam : Sandy river beds underlain by hard impervious strata below and having no surface flow, except in flood seasons, are a common feature of arid and semi-arid regions. Creation of conditions where surface water could be conserved in deep sandy bed, thereby reducing evaporation, is also important (Wipplinger, 1958).

Table 2.Effect of sub-surface barrier (SSB) on ground water recharge (1990-1992)

Item	Before the construction of S.S.B.	After the construction of S.S.B.
Rate of depletion in ground water per year	0.80 - 1.20 m	0.20 - 0.40 m
Water yield per day	80-120 m3	100-145 m3
Tube wells	-	-
Increase in command area due to S.S.B.	-	10 hectare
Recharged area		
a) Upstream		400 m
b) Downstream		700 m
c) right band		180 m
d) Left band		110 m

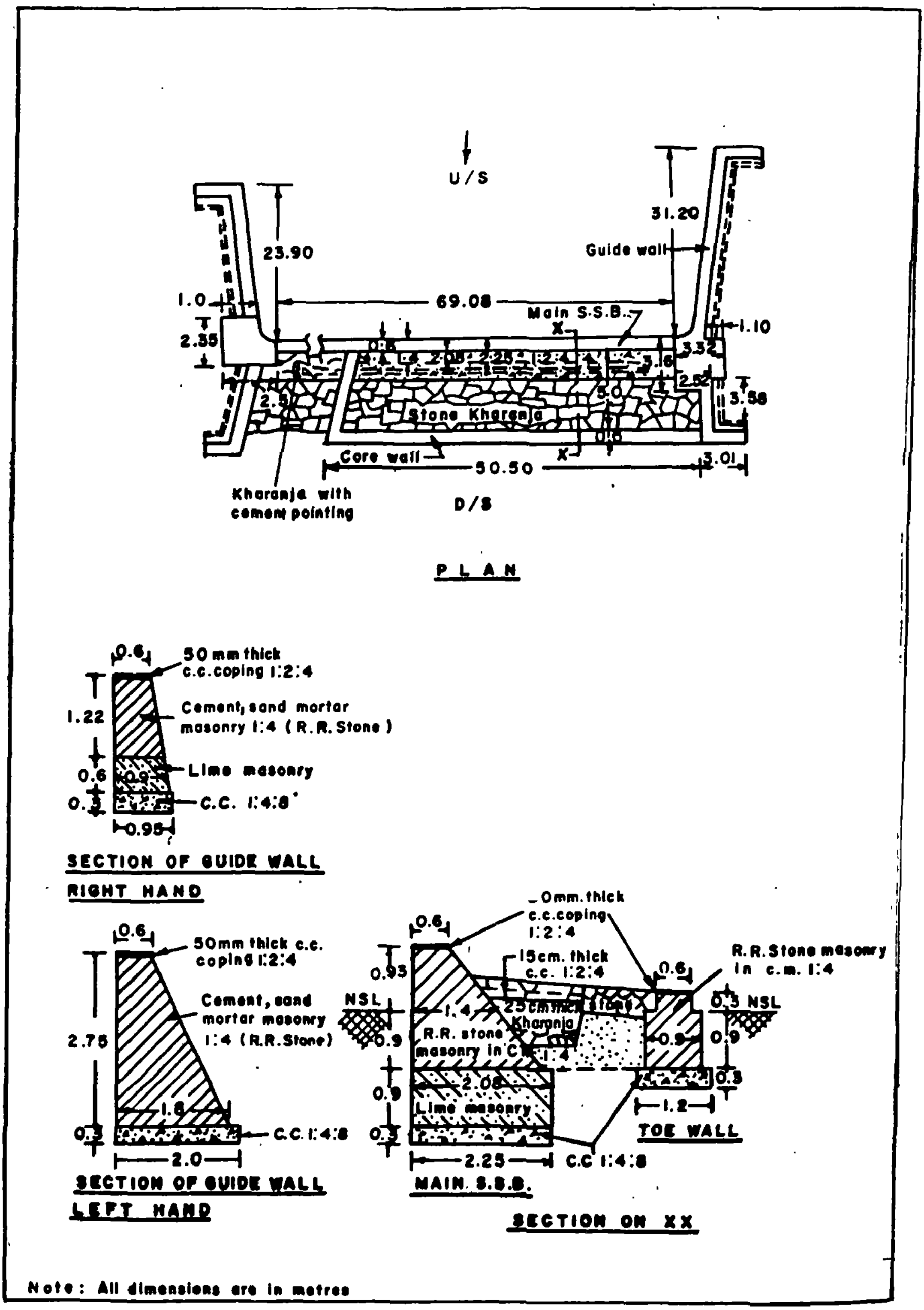


Fig. 2. Sub-Surface Barrier at Kalawas

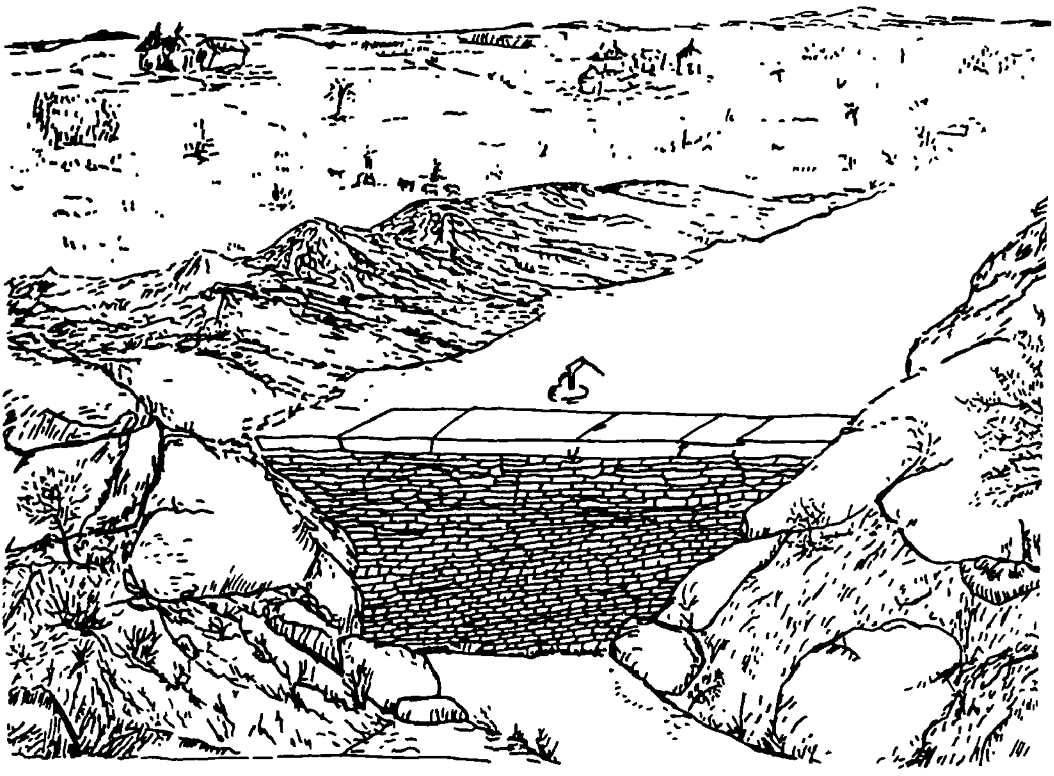


Fig 3. Sand-filled dam — a novel system of water conservation

Sand-filled dam (Fig 3) is basically a subsurface barrier that is used for stopping the flow and storing water in sand bed for domestic water supply and groundwater recharge in the vicinity The river bed gets filled with sand and gravel deposits carried by river flood during monsoon season Flood water is stored in the basin in voids and pore spaces of sand particles and the upper sandy mulch prevents its evaporation losses Initially the dam height is kept few centimetres above the stream bed and as the reservoir gets filled up with sand and gravel the height of dam is gradually raised in stages The basic principle involved in raising dam height in stages is to allow velocities of flood through the basin to transport most of the fine sediments in suspension (clay and silt) over the dam crest, which otherwise get deposited in the reservoir, thus reducing storage capacity To increase the effectiveness of storage, water stored in the upper reaches of the reservoir is guided and drained to a common draw off point where pumping station is located The natural greenery that develops around the water points helps in improving the environment in arid areas

Studies carried out for four years at Jodhpur revealed that evaporation reduction in sand filled reservoir was about 92 per cent, although reduction in storage capacity was nearly half In comparison to other treatments the quality of stored water in sand filled reservoir was superior (Khan, 1992)

Heading/Limitations

- Deposition of fine sediment load in the reservoir transported by runoff water reduces its storage capacity Evaporation losses from the reservoir are also increased as a result of favourable capillary action of the deposited material
- Runoff water received from salt affected catchment area deteriorate the quality of stored water as well as ground water
- Construction of sand-filled dam reduces recharge of aquifer downstream of the river

Conclusion

In the water deficit regions such as western Rajasthan, sustainable development of silvipastoral system can be achieved by adopting specific technology packages, including development of water bodies in open pasture lands and management of rainwater for replenishment to ground water The methods of water harvesting or artificial recharge, norms for planning and designing and rationale for justifying costs are site-specific

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WATER USE AND PRODUCTION POTENTIAL OF SEWAN (*LASIURUS SINDICUS HENR.*)PASTURES IN THAR DESERT

K.C. Singh and S.D. Singh

Introduction

The population of livestock in the arid region of Rajasthan has increased from 13.70 million in 1961 to 23.18 million in 1992. Thus, animal husbandry is the main source of livelihood and pasture production has a significant role in the economy of the Indian arid zone. The estimated fodder requirement is 23.95 million tonnes of dry fodder against the present production level of 9.03 million tonnes leaving a shortage of 63.20% (Venkateswarlu *et al*.,1992). *Lasiurus sindicus, Cenchrus ciliaris* and *Cenchrus setigerus* are some of the promising desert grasses that give sustainable production under the harsh climatic conditions of the region. *Lasiurus sindicus* commonly referred to as Sewan is a natural species of the Thar desert region dominating large areas in the extreme arid parts of Jaisalmer, Bikaner and Barmer districts of Rajasthan. This grass is highly tolerant to water stress and therefore, performs well in the sandy soils of this region receiving annual rainfall below 300 mm.

The land forms of Indira Gandhi Nahar Project (IGNP) area are high sand dunes and interdunal plains covering 58% and 23% area,respectively. Moisture storage capacity of these soils is very low and many interdunal areas are underlain by a hard pan or a salty substratum. Therefore, intensive surface irrigation from the canal for crop production is bound to result in problems of water logging and salt infestation, and hence such lands are best suited for grasslands. Light irrigations by sprinkler to the active root zone of grasses would not be as injurious as heavy irrigations for crops and would yield highly palatable and nutritive forage that would not only meet the requirements of local animals but would also be stored in fodder banks to combat the drought situation common in western Rajasthan. The areas dominated by *L. sindicus* grass in stage-II of IGNP have also been proposed for development into high producing pasture lands by sprinkler irrigation for sustaining precious livestock wealth' of the region(Kaushik, 1985). Fortunately with the construction of Indira Gandhi Nahar water is available for irrigation to *L. sindicus* grasslands in Jaisalmer region.

Management of Natural Grassland of *L. Sindicus*

About 80% of the total land area of Jaisalmer is covered by the sprawling L. sindicus grasslands. It performs well on sandy plains but also grows on low dunes, hummocks and light textured soils. The rainfall zone with 100-150 mm is predominantly occupied by natural stand of L. sindicus grassland, i.e. Nachana, west of Puggal, Mohangarh, Sultana and Binjewala. Under better moisture conditions supported by optimal fertilization, grass gives good yield (Anon 1986) and (Rao *et al*.,1996). Hence, the first step for raising the forage production from these natural grasslands should be to bring the population to an optimal level by planting seedlings or rooted slips during the monsoon season. A population density of (53,333 plant/per ha) regulated by inter and intra row spacings of 75 and 25 cm, respectively is adequate for rain fed sown pastures (Anon, 1986). The inter and intra-row spacings of 75 and 40 cm, respectively (33,333 plants/per ha) were recommended by Bhimaya and Ahuja (1967). Still another factor limiting to biomass yield is nitrogen deficiency in soil. The root biomass of *L. sindicus* during the rainy season decreases due to nitrogen deficiency. Hence, application of fertilizer @ 20 kg N per ha to *L. sindicus* grasslands is another step to boost its forage production under rainfed conditions. Harvesting of grass at the flowering stage of growth is also necessary to obtain nutritive forage, besides increased production (Shankarnarayan and Singh, 1990). Attempts have been made to incorporate tree species in natural grasslands, however, choice of species varies for different grasslands depending upon rainfall and soil types (Shankarnarayan and Singh, 1990 and Singh, 1995).Planting of tree species across the wind direction like *Acacia tortilis* on the boundaries of grassland as windbreak is also conducive to high yields as it reduces the wind velocity and provides protection to the sprinkler irrigation. *Prosopis cineraria* and *Zizyphus nummularia* are also good top feed tree/bush for plantation in such grasslands. The shelterbelts of three rows of *A. tortilis* and one row of *P. juliflora* will give high effectiveness in Jaisalmer region for controlling wind speed and also reducing the evaporation from the surface of the soil. These grasslands may be used as reserve grasslands and grass should be harvested only for storage in fodder banks to meet the forage requirement of animals during drought years or lean period.

Water Use and Forage Yield of *L. Sindicus*

Rainfall at Jodhpur mainly occurs in July and August, but time extends with moderate rains in some years by the end of September. The area does not receive rains during October - May. The experiments conducted at Jodhpur revealed that the distribution and quantum of rainfall significantly influenced the forage yield. The height of this grass ranged from 90 to 130 cm with a mean of 104 cm while the number of tillers of plant ranged from 40 to 101 with a mean of 63 per plant (Singh *et al.*, 1996). The grass matured in October giving a yield of 3587 kg DM/ha in the high rainfall year of 1990 followed by 3392, 3030, 3003 and 2955 kg DM/ha in 1992, 1994, 1991 and 1993 respectively (Table 1). The water used by *L. sindicus* varied from 144 mm in a low rainfall year (1991) to 326 mm in a good rainfall year (1994) with a mean value of 226 mm. The water use efficiency of the grass was the highest in 1991 (21 kg DM/ha/mm) and lowest in 1994 (9 kg DM/ha/mm) with a decrease in value with the increase in water use per unit of water consumed. The data further revealed that the grass had utilized the thermal energy efficiently for higher production of forage in years of good rainfall and moisture availability conditions in the region. The heat use efficiency of the pasture grass varied from 0.60 to 0.77 with a mean of 0.68 kg DM/ha/^{o}C (Table 1). Similar results were also reported by Singh and Rao (1996).

Effect of Water Conservation on Forage Yield of Perennial Grasses

Field experiment on three perennial grasses viz., *Lasiurus sindicus, Cenchrus ciliaris* and *Cenchrus setigerus* with and without water harvesting was conducted to see the effect of water conservation on the initial establishment of grass and subsequent effect on forage yield in 1990-95 at the Central Arid Zone Research Institute, Jodhpur. The soil was sandy loam having soil profile 80 - 100 cm. The water harvesting treatment was inter-row water harvesting (IRWH)

Table 1. Water use, Dry forage yield and water use efficiency of *L sindicus*

Particular	1990	1991	1992	1993	1994	Mean
Plant height (cm)	129 7	94 2	109 2	90 1	96 0	103 8
Number of tillers plant $^{-1}$	100 8	40 1	55 0	40 0	80 7	63 3
Dry forage yield (kg DM ha $^{-1}$)	3587	3003	3392	2955	3030	3193
Water use (mm)	271	144	240	149	326	226
Water use efficiency (kg DM ha $^{-1}$/mm^{-1})	13 24	20 85	14 13	19 83	9 29	15 47
Heat use efficiency (kg DM ha^{-1} ^{o}C)	0 77	0 64	0 73	0 60	0 65	0 68

(Source Singh *et al* , 1996)

in which 30 cm wide and 15 cm deep ditch was alternated by 70 cm wide raised beds Two rows of grass were planted on the edges of ridges in a compressed row system

C setigerus showed the highest increase in forage yield due to IRWH followed by C ciliaris (40 %) and least by *L sindicus* (Table 2) (Anon,1990-1995) *C setigerus* being a grass that performs well in the rainfall zone above 400 mm responded maximum to conserved water by inter-row water harvesting system *C ciliaris* also produces high forage in the rainfall zone above 300 mm and therefore utilized conserved water effectively by giving higher yield

Table 2. Air dry forage yield (kg/ha) under inter-row water harvesting(IRWH)and flat surface control(FSC)(Mean yield of 6 years 1990 to 1995)

Grass species	IRWH	FSC	% increase in yield over FSC (Control)
C setigerus	2449	1397	75 30
C ciliaris	2770	1972	40 47
L sindicus	3500	2698	29 73

L sindicus yielded maximum in the high rainfall years 1992 and 1994 and showed least percentage (25%) increase in the yield due to IRWH (Table 3) In below normal rainfall years (1991, 1993 & 1995) though the forage yield was less compared to high rainfall years but percent increase in yield due to IRWH over control was highest 31-53% Thus, IRWH can increase forage yield of L sindicus by 32-50% in the years below normal rainfall Further, high relative humidity associated with good rainfall had a positive effect on forage yields but maximum air temperature varied between 32 7 and 38 6^{o}C and wind speed that varied from 5 4 to 10 km ph had negative effect on forage yield (Singh *et al*, 1995)

Irrigation by Sprinkler in Sown Pastures of *L. Sindicus*

Field experiment was conducted to study the effect of different levels of supplemental irrigation by sprinkler method on the yield of established pasture of *L sindicus* at CAZRI, Jodhpur (Singh *et al*, 1990) One month after irrigation, grass was cut The data revealed that increasing quantities of supplemental irrigation were related to increased yield of forage (Table

Table 3. Forage yield of *L sindicus* in different rainfall year as influenced by water harvesting systems

year	Annual Rainfall (mm)	Air dry (kg/ha) IRWH	Forage yield (kg/ha) FSC	Increase in yield over FSC %
1991	192 3	3643	2381	53 00
1992	384 3	3810	3048	25 00
1993	219 6	2809	2143	31 10
1994	544 5	4666	3714	25 60
1995	339 6	2952	2238	31 93

(Normal rainfall at Jodhpur 360 6 mm)

4) 92 mm of supplemental irrigation gave highest forage yield (4 6 tonnes/ha) and water use efficiency (37 kg/mm of SUPIR)

In another experiment at the same site, the water use and production potential of sprinkler irrigated *L sindicus* pasture was studied by Singh *et al* (1990) involving different water deficit replacement (100, 90, 80, 55, 32 and 0%) factorially combined with 0, 40, 80 and 120 kg N/ha In the plot with 100% water-deficit replacement, before cut the soil was depleted by 92% of available water in November and 4 to 11 mm available soil moisture level in summer No wilting symptoms were observed in grass even at such high moisture tensions The treatment combining 80 kg N/ha and 90% available water deficit replacement (about 100 mm water) gave the highest (25 1 tonnes/ha) green forage and 8 8 tonnes/ha of dry forage Water-use efficiency declined on application of more water under low fertility and increased steadily up to 400 mm irrigation Thereafter WUE increased at a constant rate of 42 kg green fodder per mm of irrigation up to 700 mm which was the total irrigation requirement to maintain *L sindicus* throughout the year under high fertility (80 kg N/ha)

In the study area the vegetation composition was recorded in July Out of total 22 8 per cent of ground cover, 11 5 per cent was contributed by the *L sindicus* At Bikaner increasing quantities of irrigation water by sprinkler increased the forage yield to a maximum of 12 tonnes/ha under 0 6 IW/CPE ratio of irrigation level (Anon, 1986) Yield was minimum at with the lowest level of irrigation (0 1 IW/CPE ratio) The optimum level of irrigation to natural grassland was found to be 440 mm used for 6 irrigations at monthly interval (Table 5)

Table 4. Influence of supplemental irrigation (SUPIR) on forage yield of *L sindicus*

Supplemental irrigation (mm)	Total water (mm)	Forage yield (tonnes/ha)	Use efficiency of SUPIR (kg/mm of water)
0	25 7	1 2	-
40	65 7	2 3	28
84	109 7	2 8	19
92	117 7	4 6	37
105	130 7	4 5	31
120	145 7	4 5	28

Source Singh *et al*, 1990

Table 5. Water use and dry forage yield of L. sindicus under sprinkler irrigation at Bikaner,1986-87 (Total of 6 cuttings)

Supplemental irrigation (IW/CPE ratio)	Total water use (mm)	Dry forage yield (t/ha)
I_1 (0 6)	440	12
I_2 (0 4)	185	9
I_3 (0 2)	145	7
I_4 (0 1)	110	5

Another preliminary trial was also conducted at the CAZRI, Jodhpur, the green forage yield of *L sindicus* was maximum in August (5 4 t/ha) followed in February (4 3 t/ha) cutting Dry forage yield was also highest (3 3 t/ha) in August with one supplemental irrigation The total green and dry forage yields of 6 cuttings obtained from June 1987 to March 1988 were 19 0 and 8 7 t/ha, respectively (Singh 1991)

The carrying capacity of irrigated grassland on year long basis could be increased to 3 adult cattle units/ha as against one adult cattle unit under rainfed grasslands with only 400 mm irrigations and a total of 5 cuttings in a year yielding approximately 10 tons dry forage/ha/year if following schedule is practised The first cut of rainfed *L sindicus* taken at the end of August Sprinkler irrigation at 100 mm given in the month of October and November Grass cut at the flowering stage at the end of each month Third 100 mm of irrigation given in mid- February and cutting taken by middle of March The fourth 100 mm of irrigation given at the end of March but this time grass cut at the end of June (as high wind velocity in Western Rajasthan during April-June causes severe erosion) In this way one cut from rainfed grass and four cuts from sprinkler irrigated grass can be obtained per year

Conclusion

Water resources in arid areas of Rajasthan are very limited and the scarcity of water for meeting the human and animal needs in many areas has been a problem particularly in the recent years Under such a setting, irrigation for increasing the production of forage grasses is unthinkable But the extreme drought condition that prevailed in the recent years leading to large scale scarcity of fodders has left no option

The land forms of IGNP area are sand dunes and interdunal plains covering 58% and 23% area, respectively The levelling of high sand dunes for irrigated cropping is most difficult Many interdunal areas are having gypsiferous hard pan and frequent irrigations for cropping will lead to the problems of waterlogging and salt infestation Thus, intensive irrigation is neither safe nor feasible and the limited water of IGNP area in stage II can be most realistically utilised by providing supplemental irrigations to the adjoining grasslands of *L sindicus* This species can abstract and utilize soil moisture from even below the wilting point However, under better moisture conditions supported by optimal fertilization and plant population it gives high yields

Further, high water and heat use efficiency enables *L sindicus* to survive in hot Thar desert The plantation of trees for top feeds, wind break and shelterbelt is also suggested Apart from yielding palatable and nutritive forage, *L sindicus* will also help in conserving the vulnerable soil resource in the fragile arid ecosystem Proper management of irrigation and cutting schedule gave dry forage yield of 10 tons/ha/year with only four additional irrigations of 100 mm each

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USE OF EFFLUENT WATER IN SILVIPASTORAL SYSTEM OF ARID REGION

R.K. Aggarwal and Praveen Kumar

Introduction

Industrial development which is often considered key to prosperity takes a heavy toll of environment. Roy and Rai (1993) identified 20 centers of industrial development and in all the locations the problem of pollution was grave. First in their list was Bombay region where nearly 3000 industrial units pollute the surroundings by emitting SO_2, NO_2, particulates, ash, fugitive gases (like NH_3, CO) and effluents containing Cl, organics and ammonia. The situation in second most polluted region Ahmedabad-Baroda-Surat industrial belt with 2000 large scale and 6300 small scale industries, is nearly the same. Central Board of Pollution Control, New Delhi in 1981 reported the existence of 317 major industrial units besides a number of small scale industries discharging their effluents directly in Ganga and turning it into a highly polluted river. Similarly other rivers are also being heavily polluted by industrial activity.

The industrial development had been rather limited in Western Rajasthan till seventies, mainly due to characteristic physiography and harsh climate of the region. But the region is now catching up fast with rest of the country as a number of industries based on local raw materials, steel rolling mills, cement industries and textile dyeing and printing industries are being set up. Unfortunately all these industries contribute to air, land and water pollution. Chimneys from the mills and power houses release CO_2, CO, N_2O, NO and SO_2. Dust and particulate matter is added into atmosphere by foundries, cement mills and coal based electrical units while the industries like dyeing and printing and steel mill generate a large amount of effluents. It has been estimated that nearly 3 million cubic meter effluents are discharged by 88 large scale and 47 medium scale industries in Rajasthan every day and a large part of it emanates from textile dyeing and printing industries.

The textile dyeing and printing with more than 1000 units is the major industry in Western Rajasthan giving direct or indirect employment to a large number of people. The development of this industry started in 1970s, and has since grown in an unprecedented manner. Generally weaving and finishing are the two integrated processes in the textile industry. However, in this region only finishing operations are performed as the "Grey cloth" is obtained from other parts of the country. In the process of finishing this cloth various operations (Fig. 1) are carried out, using either water or aqueous solutions. Theoretical estimates have suggested that nearly 7 liter water is required in processing each meter of grey cloth (Fig. 1) and the 75% of the water used is discharged as effluents. The effluents largely contains i) Alkalis, ii) residual dyes, iii) starches and cellulose, iv) soluble salts mainly Na, Ca, v) silicate, vi) Oils and fats and vii) other impurities. It has been estimated that in Jodhpur, Pali and Balotra alone nearly 10, 15 and 7 million liters effluents are discharged every day. Due to the lack of economically viable technologies for treatment, these effluents are discharged without any treatment thereby affecting the soil, water and plant system of this otherwise fragile desert ecosystem.

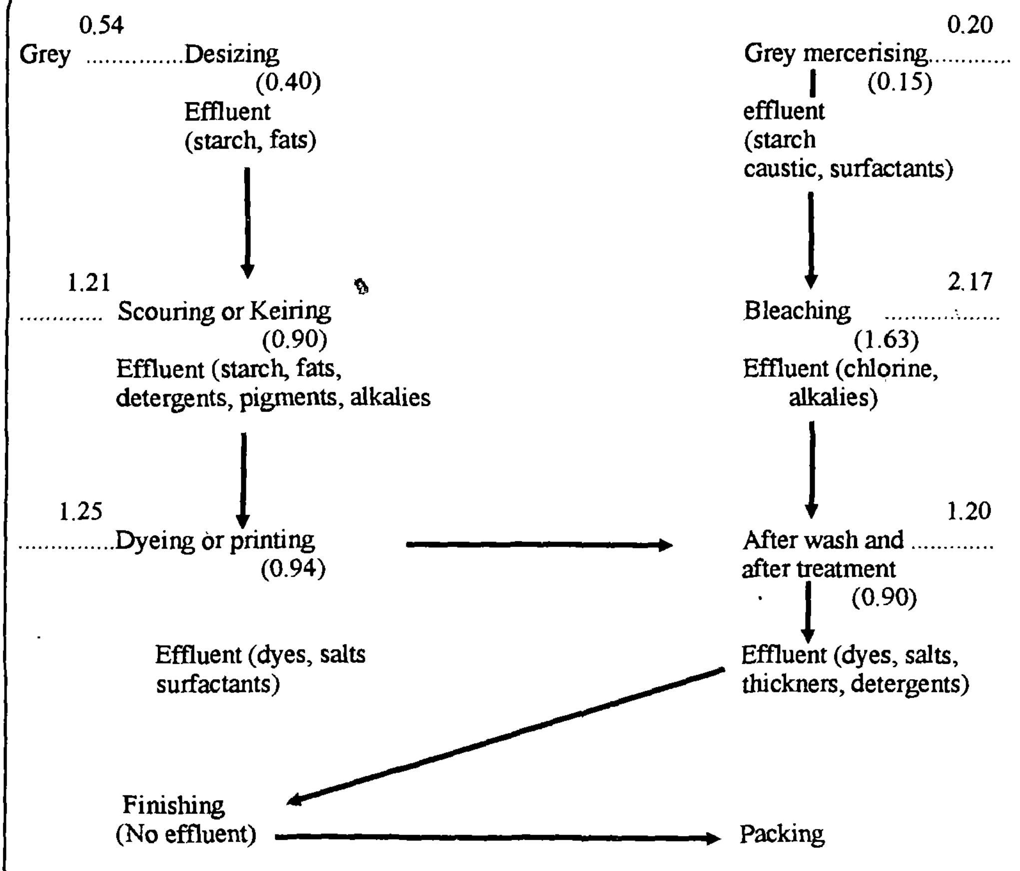

Fig. 1 Different processes of textile industry, the amount of water in litres used (without parentheses) and the amount of effluents in litres generated (in parentheses) in processing of each meter of cloth.

Chemical Composition of Effluents

The analysis of effluents (Table 1) shows that on the basis of dissolved solids, high pH, Na content, Biological oxygen demand, chemical oxygen demand and colour, the effluents do not meet the ISI standards for discharge in stream while the content of elements like Pb, Cd,Zn, Cu is within the permissible limits. The high BOD of the effluents may deplete the oxygen dissolved in the stream and may adversely effect the aquatic life.

The color of the effluents might also interfere with the transmission of sunlight to the lower depths and may adversely effect the photosynthetic efficiency of phytoplankton (Nemeron, 1963). On the other hand the high content of sodium and dissolved solids make the effluents viscous which too can be harmful for aquatic life (Arockiasamy,1982). Therefore, these effluents can be considered unfit for direct discharge in the stream. But inspite of these regulations the

Table 1. Chemical composition of effluent of textile industry.

Effluents chatactensics	Range	ISI Standard 3307 (1965)
Colour	Reddish to light green	75 *
pH	9 0 -11 1	5 5-9 0
TDS (ppm)	5700	2100
BOD for 5 days at 20 °C (ppm)	390 - 560	500
COD (ppm)	1000 - 2800	-
Sodium (%)	97	60 0
Chlonde (ppm)	1800 - 2600	600
Nitrate (ppm)	4 0 - 5 8	45 0
Lead (ppb)	10 - 134	100
Cadmium (ppb)	Traces	2 0
Zinc (ppm)	0 011 - 0 537	5 0
Copper (ppm)	0 071 - 0 748	3 0
Iron (ppm)	Traces - 0 67	3 0

* Units on platinum cobalt scale

Source Ketkar (1989), Aggarwal and Praveen-Kumar(1990)

effluents are being discharged in the three non perennial rivers of the region namely Bandi, Luni and Jojri, leading to the problems of river and groundwater pollution besides degradation of arable land

Adverse Effect of Industrial Effluents on Environment

Pollution of Rivers

Industrial effluents of the western part of Rajasthan flow through many drains and ultimately go to the three rivers viz , Luni, Bandi and Jojri They flow in their full capacity only during rainy season and gradually dry up with advance of the lean season During the lean season these rivers carry only the industrial effluents At Balotra town in Barmer district, Luni receives effluent of a large number of textiles units to the tune of about 7 million litres per day containing 45-50 tons of toxic substances which go upto Sindri river In Pali, Bandi river receives nearly 90 tons of alkali, acids, dyes, oils etc alongwith 15 million litres of water every day from Pali These effluents travel in Bandi upto village Dundara where it merges with Luni In Jodhpur, river Jojri receives approximately 10 million litres of industrial effluents containing nearly 60 tons of toxic material which flow in this river for 60 km upto the Kaleewa Thob village where this river disappears in sand dunes The discharge of these effluents remarkably change the quality of river water The chemical analysis of the water of the river Bandi (Table 2) indicated that before entering into Pali the water had low pH, EC, BOD and COD and was suitable for agriculture as well as for human and animal consumption However at Pali due to

Table 2. Chemical quality of the water of the river Bandi as affected by discharge of effluents at Pali.

Characteristics	flow period (Oct 1990) Upstream	Downstream
Color	Nil	reddish brown
clarity	Clear	Highly turbid
EC mS/cm	1 6	6 4
pH	8 4	9 7
COD (pmm)	20	370
Total hardness (ppm)	160	25
Total alkalinity (ppm)	200	1630
Na C1 (ppm)	584	1432
$Na_2 SO_4$	128	944

Source Report of under Ground Water Department, Pali (1992)

addition of a large quantity of effluents the pH, EC, BOD, COD and the content of Na_2SO_4 and NaCl are increased suddenly making it unfit for irrigation and aquatic life Rana (1986) recorded a complete absence of fishes, microphytes and macrophytes from the Nama (1987) has reported high growth of the algae belonging to the genera of *Anabaena, Anacystis, Arthrospira, Carteria, Ceratium, Chara, Chlamydomonas, Chlorella, Chlorogonium, Chlorococcum, Gomphonema, Euglena, Lepocinclis, Oscillatoria, Phacus, Phormidium, Spirogyra, Stigeoclonium, Tetraedron* etc which impart unacceptable taste and odor to water They also produce substances which are toxic to other microorganisms and sometimes to the livestock

Ground Water Pollution

Protection of ground water from pollution is one of the major problem of the day However, once the surface water bodies like river, ponds etc get polluted, it is practically impossible to exclude the ground water pollution The river Jojri and Bandi have become a pool of industrial effluents at Jodhpur and Pali respectively and almost all of the wells along the course of both the rivers are charged by industrial effluents The effluents enter in the aquifer by means of lateral filtration as a result of direct interconnection of alluvial and river water as well as due to vertical filtration of river water from inundated area

The industrial effluents have a typical odor and the colour is use are following British spellings generally purple or reddish brown in beginning but turns to light green during the course of its flow The report of Ground Water Department Pali (1992) and Vangani (1993, personal communication) mentioned that the water from some wells situated near the down stream of Jojri river in Jodhpur and Bandi river in Pali had this color even though the intensity was less The water from such wells show high value of pH, EC, RSC and high content of Na, CO_3 and HCO_3 (Table 3) Jain *et al* (1993) also reported that the EC, SAR and the RSC of the wells situated near the Bandi river were much higher than the wells of far off Rao *et al* (1993) estimated the bacterial population

Table 3. Chemical composition of well water in Pali and Jodhpur (Salawas). NP: Non polluted wells P: Polluted wells

Characteristics	Pali		Jodhpur	
	NP*	P**	NP	P
EC dS/cm	4 4	11 13	2 1	5 2
TDS ppm	2860	7160	-	-
pH	8 05	7 75	7 2	9 5
Na + (ppm)	807	2220	400 2	1499 6
RSC	0 8	28 8	2 2	39 05

*NP Non polluted wells ** P Polluted wells

Source Jain *et al* (1993) Report of ground water Board Pali (1992) Vangani (personal communication)

in the wells polluted by industrial effluents and non polluted wells at various locations along the course of Bandi river They found that the bacterial population in the wells polluted by industrial effluents was 6 77x10^2/ml and 9 33x10^2/ml at Punaita and Jevdia respectively as against 41 00x10^2 and 63 33x10^2 in the non polluted wells The lower bacterial population in the polluted wells was attributed to the toxic effect of industrial effluents Mohnot and Dugar (1987) had also reported considerable deterioration in water quality of wells from Balotra to Karana village on the banks of Luni According to the standards laid down by ICMR and WHO the water from most of these wells is unfit for drinking and irrigation of crops on a large scale

Impact on Soil and Crops

Sometimes the channels carrying the effluents get blocked and effluents are spilled over the arable land and at other times the fields are irrigated with the ground water contaminated with industrial effluents In both case the end result is the complete degradation of the soil productivity Accumulation of industrial effluents on land even for a short durations leave the land completely barren due to deposition of salts and waste material Such lands when dry show whitish/coloured hard compact encrustation mosaic Irrigation with contaminated ground water within a span of 10-15 years has rendered nearly 4000 ha of land in Pali and 1000 ha land in Jodhpur uncultivable along the course of Bandi and Jojri river respectively Mohnot and Dugar (1987) have also reported a striking case of village Salawas near Jodhpur, where the ground water contaminated with industrial effluents was used for irrigation This reduced the crop yield by more than 25% Aggarwal *et al* (1994) reported the application of only 850 liters of effluents in one year as a number of periodic spot irrigations on a pit resulted in marked increase of pH, EC, SAR of soil (Table 4) Rao *et al* (1993) have reported that the irrigation with the contaminated well water markedly reduce the microbial population and the activities of various enzymes in soil

Effect of Industrial Effluents on Human/Animal Health

At present, there is a scarcity of the reports on this subject But in the areas where the industrial water, has polluted the ground water sources for drinking water, higher incidence of pain in joints and congenital deformity in children have been reported (Rajasthan Patrika 1985)

Table 4. Changes in soil pH, EC and SAR due to irrigation with industrial effluents.

Soil characteristic treatment			Depth (cm)			
			0 - 15	15 - 30	30 - 45	45 - 60
pH*						
	Control	I	8.2	8.3	8.3	8.1
		A	8.6	8.6	8.5	8.0
EC (dSm^{-1})*						
	Control	I	1.1	0.98	0.83	0.80
		A	2.9	2.14	1.62	1.43
SAR						
	Control	I	6.19	1.95	1.03	0.84
		A	74.3	43.47	18.10	24.71

I = Initial before start of irrigation
A = After irrigating for one year.
*Saturation extract.
Source: Aggarwal *et al.* (1994)

The higher rates of abortion and adult mortality have also been observed in animals drinking this water. The greater incidence of dermal diseases in the workers of textile industries has also been observed (Nama 1987). Acute changes in morphology and behavior accompanied by 70-75% higher rate of mortality in the rats directly exposed to industrial effluents is also reported (Mohnot and Dugar 1987).

Treatment And/or Reutilization of Industrial Effluents

Due to the adverse effect of industrial effluents it has become necessary to either treat the effluents before discharging in the drains or reuse it for plantations of economic importance to reverse the process of degradation of environment.

Attempts have been made both in India and abroad to remove or reduce the level of pollutants from the industrial effluents either for their reuse or for the safe disposal. Netzer *et al.*(1976) analyzed the dye-house wastes of various textile mills and found lime coagulation, activated carbon adsorption, ozonation and polymeric adsorption treatments to be successful in removing the colour, soluble organics and heavy metals from these wastes. Mitchell *et al.*(1978) found the activated carbon produced by the pyrolysis of peanut shell most effective in removing colour from a textile factory waste water. Randall and King (1980) achieved complete treatment of dyeing and finishing effluents by combining the chemical and biological process. Rana (1987) suggested the treatment of textile effluents first with lime and then inoculation of algae for improving their quality. Aggarwal and Praveen-Kumar (1990) found the combination of flyash (burnt coal from thermal power plants) and gypsum effective in removing the color and reducing the pH of the effluents. The Scientist at CMCRI, Bhavnagar (Dasare and Rao,1993) have developed a technique of electrolytic decomposition for decolorizing the waste water. In this technique electric current is passed in a special type of electrolytic cell developed at the CMCRI. Nearly 4 KWH energy is used in this process for removal of each kg of dye from the printing bath solution. This decolorised solution can then again be used for the printing purpose. The process of reverse osmosis is also being used in some textile mills, for recovering the Na_2SO_4. Nearly 6-8 KWH energy is used in this process in recovering Na_2SO_4 from 1000 litre effluents.

Rai (1993) has listed a variety of plants which can act directly or indirectly to reduce the pollution load. Aquatic plants like *Salvia*, *Lemna* and *Spirodella* can be used to bring down the nitrogen and phosphorus load from wastes. *Eichhornea crassipes* can effectively reduce BOD, COD, heavy metals and phenols from effluents. Sacroid bacteria can be used to convert complicated organic substances into simpler ones. Algae like *Anabaena*, *Oedogonium* can increase the oxygen supply in effluents and thereby promote the bacterial growth which can further decompose organic substances.

On industrial scale, however, effluents are first treated chemically to precipitate the dissolved impurities and then the sludge is collected. However, even then the values of pH, EC, SAR, and RSC are high for considering it suitable for irrigating crops (Table 5). Thus taking into consideration the high cost of treatment and also the quality of treated water, better technologies need to be developed but at the same time utilization of effluents for biomass

Table 5. Quality of water discharged from common treatment plant.

Appearance	Slightly colorled and free from suspended solids
pH	8.0 - 8.5
EC (dSm -1)	9.2
SAR	110 - 162.2
RSC (meq/I)	30.7 - 47.6
Hardness	< 50 ppm
TDS	About 4000 ppm mainly soluble sodium salts
COD	250

Source : Mathur 1987 and Rao *et al. 1993*

production should also be studied. This assumes significance in the arid area where water is scarce and greening is necessity. This approach on long term basis would improve the environment while maintaining the ecological balance.

Establishment of Trees and Grasses With Industrial Effluents

Since the cultivation of crops is not possible with industrial effluents, therefore, attempts are being made for using effluents for cultivation of trees and grasses. *Prosopis cineraria*, *Acacia nilotica*, *Acacia tortilis*, *Acacia senegal*, *Tecomella undulata*, *Prosopis juliflora* are the major trees of this region. Grasslands in Western Rajasthan are the major source of fodder and have the potentials to meet upto 44 per cent (9.86 M mt) of the total fodder requirement (18.50 M. mt) of animal population. The area available for grass production in each of the 11 arid districts of Rajasthan is given in Table 6. More than 50% of the total area of the districts is available for forage production in Barmer, Bikaner, Jaisalmer, Jodhpur and Pali with highest value of 97% for Jaisalmer.

Table 6. Total area (sq. km) available for grass production in different districts of Western Rajasthan.

District	Total area	Area under grass production	Percent (%)
1. Barmer	28387	15387	54
2. Bikaner	27231	21448	79
3. Churu	16829	5253	31
4. Ganganagar	20629	7656	37
5. Jaisalmer	38401	37191	97
6. Jalore	10640	4378	41
7. Jhunjhunu	5929	1492	25
8. Jodhpur	22860	5929	51
9. Nagaur	17718	6085	34
10. pali	12391	6703	54
11. Sikar	7732	2407	31

Source: Rao, 1993

Silvipastoral systems are very common in arid region. The principal merit of the presence of trees and shrubs in pastures is that animals can feed on their leaves, fruits and flowers at the time of scarcity of grass fodder.

(a) Trees

Lot of work has been done on utilization of sewage water (Chhabra, 1989, Gupta *et al.* 1990, Ghosh, 1991), tannery and dairy effluents (Chaturvedi 1985, 1986). Variety of trees viz., *Acacia nilotica* (Babul), *Terminalia arjuna* (Arjun), *Ficus religiosa* (Pipal), *Cordia dicliofoma* (Lasora), *Haplophragma adenophyllum* (Kathsagun), *Azadirachta indica* (Neem), *Pongamia pinnata* (Papri), *Syzygium cumini* (Jamun), *Cassia auriculata* (Awaram), *Ficus bengalensis* (Bargad), *Adhatoda vasica* (Arusa) and *Pinus roxburghii* (Chir) have been successfully grown with these effluents. However no information was available of utilization of the kind of effluents generated in this region.

At CAZRI, Jodhpur, work was started in 1988 to study suitability of textile effluents for growing trees and grasses. Nine tree species viz., *Eucalyptus camaldulensis* (Safeda), *Acacia nilotica* (Babul), *Acacia tortilis* (Valayati babul), *Azadirachta indica* (Neem), *Hardwickia binata* (Anjan), *Colophospermum mopane* (mopane), *Prosopis cineraria* (Khejri), *Prosopis juliflora* (Israeli Babool) and *Tecomella undulata* (Rohida) were identified on the basis of germination tests and survival for three month with irrigation of industrial effluent. These trees were planted in field in July 1988 and established with textile effluents with the following techniques :

- Adding gypsum and FYM @ 5 kg each per pit
- Adapting double ring method wherein the irrigation was given the outer ring i.e. away from tree seedling.

The results showed 100% survival and establishment of these tree species and their growth was normal On the basis of the results these species were grouped into two subgroups (i) species tolerant to textile effluent water and not requiring gypsum treatment, (ii) species less tolerant to textile effluents and requiring gypsum treatment in soil for higher growth *E camaldulensis, A indica, P cineraria, A nilotica* belonged to first subgroup while *H binata, C mopane, P juliflora* and *A tortilis* belonged to second subgroup The data on growth of four treespecies with and without gypsum are given in Table 7

Table 7. Effect of industrial effluent with and without gypsum on the growth of four tree species.

Tree species	Increase in height (cm)		C D 5%
	No amendment	With gypsum	
Eucalyptus comaldulensis	112 0	112 8	NS
Azadirachta indica	156 2	147 2	NS
Acacia tortilis	103 2	131 3	25 2
Hardwickia binata	30 2	89 7	12 3

Source Aggarwal *et al* (1994)

The comparison of chemical composition of the tree leaves irrigated with textile effluents and with normal water showed no toxic effect (Table 8) The adverse effect of textile effluents could be minimised by the addition of gypsum in soil (Table 9)

(b) Grasses

In our experimental area we tried to establish the *L sindicus* with industrial effluents For this FYM @ 5 tons/ha along with gypsum @ 5 tons/ha was added in the field There after seeds were sown as pellets during the rainy season Grasses were irrigated with effluent in the post rainy season period as and when required After a year of establishment total forage yield of nearly 14q/ha was recorded

Conclusion And Research Needs

The pollution in Pali, Jodhpur, and Balotra has reached to the level where it is adversely affecting the desert ecosystem Although the treatment of industrial effluents is a necessity for safe disposal with a view to check the environmental pollution by the rapid industrialization but the economical and viable techniques are lacking Therefore till such techniques are developed a greater emphasis should be laid towards the proper utilization of effluents The efforts made so far show that there is a considerable scope of using these industrial effluents (a) prevent formation of wastelands by raising green belt on the course of flow of the effluents and effectively mitigating the hazards of pollution of surface as well as ground water bodies (b) provide biomass (fodder, fuel and timber) and generate income for the people and civic bodies

But, there is need to further the research and technology development activities in the following specific areas

Table 8. Effect of industrial effluents on chemical composition of leaves of different tree species.

Tree species		Chemical composition g/g (dry weight)				
		Fe	Mn	Zn	Cd	Na
Acacia nilotica	I E	597 8	127 6	74 0	35 1	211 0
	R F	503 1	135 4	90 3	32 4	187 2
Prosopis juliflora	I E	696 6	134 0	91 6	51 6	366 3
	R F	705 2	139 7	103 2	60 3	375 3
Hardwickiaa binata	I E	441 4	91 6	86 8	48 1	222 7
	R F	505 1	110 2	107 8	41 7	220 2
Eucalyptus camaldulensis	I E	475 6	134 3	75 5	43 6	549 3
	R F	400 1	139 2	95 6	40 3	530 4
Acacia tortilis	I E	613 3	107 8	93 3	48 2	302 6
	R F	402 5	134 3	128 8	36 7	204 9
Colophospermum mopane	I E	428 5	85 5	94 8	43 6	112 3
	R F	675 3	158 7	105 3	37 7	172 3
Prosopis cineraria	I E	428 5	85 5	94 8	43 6	112 3
	R F	532 4	103 8	106 6	36 5	195 0
Azadirachta indica	I E	688 0	225 5	128 8	30 4	376 0
	R F	441 5	103 2	100 7	44 2	254 5

Note Cu and Pb were found in traces

I E = Irrigated with industrial effluents

F = Rainfed

Source Aggarwal and Praveen-Kumar 1994 (unpublished)

Table 9. Effect of gypsum on changes in soil pH, EC and SAR due to irrigation with industrial effluents.

Soil characteristic/treatment		Depth (cm)			
		0 - 15	15 - 30	30 - 45	45 - 60
pH*	Control	8 6	8 6	8 5	8 0
	Gypsum	8 1	8 1	7 9	8 0
* EC (dSm -1)	Control	2 9	2 1	1 6	1 4
	Gypsum	6 3	2 9	1 8	1 7
SAR	Control	74 3	43 4	18 1	24 7
	Gypsum	58 3	28 5	21 9	20 3

*Saturation extract

Source Aggarwal *et al* 1994

- Selection of plant species for their suitability to effluents of varied industries specific to agro-ecological zones

- Water balance studies on different plant species which would give information on the consumptive use of water and effect of percolating water on the below ground water bodies
- In situ treatment of effluents by adopting land treatment methods using amendments like flyash, gypsum, lime, organic manures etc and irrigation techniques
- Effects on soil physico-chemical and biological properties for toxicity and productivity
- Accumulation of toxic and heavy metal in various parts of the plant of those species which have fodder value

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IMPORTANT PASTURE GRASSES AND LEGUMES FOR ARID AND SEMI-ARID REGIONS

M.S. Yadav and M.P. Rajora

Introduction

The grasses assume importance not only as livestock feed, but also as soil builders and binders and aid in soil conservation. In their principle role, the tropical grasses stand as the highest potential yielder of starch and proteins equivalent to any other crop plants and further being the dominant component of tropical pastures, as the cheapest sources of animal feed. The perennial grasses with greater root-rhizome production ability, especially in the top 15 cm of soil profile, are able to bind the soil particles and thus prevent the hazards of soil erosion, in addition to the continuous process of production of new roots, decay of old ones which help in accumulating more organic matter in the soil and thereby affecting improvement in its structure, texture and fertility.

In the animal diet, protein availability plays an important role. Besides perennial grasses legumes are rich source of proteins. Growing of high yielding and better quality legumes in rangelands may be the better proposition in increasing the production of the animals of the Thar desert. Legumes are the keys species of grasslands in agriculture as they upgrade the animal health, soil fertility status decrease the cost of cultivation, and conserve the environment

Indian desert covers an area of 2.5 million hectare, of which one million is either open grasslands or grasslands interspersed with trees or thorny bushes. Eighty per cent of the total grazing lands in western Rajasthan are poor, having an average forage production rate of grasses less than 400 kg per ha. Improvement of such denuded grasslands by reseeding of high yielding and nutritive varieties has received top priority in pasture development programmes of CAZRI, Jodhpur.

Desert Flora

The flora of Indian desert consists of 68 species of grasses. Of these, the perennial grass species, viz. *Cenchrus ciliaris, Cenchrus setigerus, Lasiurus sindicus, Dichanthium annulatum, Panicum antidotale, Cymbopogon jwarancusa, Panicum coloratum, Chloris gayana* were found to be highly productive and suitable for pasture development in the desert. Besides these grasses species, some common legumes of the arid tract are *Lablab purpureus Clitoria ternatea, Stylosanthes species, Acroptelium atropurpureum, Stizolobium deeringianum, Atyloia scarabaeoides and Rhyncosia minims*.

Selection of Pasture Species as per the Habitat: Rangelands in western Rajasthan are heterogeneous in physical nature occurring on various types of area like sandy, rocky stretches, gravelly flats, saline and other areas with climax vegetation. Based on the edaphic factors, the grass species have been identified for different habitat (Paroda *et al. 1980*).

Sand Dunes and Sandy Plains : Major portion of the western Rajasthan largely occupying sand dunes and sandy plains, is the zone of very low precipitation. Suitable pasture species for these areas are *Lasiurus sindicus, Panicum turgidum, P. antidotale* and *Cymbopogon jwarancusa.*

Well Drained Sandy Alluvial Soils : *Cenchrus ciliaris* and *Cenchrus setigerus* are high yielding pasture species for these types of soils.

Sandy Clay Loam to Clay Soils : *Dichanthium annulatum* predominates on such types of soils in high rainfall zones (350 mm and above).

Hilly and Piedmont and Shallow Soils: Sehima nervosum in association with *Dichanthium annulatum* are commonly found in these types of habitat.

Low Lying Heavy Saline Soils: The notable grass species found in these habitat are *Sporobolus marginatus*, *S. coromandelianus* and *Chloris virgata.*

Promising Pasture Grass Species and Their Characteristics

Sewan *(Lasiurus sindicus):* It is one of the most important grazing grasses of the north-west India under annual rainfall below 250 mm (Fig. 1). It is often used for the establishment of permanent pastures and five to six kg unhusked seed per ha drilled in rows, 75 cm apart upto depth of 1 to 1.5 cm with the soil cover of 1-2mm. It occurs naturally in dry areas of Mali, Niger, North Africa, Egypt, Somalia, Ethiopia, Iran, South tropics and in sub-tropical areas.

Description: It is a perennial grass, normally attains 1m height, stem much branched and often subwoody at the base, glabrous to hairy; leaves upto 30 cm long and upto 6mm wide, flatter or convolute villose and articulate raceme 10 to 15 cm long.

Varieties: The recommended varieties (Yadav, 1984) are CAZRI-30-5, CAZRI-319 and, CAZRI-317, producing 60 to 85q dry matter yield per ha.

Nutritive value: Under natural conditions crude protein ranges from 5.9 to 6.7 per cent but when cultivated and fertilized with NPK, crude protein (CP) content can reach upto 13 per cent and sometimes as higher as 15 per cent; crude fibre (CF) content varies from 24 to 38 per cent, Ca content is usually high, i.e. 0.76 to 1.11 per cent and P content ranges from 0.15 to 0.44 per cent.

Three hectares of *L. sindicus* pasture is sufficient to support one adult animal (cattle) throughout the year. Continuous grazing preferred than detered grazing.

Blue Panic (*Panicum antidotale*): Popularly known as 'gramna' in the desert of Rajasthan, a native of northern India, is well distributed in Australia, Ceylon, India and Afghanistan. It is often found on sand dunes and is excellent sand binder and drought resistant perennial grass adapted to a variety of soils, and climatic conditions. It is very productive grass that can serve as a good source of fodder supply either as hay or silage. On the livestock farms of the tropical and sub-tropical countries this can be a good fodder source through out the year because of its wider adaptability, persistency, high productivity and also good seeding capacity. It can either be grazed or cut and fed to the live stock.

Varieties: The recommended varieties are CAZRI-331 and CAZRI-347 These varieties provide 20 to 32 q per ha dry matter yield.

Description: Gramna is a tall and deep rooted grass. It grows to a height of 150 cm, bearing about 25 tillers within four months from the date of sowing. It can reach to a height of 240 cm under the optimum growing conditions. It has woody stem with a creeping root stock,

Fig. 1 *Lasiurus sindicus* - An important pasture grass in low rainfall zone

Fig. 2 *Cenchrus ciliaris* - A dominant grass species of wider adaptability

giving off stolen and thickened nodes, the lower half of the stems have large nodes and inter-nodes, having a bamboo like appearance. The leaves are linear with tips drawn to a fine point. Panicles are long spreading and drooping, held in a terminal position on the stems and branches, spikelets ovoid, acute and glabrous; seeds smooth and shiny

Nutritive value: Dry matter content of the grass is about 20 per cent when cut at the pre-flowering stage. Crude protein content is about 14 per cent of the dry matter DM. Similarly, ether extract (EE) is 1.8 per cent, crude fibre 29.0 per cent, nitrogen free extract (NFE) 45.1 per cent, ash 9.5 per cent, Ca 0.43 per cent and P 0.30 per cent of dry matter. It shows that the grass is highly nutritive when cut at the pre-flowering stage. The grass is palatable to all kinds of livestock. However, it is not liked in mature stage as the stems become very hard and woody.

Murat (*Panicum turgidum*): It is sub-shrubby species with hard, woody perennial stem. Native of North African desert and semi-desert areas in eastern Mediterranean to Sind. Although hard and woody, young stems serve as an excellent nutritive camel fodder. This grass is also valuable for fixing sand dunes under 100 to 250 mm rainfall. It may attain a height of 1m in sandy beds if ungrazed.

Dhaman(*Cenchrus ciliaris*): Commonly known as dhaman in Rajasthan and anjan in various other parts of India, it is one on the dominant grass species in *Dichanthium-Cenchrus-Elynurus* complex of grass cover of India (Fig. 2).

Climate and Soil Requirement : *Cenchrus ciliaris* is generally grown in warm, dry sub-tropical countries. It has been considered as a highly drought resistant grass species. It is adapted to a wide range of soil and climatic conditions and can be cultivated in areas receiving rainfall from 150 to 1250 mm annually. Anjan grass has been successfully established on dry sandy to stony soils in arid and sandy to sandy loams in semi-arid parts of India. It can also grow on deep basaltic soils and on red lateritic soils as well. Anjan being of rhyzomatus nature also does well in heavier type of soils, while some other strains do well on sandy soils only.

Description: It is a perennial grass with a stout root stock, leaf blade is linear, being 10 to 30 cm long 1.8 cm wide, and flat when fresh. Flowering head is cylindrical, 3 to 16 cm long and 1 to 2 cm wide with pale, pink, purple and black colour bearing clustered spikelets.

Numerous growth forms are found, ranging from rhizomatus, strong clumped tall growing types to short growing ones. The recommended varieties CAZRI -358, Marwar Anjan, Biloela and Molopo giving productivity ranging from 40 to 45 q per ha dry matter yield (Yadav, 1984). Three to four cuts can be obtained from August to April. It has 8 to 12 per cent crude protein. Dhaman grass produces 125 kg seed per hectare.

Moda Dhaman (*Cenchrus setigerus*): *Cenchrus setigerus* is commonly known as 'moda dhaman' in the desert areas of western Rajasthan and anjan in other parts of India and bird wood grass in the USA, is distributed through out Africa, Arabia, and India. It was introduced as a forage grass in the United States, Australia and South America from India. It is one of the major grasses of the arid zone pasture (Fig. 3) and known for its drought resistance. It is palatable to all kinds of livestock and can be propagated from seeds and may be used for renovating the denuded pastures or establishment of sown pasture. The grass is either grazed or cut and fed to livestock *ed lib* or turned into hay.

Description: It is perennial, forming clumps, somewhat bulbous bases. The plants grow to a height of 50 cm with an average number of 25 tillers per clump. There are various growth forms ranging from prostrate to erect types. Under good conditions, the clump may reach a height of 80 cm, leaf sheath is compressed and the leaf blade is glaborous, tapering to a point 10 to 20 cm long and 3.7 mm wide. Inflorescene is compact spike of spikelets. Burs are cup shaped with erect inner spines, short connate upto one third to one half of their length, outer spines fewer in number than inner, short, often directed outward brush and spines varying in colour from white to purple. Spikelets are one to three per bur, sessile, fruits ovoid, chromosome number 2n = 36. The short intruse spines distinguish this species from others in the genus. *Cenchrus setigerus* differs from *Cenchrus ciliaris* in its comparatively short stature, more prostrate and tufty nature of growth and less ciliated seeds.

Forage production: High yielding varieties of Anjan produce about 4 to 5 tonnes of green forage (30 to 35% dry matter) per hectare from 2-3 cutting during August to April in arid regions. The yield becomes double in semi-arid (8 to 10 t/ha). The forage production varies from 23 to 35 t /ha under irrigated conditions in humid regions of India.

Nutritive value: The dry matter content is 25 per cent when cut at the pre-flowering stage in the arid habitat. As the plants attain maturity, the dry matter content also increases and it may go upto 40 per cent. Crude protein content of the grasses varies from 5 to 11 per cent of dry matter for different cuttings. Phosphorus content of the grass varies from 0.21 to 0.64 per cent of the dry matter under different curing treatments.

Karad *(Dichanthium annulatum):* It is commonly known as karad in the arid zone of Rajasthan and Marval, Palwan and Zinjoo elsewhere. It is a tropical and sub-tropical grass of the tribe *Andropogoneae*. In the arid and semi-arid regions of Rajasthan, the grass occurs mainly in the rainfall regions of 350 mm and above. It is regarded as an excellent fodder plant and highly valued pasture grass of high quality, vigour and productivity.

Varieties: The recommended varieties are CAZRI-490, CAZRI-491, IGFRI-495-1 and Marvel- 8. Dry matter yield of these varieties ranges from 35-55 q/ ha

Description: Karad is a perennial tufted grass with creeping rhizomatus stem. Branches are erect or ascending from the creeping stem. The internodes are short and nodes are purple and hairy whereas stems are smooth and glaborous. The plant grows to a height of 75 cm at maturity stage, producing about 100 tillers per plant.

Nutritive value and carrying capacity of pastures: The crude protein content of the grass varies from 3.87 to 6.97 per cent (dry matter basis) in different cuttings at flowering stage and phosphorus content of varies from 0.43 to 0.50 per cent to dry matter under similar conditions. Native pasture under semi-arid conditions has the carrying capacity of two sheep per ha but a sown karad pasture has increased carrying capacity from two to five sheep per hectare.

Promising Pasture Perennial Legumes

Field Bean (*Lablab purpureus L.*): The plant is native to Asia and occurs throughout India. The main tract of its cultivation is Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka States. It is a semi-erect prostrate type bushy herb. It is an annual to biennial,

Fig. 3 *Cenchrus setigerus* - An important pasture grass of medium to heavy rain fall zone

Fig. 4 *Clitoria ternatea* - A perennial pasture legume of tropical pasture land

semi-pasture drought resistant, and fast growing legume. It gives luxuriant growth in comparatively drier months due to its deep root system soils. It is sown in July-August and provides green fodder during the lean period when other crops are dried up. For fodder or grazing, field bean is grown in rows using 10-18 kg seed/ha. The varieties Rongai (Kenya) is suitable for humid and warm areas. CAZRI strain No. 144,1461, 1258 and 40-10 have yielded 20 to 40 q/ha dry matter under arid conditions. In semi-arid areas, var. IGFRI 2214-II and IGFRI-S-2218-1, possessing erect and decumbent growth habit, yielded 275 and 250 q/ha of green fodder, respectively under rainfed condition at IGFRI, Jhansi.

Cordofan Pea (*Clitoria ternatea L.*): It is a twining perennial pasture legume distributed throughout tropics and sub-tropics (Fig 4.). It grows in bushes, grasslands, often on seasonally water logged black clays, wastelands, etc. upto 500m altitude. It grows well in areas of 300 to 750 mm rainfall. It is sown in rows @ 10-15 kg seed/ha. Before sowing, the seed should be treated with hot water for five minutes for better germination. It gives two to three cuts in a year and dry matter yield ranges from 20 to 40 q/ha. The herbage contains 21 per cent CP, 33per cent CF, 34.7per cent NFE, 0.8per cent Ca and 0.28per cent P. Digestibility as tested on sheep was 74.2per cent for D.M., 5.2per cent for C.P., 61.6per cent for C.F. Varieties IGFRI-23-1 and IGFRI-S-12-1, CAZRI-752 and CAZRI-1433 were found promising in arid and semi-arid tracts.

Stylo (*Stylosanthes* spp.): 'Stylo' is a promising drought resistant pasture plant. The species are suitable to wide spectrum of soils, viz. acidic and sandy to heavy loam soils. Among the perennial species. *S. hamata, S. scabra, S. quiancensis* and *S. viscosa* are promising ones. *S. humilis* is an annual and has been considered to be an outstanding pasture plant because of high protein content, the retention of high quality herbage for a long period of time and the ease of establishment.

S. hamata (L.) Taub - Spreading type herb with lanceolate leaves, seeds are brown in colour and hooked shape.

S. scabra - A vigorous shrubby, medium tall erect pasture legume. thick stemmed, woody sparsely branched.

S. humilis - Spreading type annual herb with profuse lateral branches covering the ground. It tolerates soil acidity upto pH 4. It requires high intensity of light. IGFRI-S-4109, a high yielding variety of this species, yielded 400 q/ha green fodder in two years at IGFRI, Jhansi.

Seeds of *stylo* should be covered by a thin layer of soil, i.e. 0.5 to 1 cm uniformly for better germination. Seed rate recommended for *S. hamata* and *S. humilis* are 3 kg and 10 kg/ha respectively. Pasture grasses are grown in alternate rows with *stylos*. Crude protein content of *stylo* herbage ranges from 12 to 18 per cent of the dry matter.

Siratro (*Acroptelium atropurpureum*): It is a perennial pasture plant with trailing or creeping stem. It was bred from two Mexican ecotypes of *P. atropurpureum* (Huttan, 1962). It has deep penetrating swollen root and a high level of drought resistance. It is more suitable in tropical areas because in the moist soil, the trailing stem, root arises at random along their length. Siratro is seldom grown alone but nearly always in grass mixtures. The seed is sown @ 2.5 to 4 kg/ha in grasslands. Low and frequent grazing or cutting produce detrimental effect on Siratro grown in mixture with grasses. The seed is scarified before sowing to reduce the percentage of hard seeds. It can perform well in infertile and some what in water logged ground but not on saline soils. Variety IGFRI-S-1 of Siratro possessing prostrate stoloniferous growth habit yielded 250-300 q/ha of green fodder yield in two cuts per year and had an average of 16% crude protein.

Velvet Bean (*Stizolobium deeringianum Bort*): The crop is native to India. Velvet bean is practically useful for rainfed areas, ravine lands, tidal forests, coconut and arecanut fruit plantations. It is suitable for sandy soil where most of the legumes fail. Velvet bean varieties are annual, biennial or perennial. They are prostrate, winding or trailing. Warm and dry weather with intermittent showers from 300 to 600 mm during the growing season suits this crop the most. It remains green upto the month of January even after frosty condition set in. In the month of June-July, the seeds are sown in rows at the spacing of 1m between rows and 50 cm within rows. Seeds are sown @ 15 to 20 kg/ha. Two rows of grasses may alternate with one row of legume in mixture. Green fodder yield ranges from 250 to 300q/ha, At a pasture crops the grazing is allowed after the maturity of pods. Two varieties, i.e. IGFRI-S-2276-5 and IGFRI-S-2284-1 have so far been evolved by IGFRI, Jhansi. It contribute large quantity of organic matter and nitrogen to the soil.

Bankulthi (*Atylosia scarabaeoides L.*): It is a perennial climber or trailing herb, and It is found in natural pasture with dominance of *Heteropogon contortus*. Eight kg seed is required for one ha pasture land . It is a deep rooted legume, sends its roots vertically upto 2m, horizontally 1.6m. It yields between 12 to 20 q dry matter per ha. It is relished much by sheep and goats. It is found on sandy, red and rocky soil in rangelands mixed pasture which at the ripe stage contained upto 7% CP compared.

Rhynchosia minima: It is a slow growing herb which is distributed through out the world (tropics and sub-tropics) in grasslands or in scattered bush and can tolerate seasonal water logging. It is drought resistant and slow growing, can tolerate moderate soil salinity. Young herbage is eaten better than that at advance stage of growth. Seeds are treated with hot water for better germination. Seed is shown @ 15 kg/ha. It yield 5 to 10 q dry matter per ha. *R. minima* contains 15.1 per cent CP 1.7 per cent EE 29.5 per cent EF, 45.9 per cent NFE, 1.28 per cent Ca and 0.28 per cent P. In trials with sheep the digestibility of DM was 60 per cent CP 64 per cent, CF 54 per cent Total digestible nutrient content was 60.9 per cent and Digestible crude protein 9.5 per cent.

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CHARACTERISATION OF COMMON TOP FEED SPECIES

S.K. Sharma

Introduction

In arid and semi arid regions of the country people depend on rainfed crops for their food and fodder requirement of the milch animals, and often face shortage of nutritious fodder in drought years. The burgeoning livestock population, and fast depletion of natural grazing lands and afforested areas have further worsen the animal feed situation. Since it is not possible to assure enough fodder production from the present traditional cropping pattern in the arid regions, the farmers should be educated to adopt better productive systems like agro-forestry, silvipastoral and hortipastoral systems in their arable lands.

Farmers are well aware about the top feed tree and shrub species like *Prosopis cineraria* and *Ziziphus nummularia*, which significantly contribute to their traditional cropping system in arid regions. The population of such valuable top feed species has gone down due to over exploitation and use of farm machinery in past two to three decades. There is urgent need to check the irreparable loss of these top feed species and also require introduction of more and more multipurpose tree and shrub species on the farmers fields through boundary plantation and silvipastoral system.

There are several tree and shrub species which could contribute substantially for top feed, fuel wood and timber requirements of the farmers. Some prominent top feed species, which have been tired in different arid and semi arid regions of the country have been characterised below for the benefit of field technicians and farmers.

Prosopis cineraria (l.)druce Family - Leguminosae, Mimosoideae

Description: *Prosopis cineraria* is a small to medium sized [18 m height, 0.8 m diameter at breast height (DBH)]thorny tree with spreading crown, slender branches armed with scattered conical or hooked thorns, and light bluish green ashy foliage. Its bole is usually short, seldom straight, tap root very long. Typically lopped for fodder, Bark grey, rough, with deep fissures and cracks.

Leaves alternate, bipinnate; pinnae and leaflets opposite, pinnae 2, leaflets 7-10 pairs, 5-12 x 1-3 mm subsessile or sessile, oblong, oblique, apex usually mucronate.

Flowers small, creamy white to yellow in slender spikes 5-13 cm long, appearing in March-May Pods indehiscent, pendulous, linear, 12-25 cm long, contracted between the seeds. Seeds 10-15 compressed, ovate, dull brown, smooth, hard, immersed in sweetish mealy pulp (seed weight is about 25,000/kg to 28,000/kg).

It coppices well upto a moderate age, older trees coppice poorly or at not all. P. cineraria is a light demander, but seedlings can tolerate shade. Trees are frost hardy and extremely drought resistant, but not the young plants. It has an enormous tap root which can reach ground water upto 20 m depth; is thus able to withstand the hottest winds and driest seasons, and to survive when other species would succumb (Kaul and Ganguli,1962). Grows on variety of soils. Its best habitat is alluvial deep sandy loam soil. It is common on moderately saline soil. It is also found on black cotton soil and dry stony soil.

Propagation: *P. cineraria* reproduces naturally from seed, root suckers and coppice. Ample seed is produced annually. However seedling regeneration is seldom sufficient, it comes up only under very favourable conditions.

Management: The main use of the tree is for fodder. For this purpose, it is heavily lopped annually in the winter from the age of about 15 years. Spring and summer lopping is detrimental to fodder production and growth.

Ziziphus nummularia (burm.f.) Wt. and Am. Family: Rhamnaceae

Description: It is a gregarious prickly, multi-stemmed shrub about 2 m tall, with deep and extensive lateral root system. It produces copious coppice shoots and root suckers, thus forms dense thorny thickets, often collecting mounds of leaves and dust. The branches are sidely divaricate, purplish in colour and with a velvety surface. Leaves are evergreen, small orbicular to obviate (2.5 cm long) serrate, deep green and shining above, white tomentum beneath. Two stipular prickles, dark brown; one short, hooked, bent downwards; the other straight (1 cm). Leaves fall in January-March, and are simultaneously replaced with new ones.

Flowers are minute, creamy yellow, in axillary cymes. They appear in the rainy season (July to September). Fruits are formed soon after, as drupes; at first green in colour, turning yellow and then scarlet red and shining when ripe in winter; globose, with a thin layer of edible sweet sour pulp; 1 cm dia. The central stone contains usually two seeds.

It is found on hills, ravines or plains upto 1700 m elevation, including cultivated fields. It tolerates pH 6.0 to 7.5 but avoid saline and water logged patches.

Tolerates extremes of climate. Temperature-6^{o} to 50^{o}; rainfall, 100 mm to 1000 mm. Light demander, but tolerates shade also. Extremely drought, fire and wind hardy but prolonged frost affects the foliage and fruits; recovery, however, is quick.

Propagation: Natural regeneration is by self seeding and coppice. Artificial propagation is by direct seeding, coppice and root suckers. The seeds are contained in the hard stones of the fruit. They are smooth, brownish, shiny and soft. Stones are 1800-2000/kg and very hard. No pretreatment is required but stones are often cracked by hitting with a rock or hammer just before sowing in June at a depth of 1 cm. Seedlings grow relatively slowly, 5-6 months old seedlings are 30-35 cm tall and ready for planting out.

Management: Shrubs are regularly harvested from arable fields in the desert fringe areas of Rajasthan and Sindh (Pakistan)., where it then coppices during the cropping season. The thorny stumps of *Z. nummularia* are used as fence. It makes an excellent firewood. Fruits are edible and are sold in the market.

Grewia tenax (forsk) fiori; Family -Tiliaceae

Description: *Grewia tenax* a winter deciduous, multistemmed shrub or small tree, 0.5-1 m high when browsed or reaching 3 m in protected areas. Branches stiff but slender, thinly pubescent; bark green and smooth when young, ashy grey and rigid when old. Leaf size variable, 2-4.5x1-3cm, broadly ovate, orbiculate at the base, acute or abtuse at the apex, coarsely dentate, the upper surface glabrous, the lower shortly stellately pubescent, palmately 3-5 nerved. Petioles 5-8 cm long. Leaf opposed or terminal on short contracted branches.

Flowers white, on simple (1-2 cm) pubescent peduncles. Flower buds more or less angular, 7-9 mm long, green and oblong. Bracts 2 or more, usually 3, 4-5 mm long, pubescent. Stamens many, filaments pinkish white, anthers white and unequal. Ovary 4 lobed, glabrous, style 9 mm long, longer than stamens, stigma 4-5 lobed and green. Fruits 0-4 lobed, drupe, smooth, shining, yellow orange to red when mature, 12-13 mm broad, usually of two separable halves, each half didymous, sometimes unequal, each with two stones.

Flowering season is August-October, fruiting in September-December, Leaf fall from November; earlier in drought years, remains leaf less January-June. The new leaves sprout in July with the onset of rains.

The natural habitat of this bush is buried pediment, hills and pediplains. It does best on deep sandy loam, and can grow in very shallow, skeletal, gravelly or clay soils. Its efficient root system can penetrate into minute rock crevices for survival in quite extreme sites.

Temperature in its native range is -2 to 40^0 C; annual rainfall 200-1000 mm. It is extremely drought hardy and tolerates frost well. Plant growth is slow in arid climate, reaching harvestable size only after 6-8 years.

Propagation: Natural regeneration occurs through dispersal of seeds after being eaten by birds. Fruit production in natural stands varies from 15 to 100 per plant. Seeds excreted by birds germinate during the monsoon.

Artificial propagation can be done by planting out nursery-raised seedlings or by branch cutting, Winter collected fresh seeds are prepared by rubbing the fruits to remove the pulp, rinsing and drying in the sun. The average weight of 100 seeds is 5 gm. The favourable time for sowing seed of G. tenax in the nursery is mid February to March. Seed should be soaked in warm water for 24 hours and sown about 1 cm deep, 3-4 seed per polybag filled with soil + FYM. Fqur to five month old seedlings grow to about 30-40 cm height and are ready to plant in the field after the rains start in monsoon season.

Vegetative propagation of the bush can be done through stem or branch cuttings about 1-2 cm thick and about 20 cm long. Ordinary (untreated) cuttings take about 15-20 days to sprout,

Management: Green or dry leaves are good source of fodder for sheep and goats. An average growing bush can yield 150-250 g dry leaf fodder. The optimum time to harvest leaf fodder is October-November every year. The fruits are edible and are often sold in market. Dry wood is good fuel which has high calorific value and little ash.

Ailanthus excelsa Roxb. Family - Simarubiaceae

Description: A handsome, large (upto 25 m high and 1 m DBH), deciduous tree with enormous pinnate leaves and spreading crown and dark grey fissured bark. Leaves are opposite often 1 m long, tomentose, with 8-14 pairs of deeply serrate leaflets of 5-8x2-4 cm. Leaf fall takes place in February and new leaves appear in March-April.

The flowers are in panicles shorter than the leaves, yellowish; appear in February-March in central India and In April-may in North India. Fruits form soon after flowering, ripen in May-June, is a red Samara with one seed, 5-7x1-2 cm, prominently veined and winged, twisted at the base.

A. excelsa is an indigenous species and found throughout the drier tropical and subtropical parts at altitudes upto about 1000 m, but not in heavier rainfall areas of western India.

It grows on almost any soil except heavy clay with poor drainage. It thrives best on porous sandy loams. It can grow on shallow, dry, and gravelly soils but growth on such sites is poor.

The mean annual rainfall in its native areas is 500-1200 mm, but it can also be grown in parts of Rajasthan with average rainfall of 400 mm.

Propagation: The tree is a strong light demander, seedlings easily get suppressed by woods as a result of shading. They are also susceptible to frost and to prolonged drought, through the poles and mature trees and drought resistant. The seedlings are also susceptible to insect attack.

Natural regeneration takes place largely through seeds. The plants are not readily browsed because of the offensive smell in young leaves, although when nature leaves are lopped for fodder, it is relished by animals that are used to the taste.

Artificial propagation can be done by direct sowing. Fresh seeds (about 9,000/kg) should be collected in May-June and sown immediately, either in the field or in the nursery, as they cannot be stored. Not pre-treatment is required.

Management: The tree has been successfully used for planting around field margins. Lopping of foliage twice a year leaves the tree leafless during the main cropping season, thus reducing direct competition. It can also be used for silvipasture. An average mature tree yields 5-7 quintals green leaves twice a year. The light wood is in great demand for match industry.

Moringa oleifera Lam. Family - Moringaceae

Description: A medium sized (10 m high) deciduous, nitrogen fixing tree, with pretty fern like, feathery foliage. Bark thick, soft white, corky and with deep fissures. Leaves opposite, usually tripinnate but bipinnate leaves are often also found on the same tree, the bipinnate leaves being located at apical portions. Leaves turn yellow before falling in winter (December-January) and new leaves appear in spring (February-March).

Flowers fragrant, white, handsome, in clusters of large panicles. Flowering season February-March. Fruits are pendulous capsules; initially whip like, green triangular, nine ribbed, as long as 50 cm in wild trees. Fruiting season April-June, occasionally also September. Fruits dehisce in June, setting free the winged, three cornered seeds.

The tree coppices and pollards vigorously. It is a strong light demander requiring overhead light for optimum growth. It grows on variety of soils, preferring alluvial sandy soils and avoiding stiff clay and water logged soils. On dry hilly slopes where soil depth is poor, it survives but remains stunted. In its natural zone annual rainfall is 750-2000 mm mostly occurring in monsoon.

The tree is fast growing and the wood is not durable. Young seedlings are susceptible to frost, drought, browsing and fire.

Propagation: Natural regeneration is by seeds, but rarely succeeds due to browsing damage. Artificial propagation can be done by seeds, coppice and branch cuttings. Seeds are collected from trees in April-June and are dried in shade. Seeds weight on an average 9000/kg. For 1000 plants about 200 g. of seeds are needed. Seeds are sown in nursery beds in May-June. They can be sown in polybags also, 2 seeds/bag.

Stumps are prepared from one year old seedling with 5 cm of shoot and 20 cm of root. These are planted in holes made with a crow bar. Branch cuttings 2 m long and about 10 cm girth are taken in the monsoon and planted at least 50 cm in the soil. They throw leaves within a month.

Management: The plant is grown mostly for fodder and fruits. For leaf fodder, the branches upto thumb-thickness are cut in the post monsoon period before leaf fall. It can be grown on farm boundaries and near water channels. It does not affect the agricultural crops production due to its deciduous nature.

Hardwickia binata Roxb. Family - Leguminosae

Description: *Hardwickia binata* on good sites is a large tree (upto 36 m height and 1.4 m DBH) with long clear bole and dropping feathery foliage. More commonly, it is rather stunted owing to poor site quality and rarely exceeds about 15 m height and 75 cm DBH. Bark is dark grey with irregular vertical cracks. The tree sheds many twigs and branchlets in April-May. Leaves small (2-6x2-3 cm) almost kidney shaped with 4-5 arcuate nerves, come in pairs with a minutes bristle between them. Deciduous at the end of the cold season (About February-March), new leaves tinged with red appear in April. Typical greenish yellow flowers appear from July to September; flowers are tiny in long, slender, axillary and terminal racemes.

The pod is flat with slightly tapered ends, very light, winged, strap shaped, 5-8 x 1-1.5 cm, with the single seed, lodged in one end, ripening in April-May, dehiscent when shed. The seed is also flat 2x1 cm., pointed at one end and rounded at the other,with a hard testa. H. binata is an indigenous tree species and found throughout the drier parts of India.

It grows on wide variety of soils, but does best on deep reddish sandy loams overlying sandstone. It can establish itself on very shallow soil overlying fissured rocks. Drainage is an important factor for its successful growth. Porous soils with good drainage are favourable sites for natural regeneration. The tree thrives best in areas with rainfall of 500-1000 mm, but can tolerate 250-1500 mm. Within its natural range, temperature is upto 48^{o}C; most of the areas in its natural range are frost free.

Propagation: Natural regeneration occurs freely by root suckers, and by self seeding and wind dispersal of the plentiful winged seeds.

Artificial propagation is best by direct sowing. Direct sowing is done either in lines or patches with the onset of rains, after soil working has been done in advance. The sowing should be shallow as possible, but the seeds should not be left uncovered. Sowing in nursery is done in

May-June. The seed should be soaked in water for 24-hours before sowing. Lines are spaced 20 cm apart and uniform sowing is done in the lines or for polybags, sow 3-4 seeds/bag.

Germination of direct sown seeds takes place with the onset of monsoon rains. The tap root develops rapidly, attaining a length of 15.0 cm, within a week and 20-40 cm in a month. The growth of the shoot is comparatively slower, reaching a height of 12 to 15 cm in the first season.

Management: It has a little adverse effect on under crops when it is grown in cultivated fields. Because of its high fodder value, farmers often protect wild seedlings that come up in their fields. Its deep tap-rooting habit would tend minimise competition with arable crops.

Colophospermum mopane (kirk Ex Benth)kirk Ex. J.l.e.on; Family - Leguminosae

Description: *Colophospermum mopane* is a native of southern Africa. It is a small to medium sized tree (10-15 m; on arid sites 5-6 m) having rough, dark grey bark. With longitudinal fissures and wide spreading branches. It is winter deciduous in India remains leafless from January to May, sometimes to June. Leaves in pairs; appear almost like butter flies or camel hoof prints, alternate, with petioles 1.5-2.5 cm; leaflets kidney shaped, 3x6 cm, having seven veins, inner margins slightly convex and outer margins slightly cordate or truncate at the base and strongly convex at apex. Flower buds globose, in India appear in August, flowers are slender racemes, pale greenish-yellow, on short pedicels (4-8 cm). Pods flat, kidney shaped, asymmetric, 2.5x1.3 cm; pale yellow and very light when ripe, hence wind dispersed. Seeds 1-2x2-3 cm 2-4000/kg, ripening by October-November in India. In arid conditions it generally starts flowering at the age of five years, while in semi arid tracts flowering starts little earlier.

Its best growth occurs in fertile, slightly acidic, friable and permeable, sandy to sandy loam soils, but is also grows in shallow, compacted clay, alkaline and even in badly drained soils. The spices can withstand temperatures from below freezing (-3°C) to as high as 50°C and does well with annual rainfall of 300-800 mm, surviving with as little as 150 mm but with poor growth.

Propagation: Natural regeneration occurs readily and profusely by wind disbursed seeds. Fallen seeds immediately start to germinate with onset of monsoon rains. Root suckers also come up around the base of established trees.

Artificial propagation by direct seeding in polythene bags, seeds do not require any pretreatment, but soaking in water for 24 hours speeds germination. Planting out, nursery raised seedlings (5 to 6 month old) should be done in monsoon rains.

Management: The tree encourage growth of understorey herbage and crops. It can be adopted in Agroforestry system. Leaves of C mopane are highly palatable. Crude protein content in green and fallen leaves is around 14%. The green leaves production from 7 years old trees at CAZRI, Jodhpur had been recorded 7 kg/tree. The tree is very hard, heavy and durable. Wood poles are used in hut construction. It is an excellent fuel.

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MULTIPURPOSE TREE SPECIES FOR SILVIPASTORAL SYSTEM

K.R. Solanki and Manjit Singh

Introduction

Multipurpose trees and shrubs provide more than one significant product and/or services in the land use system which they occupy. The most common uses of trees/shrubs are wood (fuel and timber) and foliage as fodder/green manuring, fruits as food, medicine etc. Some of the multipurpose trees could be nitrogen fixing with symbiotic association with N-fixing organisms like nodule forming bacteria (genus *Rhizobium*) or actinomycetes (genus *Frankia*). There are more than 640 tree species which are known to fix nitrogen although it represents only a fraction of the total nitrogen fixing trees available in the world (Holiday and Nakav 1982). Most of the common nitrogen fixing tree belongs to Leguminosae but there are more than ten families e.g. Betulaceae, Casuarinaceae, Chrysobolanaceae, Coriariaceae, Myricaceae, Eleagnaceae, Rhamnaceae, Rosaceae, Zamiaceae which are known to fix nitrogen (Brewbaker *et al.*, 1984).

Multipurpose tree species (MPTS) could be multipurpose only when managed for multiple outputs or uses. We all know that *Leucaena leucocephala* is a multipurpose tree which could be managed for fuelwood, fodder, fertilizer, shade, erosion control etc. but it could be managed for single purpose e.g. fodder. Leaf may be lopped number of times in a year with no other consideration. It could be used as fuelwood or pulp wood if not used for fodder or fertilizer. Similarly *Eucalyptus* is known more as a single purpose than multipurpose even though it can be used for multipurpose like wood, fuel, pulp wood or timber and at the same time and leaf could be utilised for oil.

Multipurpose trees as a component of silvipastoral systems irrespective of whether they fix nitrogen or not has the following benefits :

- provide foliage for fodder and other purposes.
- hold the soil in places like sloping lands.
- provide shade for both human being and their livestock.
- modify microclimate.
- improve soil through leaf and other litter form in addition to decomposition of old roots beside its capacity to fix atmospheric nitrogen.
- acts as a nutrient and moisture pumping machine (drawing nutrients and moisture from deeper soil layer).

Following are some of the desirable traits farmers may expect in silvipastoral systems : -

- Easy to establish and adopted to edapho-climatic conditions.
- Suitable as a fodder with ability to tolerate lopping, pruning and coppicing and resistant to pest and diseases.
- Multiple uses as fuelwood, leaf fodder and for improving soil etc.
- Rapid decomposibility of litters e.g. *Leucaena*, *Grevillea*, etc.
- Nitrogen fixing ability -Most of the leguminous and other non-leguminous NFTS.
- No allelopathic effect.
- Deciduous nature, leaf falling during crop season like *Melia azedirach*, *Poplar* etc.
- Should not act as an alternative host for common pathogen in crop field.

Common MPTs for Silvipastoral System

Some of the common multipurpose trees being used in India for various agroforestry systems are i) *Leucaena leucocephala,* ii) *Sesbania* sp., iii) *Albizia* sp. iv) *Gliricidia seplium v) Hardwickia binata,* vi) *Acacia cupressiformis,* ,vii) *A. nilotica,* viii) *Casuarina equisetifolia,* ix) *Ailanthus* sp., x) *Melia azedirach,* xi) *Prosopis* sp., xii) *Azadirachta indica, xii) Grevillea robusta,* xiv) *Calliandra calothyrsus,* xv) *Erythrina poppiglana,* xvi) *Dalbergia sp., xvii) Cassia siamea,* xviii) *Alnus* sp., xix) *Ziziphus mauritiana, xx) Faidherbia albida (Syn- Acacia albida).* xxi) *Emblica officinalis,* xxii) *Madhuca latifolia,* xxiii) *Syzigium cumini*, and xxiv) *Eucalyptus tereticornis* in addition to various fruit trees under agri-horti-silvicultural system. At National Research Centre for Agroforestry, Jhansi, multipurpose trees namely *L. leucocephala, Albizia lebbek, A. cupressiformis, A. nilotica, C. equisetifolia, S. cumini* and *E. tereticornis* are being systematically studied alongwith crops under different tree density under rainfed (summer) and partial irrigation (winter season) and under rangeland condition. Solanki (1992) summarised list of multipurpose trees (Table 1).

Properties of MPTs for Soil Improvement

Recently Young (1989) enumerated the following characteristics of multipurpose trees which favours soil improvements:

- High biomass production
- Nitrogen fixation
- Well developed rooting system
- High nutrient content in the biomass including roots
- Fast or moderate rate of litter decay
- Absence of toxic substance in foliage or root exudates

A major advantage in using nitrogen fixing MPTS is its ability to fix nitrogen into a form which can be utilized by plants and animals. This ability to fix nitrogen and extract efficiently phosphorus and potash from otherwise inaccessible soil horizon allows NFTS to improve degraded soil and make them more suitable for better uses for agroforestry systems in marginal and sub-marginal lands where arable farming is practised.

Shifting cultivation practices in hilly region are being improved by speeding up nutrient accumulation process through the use of fast growing nitrogen fixing MPTS. Trees like *Leucaena, Sesbania, Gliricidia, Albizia, Bauhinia* have shown promise. The advantage of soil build up is also in alley cropping or hedge row intercropping system. Here hedge rows of MPTS are periodically pruned to prevent shading and utilised for mulching/green manuring both for high as well as low rainfall zones in sloppy and plain areas (Chinnamani, 1989).

Other Uses of MPTs in Silvipastoral System

In addition to the soil improvement MPTS, in silvipastoral system provides fuelwood, timber, fodder, food, fertilizer, gum, lac, and other minor products. They also act as wind break, shelterbelt, living fence, ornamental plants and provide shade and shelter for human and livestock.

MPTs in silvipastoral system for sustainable agriculture: Out of the total cultivated area of 147 m ha in our country more than 65% cultivated land is under rainfed agriculture out of which

Table 1.Multipurpose trees suitable in arid western plains

Species	Fuel	Fodder	Timber	Edible	Soil slab	Farming system	Remarks
Acacia nilotica (1) *ssp. cupressiformis*	+	+	+		+	CS(M),MF	Quick grown as wind break
Accacia senegal (L.) *Wild*	+	+	+	+	+	ASPS,MF	Rocky and dune areas
Prosopis cineraria (L.) *Druce*	+	+	+		+	ASPS	Soil improvement coppices drought tolerant
Albizia lebbek	+	+		+		CS(M),ASPS, FTS	Wind break in plains avenue
Pongamia pinnata (L.)	+					MFTS,CS(M)F TS	Oilseeds green manure ornamental
Azadirachta indica	+	+		+		MFTS,CS(M)	Fast growing for afforestation of drier areas seed oil medicinal industrial use
A. tortilis Forsk heyna		+	+		+	MF	Dune stabilization
Ailanthus excelsa	+	+		+		MF	Quick growing, canal bunds
Carissa carandas		+	+			CS(M), CS(B)	Easy to establish, excellent hedge
Cassia siamea *Lamk*			+	+		CS(M),MFTS	Quick growing avenue as wind break
Commiphora wightii (Arnott) Bhandari		+		+		MF	Resin, medicinal, hedge refractory sites
Chordia dichotona Forest	+	+	+		+	CS(M), NFTS ASPS	Easy to establish gum from bark backyards
Moringa oleifera Lam	+		+	+		CS(M),MFTS ASPS	Quick growing, fruit as vegetable picked paper pulp
Prosopis chinensis Stuntz.	+	+		+		MF	Quick growing, wind break for wastelands
P. juliflora DC	+		+			MF	-do-
Salvadora oleoides Decne	+	+	+		+	MF.CS(M) ,F	-do- for arid areas oil for industrial uses
S. persica Linn.	+	+		+		MF,CS(M). MF	-d0-
Tamarix troupii Hole				+		MF	Quick growing, for sandy arid tracks
T. aphylla Karst			+			MS,CS(M)	-do_
Zizyphus nummularia	+	+		+			Quick growing drought resistant
Z., mauritiana	+	+		+		CS(M) CS(B)SPS	-do- best fruit in arid zone

substantial area is marginal and sub-marginal which is not fit for arable farming. Multipurpose trees and shrubs including fruit trees in the farming system help farmers to overcome these difficulties and make the agriculture sustainable. In arid Rajasthan, MPTS like *Prosopis cineraria, Acacia nilotica, Ziziphus* sp. are being allowed to grow alongwith crops as important components of sustainable agroforestry system. In semi-arid areas *Dalbergia sissoo, Acacia cupressiformis, Casuarina equisetifolia, Acacia auriculiformis, Leucaena leucocephala,* *Sesbania sesban*, *Eucalyptus tereticornis* etc. are grown alongwith crops either in the crop boundary or intimately mixed with crops in order to avoid possible crop failure in drought prone areas.

MPTs in silvipastoral systems provide quick production of wood including fuelwood in addition to leaf fodder under various agroforestry systems. Because of the acute shortage of fuelwood and high price farmers are often forced to use cow dung for fuel purpose and as such the so called agricultural field which are marginal and sub-marginal and poor in organic matter nutrient and water holding capacity is devoid of its precious organic matter input leading to poor production. Out of the total 500 mt of cow dung burnt annually even if 60% of the cow dung is diverted to the agricultural field it will increase the crop production by atleast 15 mt besides increasing other benefits. As such MPTS in silvipastoral system especially in marginal and sub-marginal land will help the farmers make to agriculture sustainable. It is a happy augury that because of the paucity as well as the high price of wood including fuelwood farmers are taking interest in planting fast growing multipurpose trees including nitrogen fixing trees under various silvipastoral systems, but, there is still need to improve upon these new integrated systems and demonstrate their superiority over the traditional agricultural system.

Prosopis Cineraria as MPTs in Arid Region

Prosopis cineraria, commonly known as *khejri* in Rajasthan, is the most important multipurpose tree of the Indian arid zone. The importance of this tree was long ago recognized by the natives of this region. It has a significantly important role in the rural economy of western Rajasthan since it provides fodder, timber, fuel and edible pods useful as fresh as well as preserved vegetables. Moreover it has medicinal as well as ritualistic values and literally all parts of the tree have some utility or the other congenial to the various life forms enveloping humans, livestock, microbes and surrounding vegetation. The tree being a phreatophyte is able to draw moisture from the deepest layers of soil profile in extreme conditions of drought when most other vegetations perish. During famine, it proves to be the only source and hope for sustenance of livestock as well as humans. Therefore, *khejri* has continued to be a celebrated tree since epics, with great religious sanctities and social traditions to provide it total protection from cutting in a desert dwelling community of 'Bishnois'.

Thar is the most thickly populated desert of the world and there is great pressure of livestock and human populations on the available natural resources, especially vegetation. The common property resources like pastures are fast dwindling and unable to meet the requirements of livestock. The nomads and migrating livestock further worsen the situation particularly during famines. To improve the pastures as well as to mitigate droughts and famines by arresting the processes of desertification, there is urgent need of afforestation. Under the prevailing circumstances of socio-economic constraints, there is need to encourage well adapted and multi-purpose trees in social forestry programmes. Research work at CAZRI for the last four decades has established that indigenous species of trees fare far better than the exotics and among indigenous species, no other tree species excels *khejri*. All done and said, this marvellous tree suffers from relatively slow growth. The required expanse of its stands in the afforestation programmes is felt by all but this lacuna is brought on the fore while deliberating for the choice of species. The increasing demands for fodder and fuel leave much to be desired in this 'boon of the desert'. Propagation through seeds has been the only method in its plantation efforts but little attention has been paid to collect seeds from superior stocks. There is no published report on the genetic studies of *Prosopis cineraria* in Indian arid zones earlier than 1981. The vast potential of genetic variability, its conservation and exploitation still remains to be tapped to give a boost to its growth and to get the increased supply of fuel and fodder commensurate with the increasing demand of the rising population. Besides this, methods of its rapid propagation through vegetative means, protection of establishing sapling from various herbivores and increasing the fruit setting through protection from gall formers and other phytophagous arthropods are other aspects which require concerted team efforts of scientists of different disciplines. Concerted efforts have been made towards collection of germplasm, macro and micropropagation methods, establishment of progeny trials and seed orchards. The results have clearly demonstrated that vast genetic potential is available.

Nursery Techniques

Seedlings of top feed species are generally raised in nursery. To have optimum germinations following points needs to be considered :

- Well balanced potting mixture of sand, FYM and clay in equal proportion is required.
- Watering should be done at the rate of 9 litres at a time per set of 50 containers.
- Overhead shelter during the season should be provided and nurseries should have windbreaks around it.
- Sowing of seeds in nursery beds/polythene bag should be done either in August September or in February-March.

Soil working and Planting : Soil working should be done as per standard techniques for different habitats. Spacing of 5x5 is suitable for arid zone conditions. Planting should be done from middle of July to first fortnight of August. Seedling should be planted in the pits provided with saucer like depression in in sloppy lands. Two weedings and soil working in a year round the plants for the first three years would be beneficial. For optimum populations replacement of casualties with in the same year would be beneficial. Plantation should be protected from biotic interferences. In the year of extreme low rainfall year watering the seedlings at 9 litres/plant will be helpful.

Lopping

General principles : Literature on lopping on fodder trees/shrubs is very scanty. The main reason for this is probably the emphasis on raising fodder trees has been given only recently, whereas it takes years in most of the trees to initiate and complete lopping studies. Although some of the tree species like *Prosopis cineraria, Ziziphus nummularia, Acacia nilotica, Azadirachta indica, Albizia* spp., *Hardwickia binata, Ficus* sp., *Anogeissus* spp. and *Grewia* spp. are extensively lopped by the villagers in various parts of the country but scientific informations are lacking in most of the species. Although lopping management will vary from species to species depending on their regrowth capacity after lopping, their active growing period, period of leaf fall etc., but in general, the following guidelines may be kept in mind at the time of lopping:

- Fresh leaves should not be lopped as they are toxic.
- Saplings and poles are not to be lopped.
- It is safe to give one or two seasons rest after lopping so as to recover from the injury due to lopping.

- Lopping may be restricted to lower two-third of the crown protecting the upper onethird which can manufacture the food for the plants till new leaves come up.
- At the time of lopping branches having a diameter of over 7.5 cm may be avoided.
- Lopping should not be carried out as far as possible on the eroded area or area prone to erosion hazard.

Lopping management for *Prosopis cineraria*

Lopping should be started only after the tree attains a minimum canopy growth which takes about 8-10 years in *P. cineraria* (Sharma and Gupta, 1981). The lopping schedule of will growth trees should start from middle of November each year and continue upto first week of January. Peak period of lopping ranges from the last week of November to first week of December.

In the year of heavy rainfall when water logging of fields occurs for few hours, there is severe leaf fall during August -September months. Thus,in the abnormal rainfall years, the harvest of leaf fodder is comparatively lower than the normal years. The gradual leaf fall during the winter months is due to ageing of leaf. Therefore, lopping should be completed before leaf fall.

Lopping is done in such a way that branches of 2-3 cm thickness are cut and the lopping of thicker branches is avoided. Thus lopping pattern allows the tree to attain a well developed, round and balanced canopy. The tallest branch of one or two year old is left with some foliage which bears pods and seeds, as the lopped twigs seldom produce seeds. Leaf fodder yield *in P. cineraria* ranges from 25-45 kg leaf fodder/tree/annum. On a 10 year stand of *Albizia lebbek*, leaf fodder yield ranges from 4.5 - 6.0 kg per tree. In *Z. nummularia* 'pala' yield varies from 15.0-169 kg/ha and bush yield vanes from 23.0 kg to 323 10 kg.

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PASTURE ESTABLISHMENT TECHNIQUES

M. S. Yadav

Introduction

Natural succession of grass species especially that of high yielding ones in arid zone is a slow process. However, reseeding of these natural grasslands results in increased yield of forage and better soil protection. In recent past there has been encroachment on marginal and sub-marginal lands for cereal crop production as a result of growing population pressure and associated demands. Crop production in such lands has always remained much below the expectation. Land falling under class V to class VIII capability classes are unfit for crop cultivation and those under class IV are subject to wind and water erosion hazards. Such lands have been considered suitable for pasture development. Pasture established with optimum population during the year of establishment is likely to remain productive for five to ten years. If it is poorly established than we can not expect good return.

Pasture Development

For development of pasture following steps are needed :

Protection of Site

For proper protection from stray animals and also for preventing other damage in the areas of grassland development, trench digging around the area should be done. Trenches of trapezoidal shape of 1.5 m wide at the top, 1m wide at the bottom and 1 m deep are recommended.

Land Preparation

Before the establishment of pasture proper cleaning of field and soil working are essential. The soil working should be as thorough as is done in case of normal agricultural crops. The land should be properly ploughed with disc-culti-harrow and all unwanted vegetation should be removed.

Sowing Method

The following two methods are adopted for seed sowing :

(a) Sowing of seed behind cultivator: Seeds of pasture species are mixed with moist sandy soil, 3-4 times the volume of the seed and drilled uniformly behind the cultivator (Fig. 1) in lines 50 cm to 75 cm apart depending on the type of grass species immediately after the first effective showers in 8 to 10 cm furrows at a depth of 1 to 2 cm under the soil (Yadav, 1991).

(b) Pelleted seed sowing : In order to have better establishment of pastures on large scale, the seed pelleting is appropriate. Pellets are prepared by mixing seeds of grass, clay, FYM and sand in the following proportion :

Seed :	Clay :	FYM :	Sand
100-125g :	3500g :	500g :	500g
1-1.25 :	30 :	5 :	5

Pellets are prepared by pellet making machine (Fig. 2). It is a simple rotatory tyre device designed at CAZRI, Jodhpur. Pellets of about 0.5 cm diameter are prepared. Each pellet contains 2 to 3 spikelets. Pellets are dried and stored. The pellets should be sown in lines 50 to 75 cm apart depending upon the grass species. Sowing operations should be carried out immediately after first effective rainfall of monsoon. Sowing can also be done a couple of days before expected rains (Yadav, 1986, 1991).

Seed Rate

For optimum establishment of pastures by direct sowing of seeds *Panicum antidotale* and *Dichanthium annulatum* may be sown @ 2.5 kg/ha and *Cenchrus ciliaris and C. setigerus* @ 5 kg/ha each, whereas comparatively higher seed rate, i.e. 7.5 kg/ha is recommended for *Lasiurus sindicus*. In case of pelleting half of the seed quantity is required (Yadav, 1991).

Fertilizer Management

The arid zone soils being sandy in nature, are poor in nutrient content. *L. sindicus* showed better response with N, P and K than application of N, P or K alone. The crude protein content

Package of practices of some important grass species

Name of species	Rainfall (mm) and soil	Sowing time and seed rate (kg/h)	Spacing (cm)	Manuring (kg/h)& harvest No.	Green fodder yield (q/h).
Buffel grass (*Cenchrus ciliaris*)	250-900, Sandy to sandy loam	June-July (north) March - Sept. (south) 4-5	50x50	N-40 P- 20 2-3 cuts	150-350
Bird wood grass (*C. setigerus*)	200-700, Sandy to sandly loam	-do-, 5-6	-do-	-do-	110-250
Marvel grass (*Dichanthium annulatum*)	350-1500,Clay soil	-do-, 2-2.5	-do-	-do-	200-300
Sen grass (*Sehima nervosum*)	600-1200, Red gravelly sandy loam to loamy soil	-do-, 5-6	-do-	- do -	225-300
Sewan grass (*Lasiurus sindicus*)	50-500,Sandy duny	-do-, 6-7	50 x 75	N-20, P-20 2 cuts	150-250
Blue panic (*Panicum antidotale*)	200-1000, Sandy to sandy loam & saline soil	-do-, 2-2.5	50x50	N-40, P- 20 2-3 cuts	200-300

Fig. 1 Line sowing of *Cenchrus ciliaris*

Fig. 2 A simple grass seed pelleting device

with fertilizer treatment was 12.8% (Dabadhgao *et al.*,1965). In grasses, 30 kg N and 30 kg P should be applied for better establishment and high forage yield

The N fertilizers must be given in split doses for its better cultivation, whereas P and K should be supplied as basal dose. In case of legumes 15 kg N, 40 kg P and 20 kg K should be given as basal dose in furrows or by broadcasting at the time of sowing.

Weeding

Removal of weeds from the fields at seedling stage between the rows of sown grasses in the first year of sowing ensures better establishment of pasture and its production. In first year of pasture establishment two weedings are generally required, first after 10-15 days of germination and second after 25-30 days of growth.

Moisture Conservation

Contour furrows 60 cm wide and 25 cm deep are constructed in grasslands at a distance of 10-15 m across the slope of land. Reseeding of *Cenchrus* species was done in furrows. The results revealed that contour furrowing increased forage production by 130% over non-furrowed (Singh, 1992).

Inter-row water harvesting (IRWH) system in which 30 cm wide ditch alternated with 70 cm wide raised bed was tried on different grasslands. Two rows of pasture legume and grass were sown on the edge of the ditch. IRWH system increased fodder yield of legumes and grasses by 124 and 66%, respectively over conventional system of planting (Singh, 1992).

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NURSERY TECHNIQUES FOR RAISING TREE SEEDLINGS

J.C. Tewari and L.N. Harsh

Introduction

In recent years, concern for trees and forests has increased tremendously and this is primarily because of disappearance of large quantities of forest from many countries. Some countries lost most of their forests several generations ago and have either adjusted to living with less trees or now import tree products from countries that still have them. People whose way of life depends on daily easy access to tree products are most directly affected by loss of trees and consequently are especially interested in how to replace them.

There are many ways to propagate a tree. Often all that is needed is 'protection'. In fact, this is required anyway, for growing trees by any method. Leave the site free from grazing, cutting and other kind of stresses for a year or two and see how trees grow from old stumps and roots. In case of many other tree species, direct sowing of seeds is the cheapest and best way. But this still requires 'protection'.

But when a large area has to be brought under systematic plantations, it becomes essential to use seedlings grown in nursery. Just raising seedling, under nursery environs is not much difficult, the trick is to make them survive and grows. Fortunately, last two decades have witnessed dramatic increase in use of containerized tree seedlings in plantation forestry programmes and consequently sufficient emphasis is being given for nursery research and development practices. This paper describes the basic approaches needed for raising tree seedlings in nursery.

Nursery Site Selection

Because no potential nursery site is perfect, site selection inevitably requires compromise. However, careful attention to the selection of a site for nursery will amply repay all the efforts expended. Criteria for selecting a nursery site involves the knowledge of soils, water, climate, topography, and land availability and cost. Perhaps the most important factor in establishing a nursery is correct choice of soils. Sandy loam or loamy sands with good drainage are excellent for nurseries (Morby 1983). Other site features of soils including fertility, moisture and microclimate can be manipulated by nursery manager (Chavasse 1980).

Securing an adequate supply of irrigation water can be major problem. Water rights must be obtained from any water source. Water drawn from wells is probably one of the best irrigation source for most locations. As far as climate is concerned, the growing season requirement will vary with stock type. Extremely low as well as extremely high temperatures can be detrimental to seedlings. When temperature goes up above 40 - 42^{0} C, especially in arid and semiarid regions, properly designed irrigation system with adequate roofing to provide shade can protect the seedlings from burning. There is no problem associated with monsoon rains, however if they occur as cloudbursts with resultant flooding, erosion etc., then only they cause problems. High wind velocity, particularly where humidity is low (as in case of arid regions) are quite harmful for growing seedlings and therefore, nursery site should be protected from the influence of high wind velocities by growing two rows of shelter belts around the site or by building a dry stone wall (without cement mortar).

Moreover, a nursery has to be protected from domestic livestock and from wild life. In many areas this can be done cheaply and effectively by digging perimeter trenches and growing thorny hedges along the spoil mud. But in desertic environments these measures are impossible as trenches get filled with blowing sand, and mounds easily slumps and slide down. Therefore, barbed wire fencing is recommended in such areas.

Nursery Layout

A nursery is usually arranged in a series of beds with pathways between them. An open area is needed at one end, where work such as sieving of soil and filling of containers can be done. Usually a small hut or shelter is required for staff and the watchman and where equipment can be securely stored.

Generally nursery beds are of two types viz., seedbeds and transplanting beds. Seeds beds are level, cultivated areas about 1x10 m in size for direct sowing of large seeded tree species at spacing which is suitable for growth to planting out size, usually 5-10 m. Transplanting beds are similar areas used for transplanting seedlings in a wider spacing for growing larger stock to be used in more difficult sites. However, neither seed beds nor transplant beds are used much in dry areas because of the problems with bare root planting out. A certain amount of damage can not be avoided when lifting seedlings for planting out. It is difficult to retain a ball of soil around the roots and field conditions are usually difficult for planting bare rooted seedlings.

In case of raising containerized nursery, generally similar size i.e. 1x10 m level beds are constructed to keep polybags or any other type of container systematically. However, in advance containerized nursery techniques, bed preparation is not observed as a rule.

Containers for Forest Nurseries

Although ornamental plants have been grown in containers since the early days of human civilization (Matkin *et al.* 1957), the production of forest tree seedlings in containers is relatively recent. Most easily available and most widely used containers are 'polybags'. They are closed at the base and have drainage holes punched in the sides and around the base. Bags should be transparent where the size of the container is small (10x15 cm lay flat) and region is hot. For large size, black polyethylene is recommended but measures must be taken to prevent overheating of black polybags due to absorption of sun light. Size of poly bags used depends on tree species, quality of planting site and on the size of seedlings needed. In dry areas, it is always best to have large polybags that can be well watered before taking to planting site, thus providing sufficient water to seedlings in order to survive for longer periods (Hocking 1993). A lay flat size 10x15 cm is minimum; for large seedlings (upto 1.5 m height) 12.5 x 20.0 cm to 20x30 cm lay flat size is recommended.

In addition to polybags, a number of other types of containers are now available for raising forest tree seedlings in nurseries. These containers can be grouped in two types

- Containers planted with seedlings
- Containers removed before outplanting.

The details related to both these groups of containers are set in Table 1. Within the first group i.e., containers planted with seedlings, two different types were developed. First type are made up of biodegradable material, such as molded peat moss or wood fibre that decompose after out planting. These containers are probably useful only for growing seedlings for short periods before their root system become too expensive. The second type of biodegradable containers consist of a shell of hard plastic, plastic mash or specially treated paper that is filled with growing media and sown with seed to produce a tree seedling under normal nursery culture. The tree seedling is then outplanted in the container, which theoretically would then expand, decompose or somehow allow roots to grow out into surrounding soil.

Table 1. Some major types of currently available containers

Contaniner type	Construction material	Remarks
Containers planted with seedlings		
Paper pot	Specially treated paper	Good for raising seedlings of small trees
Jiffy pot	Molded peat moss	-do-
Fibre pot	Molded wood pulp	-do-
Containers removed before outplaning of seedlings		
Poly bag	Polyethylene film	Highly useful utilized maximum
Ray leach single cell system	Low density polyethylene cell	Good for raising seedlings having less expanded root system
Spencer-Lemaire Rootrainer	PET (Polyethylene terephthalatge)	Good for raising sedling of all type of tree species
Styroblock	Expanded polystrene (themcool)	Space saving; good for raising large number of seedling
Hiko system container set	High density polyethylene	-
Seeding tray	Expanded polystyrene	-
Rootrainer one cell	PET (Polyethylene terphthalate	Very good for the seedling of those tree species in which roots are often coiled
Used containers		-

The second group of containers viz., containers removed before outplanting are most popular (accounting 91%) type in forest nurseries (Landis *et al.* 1990). The term 'plug seedling' results from the fact that their roots bind the growing medium together into a relatively firm mass or plug. The containers producing plug seedlings should have two common characteristics (Tinus and McDonald 1979): (a) The walls of containers should be relatively smooth so that roots do not penetrate and make the plug difficult to remove and (b) the cavity of container should be tapered from top to bottom so that seedlings can easily be extracted from the top.

Seed Quality Tests

Before initiation of any activity in nursery, it is highly essential to test the seed lot of the species whose nursery is to be raised. The evaluation determines seeds per kg, purity percentage and soundness.

Seeds per kg: Seeds per kg are calculated by weighing five replications of 100 seeds to nearest 0.001 g. The mean weight is then placed into this equation.

Seeds per kg = Mean weight in grams of 100 seeds x 1000

Purity percentage: Purity is determined by removing debris from a 40 g sample of seeds But this weight (sample weight) vary from species to species.

Purity % = [Clean seed lot wt./ (Clean seed wt + debris wt.)] x 100

Soundness percentage: The percentage of hollow seeds is determined by X-raying a 100 to 200 seed sample. This could also be achieved by cutting the same number of seeds If more than 3 per cent seeds are hollow, the seed lot should be reprocessed by gravitational means to eliminate the empty ones.

Pre-treatments and Germinations Tests

After evaluating the seed quality the next most important step is to test the seed germination in laboratory conditions but if available, the germination testing in green house is most viable proposition.

Tree seeds unlike agricultural seeds, are in many cases characterized by deep dormancy. In fact this is true for most arid zone tree species (Shankarnarayan *et al.* 1987). Seeds of different tree species or different geographical origins often require different pre-treatments and conditions for optimum growth (Villiers 1961, Villiers and Wareing 1960). Pre-treatment of seeds by boiling water, growth hormones like IAA and IBA, certain chemicals and mechanical seed scarification were studied by different workers time to time (Kumar *et al.* 1991; Bohra *et al.* 1993). Some important characteristics of common arid zone tree species in respect of pre-treatment and germination percentage are given in Table 2.

Pre-treatments and germination tests give accurate idea regarding the amount of seed needed for sowing to achieve the targets. It also minimise the chances of germination failure or poor germination.

Table 2. Certain characteristics of important arid zone tree species seeds

Species	Time of seed collection	No. of seeds/ 100g	Pretreatments, if any	Germination (%)
Acacia tortilis	Nov.-Feb	195	50% conc, sulph.acid;30 minute in summer and 40 minutes in winter	90-95
A. senegal	Aug.-Sept.	86	Soaking in water for 24 hrs	70-75
A. aneura	March-April	659	50% conc. suplh acid; 15 minutes	60
A. jacquemontii	March-April	126	-do- 40 minutes	80
A. albida	-	143	-do- 30 minutes	90
A. catedchu	Dec.-Feb.	415	Soakinging water for 24hrs	80
A. nilotica	May.-June	79	Soaking in water for 6 hrs	75
P. cineraria	May-June	231	Soaking in water for 30 minutes	90
P. juliflora	Nov.-May	202	Manual scarification	90
Azadirachta indica	June-July	60	*	50
Tecomella undulata	April-June	800	*	50
Dalbergia sissoo	April	256	*	70
Hardwickia binata	June-July	56	*	65
Colophospermum mopane	Dec.-Jan	25	*	95
Leucaena leucocephala	Nov.-dec.	425	Soaking in water for 1hr	95
Albizia lebbek	Dec.-July	118	*	
Parkinsonia aculeata	Feb.-June	160	50% conc.sulph. acid; 15 minutes	80
Dichrostachys nutans	Dec.-Jan	453	Soaking in previously boiled water for 6 hrs	80

* Seeds do not require any pre-treatment before germination

Growing Media

Many different terms have been used for container nursery culture media including potting soil, potting mix, soil mix, compost and growth medium. But to avoid confusion growing medium/growing media appeared to be most appropriate term. The cultural characteristics of growing medium are the properties that affect its ability to consistently produce crops of healthy tree seedlings under nursery conditions i.e., slightly acidic pH, high cation exchange capacity, adequate porosity and freedom from pests.

A suitable growth medium provides anchorage, nutrients and moisture for growing seedlings. The growing media can conveniently be grouped into two types:

- Soil medium/media
- Soil less medium/media

Major problems with soil media are limitations because of their weight. However, still the soil media dominate the scene of nursery raising throughout the India. Soil mix contains roughly 1:1:1 of sand:silt:FYM (farm yard manure); all sieved to 2-3 mm and mixed well. Some phosphate fertilizer (DAP or TSP; about 1% of the total soil) can be added and mixed well. To protect the seeds and seedlings from termite attacks, about 0.1% of 10% BHC powder may also be added. Alternatively, 5% neem cake or shredded neem leaves also has a protective, insecticidal effect. While filling the container (polybags), one should be very sure that container has well filled and tamped down, leaving no air gaps in the column of soil.

In many developed countries the container operations have been highly mechanised and the mechanized container operations require that a growth medium be light, be easily handled, maintain constant volume when wet or dry, be free of pest, be readily stored for long periods without change in physical and chemical properties and be easily blended into easily reproducible material (Liegel and Venator 1987). Few important soil less media commonly used in containerized nursery operations are: peat, vermiculite, perlite, sugarcane waste, rice hull and compost.

Seed Sowing

Seeds must be collected and sown in time (season depends on the species) after proper preoperation. Seed should be sown early enough but not too early. The actual date depends on the season of fruiting, seed viability, growth rate and season of planting. Some seeds like *Azadirachta indica* have very short viability and must be sown soon after collection.

After sowing, seeds should be covered with a layer of fine sand and watered. If necessary, partial shade should be provided by errecting grass or twig thatch roof over seed beds. In certain hard coated seeds of some arid zone tree species, the effect of sowing depth on germination and seedling quality appeared to be highly important factor. One such study carried by Mutha *et al.* (1994a) on seeds of *Prosopis juliflora* indicated strong negative correlation between sowing depth and germination percentage (Table 3). Similarly, seed weight in case of same species partially related to better germination (Mutha *et al.* 1994b). In case of seed weight bold and heavy seeds showed early germination and had higher per cent of germination as well as mean daily germination (Table 4).

While sowing, it is always safe to sow two seeds per container to get desired number of seedlings. After germination, one seedling per container is retained. Gap filling can be carried out with fresh and small germinants which are surplus and picked out from the containers. Soil surface crusts may need to be broken to allow seed emergence.

Germination, Seedling Growth and Care

Once sowing is complete, the containers are irrigated until medium is thoroughly moist. In arid zone conditions, the majority of species are sown during the first fortnight of February i.e., the beginning of spring season. Nine litres of water at a time per set of 50 containers have found to be most economic dose of watering for successful raising of seedling (Mann and Muthana

Table 3. Effect of sowing depth on germination of *Prosopis juliflora* seeds

Sowing depth (mm)	Germination (%)	Mean daily germination	Germination value
10	80.0	8.00	166.60
20	67.5	6.75	71.71
30	37.5	3.75	20.31
40	22.5	2.25	7.40
50	2.5	0.25	0.08

Source: Mutha *et al.* (1994).

1984). Alternate day watering for first one month followed by regular watering till the onset of monsoon season is recommended. But this irrigation schedule can be adjusted according to various needs. In majority of arid zone tree species germination is completed with in 18 to 26 days. Seed lots with high germination energy tend to shed their seed coats rapidly. During seed coat shedding seed enters the 'initial growth phase'.

During initial growth phase root system is developed on the germinants, making them capable of incorporating large amounts of nutrients and producing rapid shoot growth during accelerated growth phase. During this phase providing 42 ppm N supplement with some phosphorus and potassium preferably twice weekly (with irrigation) proved to be quite helpful to meet targeted growth. This initial growth phase generally extended upto 6 weeks. After this growth phase, 'accelerated growth phase' is initiated. In accelerated growth phase, seedling height and collar diameter are increased. Weather conditions, particularly amount of sun- shine have a strong influence in this particular growth phase. This phase, in arid zone conditions extends upto 18 week.

As the seedling grow, roots start penetrating into soil through the drain hole in the containers (bags). This must be checked by regular (at least once per month) shifting all the containers and pruning off (with a sharp knife) any protruding roots. However, if the containers are kept on an elevated platform, protruding roots are prunned naturally once they come in

Table 4. Effect of seed weight on germination of *Prosopis juliflora* seeds

Seed weight group	100-seed weight (g)	Percent germination*	DQI
A	1.07	30.8	3.30
B	1.46	58.7	2.76
C	1.93	60.5	2.71
D	2.64	65.5	2.21
E	3.21	64.9	4.82
F	3.44	61.2	4.84
G	4.00	69.3	4.36

* Percent germination values are angular transformed values

contact of air/outer environment (the process is known as aerial pruning). The aerial pruning techniques have been proved to be vital, as the risk of shock to growing seedlings, which is always there in case of container shifting and pruning off protruding roots manually is completely excluded.

After accelerated growth phase further development of root and shoot occurs but with relatively lesser pace and by the end of 24th week the seedlings are ready for out planting. In arid region conditions of Indian sub continent this period coincides with onset of monsoon.

If the plants have to be held over longer period than planned, for example by the long delay or failure of rains, they will have to spaced out more wider. Stripping off the leaves also helps to retard the growth in off season. Ideally, such held over stock should be transplanted to larger size bags or other containers (about double the diameter).

Seedling Quality

Many factors influence the quality of seedlings. But a single indicator has been found useful for quick and easy testing. This indicator is the stem diameter at the point where it emerges from the soil called the 'root collar'. A simple gauge can be made for checking the root collar diameter and used for quality control before outplanting. If the quality of a specific group of seedlings is to be assessed, destructive sampling through random selection of some seedlings of the group and computing Dickson Quality Index (DQI) is quite useful (Dickson 1960). The DQI is calculated as follows:

DQI = [(Total seedling dry weight (g))/{ height (cm) /Stem diameter (mm) + shoot dry wt (g) / root dry wt (g)}]

Some other Important Points for Consideration

- High quality seedlings are those that meet defined levels of performance on a particular site. Improved seedling quality allows better interaction of planted seedling with the planted site.
- Irrigation can affect seedling nutrient status both positively and negatively. Excessive irrigation or heavy rainfall can leach soluble nutrients such as nitrate,nitrogen and potassium from the root zone and reduce the amount available to the plant. Therefore, all the precautions should be taken to standardize irrigation regime.
- Root rot and wilt are the major diseases as far as seedlings of arid zone tree species are concerned. Similarly, various aphids are most important insect pests and rodents and seed eating birds are frequent animals pests. Timely pest management by the advices of pest management specialists can save the seedlings from mortality.
- Soil-solarization of nursery mixture before filling the containers was also found to be very effective in controlling soil borne diseases.
- In certain species, some relationship is found between time of seed collection and germination. Kaul and Manohar (1966) observed, if seeds collected at the stage when pods just turn bronze in colour, the germination percentage can be maximized in *Acacia senegal*. This aspects should also be given due consideration.

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METHODS OF TREE/SHRUB GROWTH MEASUREMENTS IN SILVIPASTORAL SYSTEMS

L.N. Harsh and J.C. Tewari

Introduction

While agriculture is understood to cover the whole theory and practice of raising and harvesting field crops, the term 'silviculture' commonly refers only to certain aspects of theory and practice of raising forest crops. Silviculture is used to imply only the methods of raising tree crops, their growth and care upto the time of final harvesting. The forests of India probably include a greater range of composition and appearance than can be found over a similar area in any other part of the world.

Silvicultural studies in plantation forestry of arid regions have their own importance. In contrast to the arid regions of Arabian peninsula, Australia, Israel and United States of America where oil, natural gas and other petroleum products provide most of the energy, in Rajasthan desert of India the natural vegetation forms the chief source of fuel, besides contributing to requirement of small timber for agricultural implements and fencing material (Kaul, 1963).

Silvicultural studies in broad sense include a wide range of factors and subjects. It range from the study of locality factor and community/stand organisation to all the aspects of plant growth from germination to tree crop harvesting. Thus the domain of silvicultural practice is very wide. Following description summarizes the major aspects of silvical practices used in arid zone forestry, especially in western Rajasthan.

Analysis of Stand Structure

Classified as Tropical thorn forest by Champion and Seth (1968), the forest vegetation of arid western Rajasthan is very sparse and consists of scattered trees, shrubs and grasses. Satyanarayan (1963) classified the vegetation of the region into five formation types. They are (i) mixed xeromorphic thorn forest, (ii) mixed xeromorphic woodlands, (iii) dwarf semi-shrub desert, (iv) psamophytic scrub vegetation, and (v) succulent and halophytic plant community.

In natural plant communities, to analyse the forest stand structure is one of the important aspects of silvicultural practices. For qualitative assessment of a forest stand, the identification of flora is sufficient. However, for quantitative assessment following two factors are most important.

Density

This is a count of the number of individual trees within an area. It is usual to count the number of individual trees within a series of randomly distributed quadrat. Average number of individual trees within 10 x 10 m quadrat is calculated to study the tree component and for the shrubs 5 x 5 m quadrat is sufficient. The unit of density will be thus, individuals per unit area.

Cover

In a forest stand, the cover is analysed in two forms:

- Basal cover
- Canopy cover.

The basal cover is defined as proportion of ground occupied by the stems of wood species. I. is calculated as follows:

Mean basal cover = $C^2 / 4\pi$

where, C is the average circumference of the individuals of a tree species. By multiplying this value with the density, the total basal cover of a species can be assessed. Finally, by summing up the total basal cover values of all individual species of a forest stand, the total basal cover of that stand can be computed. Thus the unit of mean basal cover is cm^2 per tree, while the total basal cover is represented as cm^2/tree/unit area.

Canopy cover is simply the measure of canopy expansion. This can be assessed by expanding the measuring tape on ground level throughout the canopy length. Two measurements should be taken, i.e. perpendicular to one another. the canopy cover can be computed by the following formula:

Canopy cover = $(W_1 + W_2)^2/4\pi$

where, W1 is the diameter of canopy in one direction and W2 in the other direction (i.e. right angle to first one). Thus, the unit of canopy cover of individual species will be cm^2 per tree. The data for the same will be recorded in the quadrat used for density measurements.

The above values are important in quantitative analysis of stand structure. These values reflect the relative importance of individual species in a forest stand. They further throw light on sociological behaviour of different species in a forest stand. This type of analysis is generally done in natural forest stands.

Silviculture Practices In Plantation Forestry

The plantation forestry, especially in arid regions of India, where well stocked natural forests have completely diminished and whatever forest land is there in the form of highly degraded stage, has very important role both from conservation and productivity points of view. Following silvical practices are involved in raising large-scale plantations:

Nursery Technique: Development of appropriate nursery technique is a pre-requisite for any forestry activity. For raising seedlings in nurseries, the technique has been standardized at CAZRI, Jodhpur (Kaul and Ganguli, 1963). In brief it is as follows:

(i) Before raising nursery it is essential to assess the viability of seeds in a given lot. For the quick assessment of seed viability, tetrazolium test (Moor, 1969) is highly appropriate. This method involves four steps. These are, (1) soaking, (2) cutting, (3) incubation, and (4) evaluation. The seed viability can also quickly be assessed by X-ray method.

(ii) The next important thing is pre-treatment of seeds to facilitate quicker germination. A number of studies have been carried out at CAZRI, Jodhpur, on this particular aspect (Mann and Muthana, 1974). These include pre-treatment of seeds by sulphuric acid, soaking of seeds in water previously brought to boiling point, manual scarification, etc. In general, results of these studies revealed that by giving pre-treatment to seeds, not only germination percentage increases, but it also reduces germination time (Table 1). For certain species, some relationship was found between seed collection time and germination percentage. In case of *Acacia senegal* if seeds are collected at the stage when pods just begin to turn bronze in colour, the germination percentage can be maximized (Kaul and Manohar, 1966).

Table 1. Characteristics of some arid zone tree species

Name of tree species	Time of seed collection	No. of seeds / 100 g	Pre-treatment, % germination	
Acacia tortilis	Nov-Feb.	195	50% concentrated sulphuric acid 30 min. in summer and 40 min. in winter	90-95
A. senegal	Nov-Dec.	86	Soaking in water for 24 hour	70-75
A. aneura	Mar-Apr.	659	50% Concentrated sulphuric acid with 15 min.	
A. jacquemontii	Mar-Apr.	126	40 min. in sulphuric acid	70
A. albida	-	143	40 min. in sulphuric acid	80
A. catechu	Dec.-Feb.	415	24 hour soaked in water	90
A. nilotica	May-Jun.	79	60 min. Soaked in water	70
Prosopis cineraria	May-Jun.	231	24 hour soaked in water	90
P. juliflora	Apr.-Nov	202	-do -	50
Azadirachta indica	Jun.-July	27	-do -	75
Tecomella undulata	Apr.-Jun.	800	-do -	50
Dalbergia sisso	April	256	-do -	70
Hardwickia binata	Jun.-July	56	-do -	60
Dichrostachys nutans	Dec.-Jan.	453	15 min.	95
Colophospermum mopane	Dec.-Jan.	25		85
Leucaena leucocephala	Nov - Dec.	425	15 min.. -do-	95
Albizia lebbeck	Dec.-Aug.	118		75
Parkinsonia aculeata	Feb.-July	160	45 min.. -do-	80

(iii) For sowing the seeds, cylindrical metallic containers of 6.9 cm in diameter and 22.9 cm long have been found to be most suitable for raising seedling. However, polythene bags of similar size were also found equally suitable.

(iv) A well balanced potting mixture containing equal proportion of sand, clay and farmyard manure is essential for seed sowing.

(v) The irrigation of 9 litres of water at a time per set of 50 polythene bags was found to be effective as well as economical. The watering is done on alternate days during cold period and regularly during hot period. The seedlings grown in poly-pots and when kept on cemented beds, require 29.8% less water as compared to those kept on earthen beds. Recently some polymers were mixed with nursery mixture and it was observed that by doing so 30% water could be saved.

(vi) Under Jodhpur conditions majority of tree and shrub seeds are sown in February and seedlings are ready by the last week of June for field transplanting. However, some species like *Eucalyptus* sp., *Simmondsia chinensis* and *Parthenium argenatum* respond best to sowing period of October and November.

Field Transplanting : After successful raising of nursery, the most important step is the field transplanting of seedlings. The whole operation involves a number of steps. In brief these are as follows:

(i) *Field preparation*: The field preparation is done one month before the onset of monsoon. Under this task, digging of pits is most important. In general, the recommended pit size is 60 cm^3, but this may vary according to site conditions and landforms.

(ii) *Spacing*: The spacing (i.e. row to row and plant to plant) generally vary according to the objective of plantation. If plantation is meant for fuelwood, the spacing will be kept closer and if it is meant for fodder production, it would be little wider. For conservation purpose, like sand dune plantation and shelterbelt plantation, the spacing is kept according to site conditions.

(iii) *Transplanting time*: The best time for transplanting of seedlings in the field is first fortnight of July.

(iv) *Soil working*: Transplanting of seedlings showed better results than the direct sowing. Soil working of 60 cm^3, half filled pits with a crescent shape ridge along the local slope gave higher rate of establishment.

(v) *Irrigation, cultural operation and fertilization*: If the rainfall is adequate during field planting period, the irrigation is not required at all. If longer dry spells persist after field transplantation of seedling, one or two life saving irrigations are essential. Weeding on field conditions significantly promote the growth of different tree species. In arid climatic conditions, the use of fertilizers for enhancement of tree growth is not recommended.

(vi) As the arid region is characterized by considerable heterogeneity of landforms and soil types, the planting technique for afforesting different habitats have been standardized at CAZRI, Jodhpur. In brief, these techniques are given in Table 2.

Plant Growth: The growth of established seedlings and adult tree has to be considered. In general, the seasonal progress of growth is studied for height and diameter. Another important factor is the study of canopy expansion. The growth of tree species is generally recorded

Table 2. Planting techniques and suitable plant species for different landforms

Landform	Planting/Afforestation	Suitable tree/shrub/grass sp.
Sand dunes	Protection from biotic interference by angle iron post with barbed wire Establishment of microwind breaks by brushwood in chess board form at the spacing to 5 m apart in right angle to wind direction Afforestation of treated dunes either by direct seeding or by transplanting nursery raised seedlings	*Colophospermum mopane Acacia tortilis, Citrullus colocynthis, Prosopis cineraria and Lasiurus sindicus*
Sandy plains	Planting should be done in pits of 45 cm3 spacing of 5x5 m Around the pits saucer shaped structures about 30 cm in height and 1 m in dia should be constructed to harvest maximum rain water	*Acacia tortilis Ziziphus mauritiana Azadirachta indica*
Shallow soils	Planting should be done in pits size of $60cm^3$ The hard calcareous layer below the soil surface should be broken by crow-bar to facilitate root growth of tree species	*Eucalyptus tesselaris E. melanophloia E. camaldulensis Acacia nilotica and Z. mauritiana*
Rocky area	Preparation of staggered contour trenches with a cross section of 60x40 cm to minimize water erosion	*Acacia tortilis A. senegal Prosopis juliflora and Euphorbia sp.*
Saline patches	Planting should be done in raised bunds having a height of 1 m and a width of 70 cm	*Prosopis juliflora p. pallida P. tamarugo P. chilensis and Atriplex spp.*

annually at the end of growing season. To study the growth a number of instruments are available (i.e. haga- altimeter, hipsometer, etc.). The growth in diameter can be measured by diameter tape or by callipers. When it is measured at base or ground level it is known as collar diameter (CD) and when it is measured at 1.37 m above the ground level it is known as diameter at beast height (DBH). Canopy expansion can be measured by simply running a tape throughout the canopy diameter. It is generally known as canopy diameter. The values of canopy diameter and stem diameter can be converted into canopy area and stem area by simple mathematical calculations.

Other Silvical Parameters

Under the silvicultural studies a number of other factors are also considered. A few of them are as follows:

(a)*Phenology*: The seasonal changes in development of foliage, flowering, fruiting, etc. are also important from silvicultural point of view. The study of seasonal changes in vegetative structures is known as vegetative phenology and that of changes in reproductive structure is studied under reproductive phenology. these factors are studied by simple observations.

(b)*Crown form*: Under this, the shape and size of crown i.e. branch system with foliage, is studied.

(c)*Root structure*: The spread of roots play a very important role as far as establishment and growth of tree species is concerned.

Conclusion

As already mentioned the domain of silvicultural studies is very wide. A number of studies are carried under silvicultural system. One basic aim of the silviculture practices is to maintain the plantations in perfect condition according to the objectives. Locality factors like climate, landforms, soil types, etc. also play important role in forestry practices of a particular area. Thorough analysis of these factors is also very important for silvicultural system studies.

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ON PLANTATIONS IN DRIER TRACTS OF INDIA, SUDAN AND LATIN AMERICA

K.D.Muthana

Introduction

Forests and forestry have many important roles to play for the upliftment of rural populations inhabiting degraded lands any where in the world. In fact, in majority of developing countries, wood is still the main source for meeting out the domestic energy needs. As the population grew, more land came under cultivation and more stress was applied to remaining woodlands to provide range of products needed for domestic requirements. As long as there was sufficient forests, these needs were easily met. But rather suddenly, the era of sufficient forests ended (Hocking 1993).

Land degradation do not occur suddenly, it is an outcome of so many factors operating in an area for a long period. During this period many abiotic and biotic factors play their own roles in this degradation process. Rural populations inhabiting at and around such continuously degrading lands generally overexploit whatever forest resources left over there in order to meet their fuel and fodder requirements. More over, ever increasing population pressure also force them to encroach the more and more woodlands in order to cultivate crop for their sustenance, though such lands can hardly support agriculture for a longer period due to erosion hazards and/or poor soil fertility status. Ultimately the influence of all these factors accelerates the process of desertification in such land forms. Once the fuelwood availability in declined, the rural masses obviously start searching some alternatives to meet their domestic energy needs. In majority of developing countries, therefore, cattle dung and crop residues are frequently used for burning and consequently soils in such areas suffer heavily as they are deprived of these vital fertilizer and soil conditioning resources.

In nut-shell, major factor behind land quality degradation (including degradation of forests) is over exploitation caused by continuous escalation of human population and activity, including livestock rearing. These factors bear with particular force on dry areas. The situation is more or less similar in Indian desert as well as desert areas of Africa and dryland situations of south America. In fact, in these regions the way of life of people depends on daily easy access to tree products and they are most directly affected by loss of trees. Therefore, they are especially interested in how to replace them. The present report summarizes the plantation techniques being adopted to revegetate the degraded lands in India, Africa and south American countries.

Essentials of Degraded Land Rehabilitations

Rehabilitation of degraded areas is often possible. The first step is always to remove the cause for its present conditions. If nobody who lives nearby such degraded areas has secure rights to the production, then everybody will take what they can. Some form of agreement is needed that classifies and ensures the rights of people who live nearby to use the land and its production. The another most important point is to have land-use capability classification. Such classification helps in deciding the types of land fit or otherwise for cultivation of agricultural crops. Incorporating forestry programmes to a proper extent will go a long way in enhancing fuel and fodder production. In dry land situations, degraded lands can be brought under tree plantation cover with systematic management and in fact, these lands are only suitable for tree plantations or silvi-pasture plantations (Shankarnarayan 1984).

Basic Approach for Tree Plantation Programmes

The indigenous tree species of arid regions are few in number and are very slow growing by habit. Therefore, it is highly essential to try and introduce fast growing, drought and frost resistant tree species from isoclimatic regions of the world. The species grown should have multipurpose utility such as nutritive fodder value of leaves, fuel of high calorific value, small timber, usefulness for soil conservation, etc. The approach also demand detailed investigations on:

- selection of exotic and indigenous species and their ecotypes for different habitats.
- standardization of nursery techniques for large scale seedling production.
- Investigation on silvicultural characteristics of selected tree and shrub species.
- standardization of soil working techniques and cultural operations.
- standardization of proper techniques on disease and pest management.

Following discussion is essentially limited to various plantation techniques being adopted in rehabilitation of degraded lands in India, Africa and south American countries, especially in arid and semi-arid conditions.

Plantation Techniques

Indian Dry Lands : Pit planting of nursery raised seedlings has been found to be highly successful in dry hot arid tract of India, which is spread over in more than 3 lac sq. km. Pits of 45 x 45 x 45 cm size dug prior to monsoon season have been found to be most appropriate for better establishment of seedlings (Mann and Muthana 1984). In case of failure of monsoon rains after the outplanting, seedlings needed to be watered till they establish satisfactorily (i.e., at the intervals of 15 to 20 days). Weeding and soil working around the seedlings should be done at least once in a month during initial establishment phase to minimize the root competition and also for better soil aeration.

Desert Region of Sudan (Africa) : Conditions similar to Indian desert are also found in desert areas of Sudan. Till 1960, Kordofan region of Sudan was self sufficient in food items like sorghum, meat, milk and edible oils. It also contributed substantially to the country's foreign cash earning through export of peanuts, sesames, Karkade (*Hibiscus* sp.), melon seeds and livestock (viz., camels, sheep, goats and cattle) production and the export of gum arabic exuded from *Acacia senegal*, locally, known as Hashab trees had production about 50% of the world's total gum production (on an average about 25 to 30,000 tonnes per annum).and was major source of eanring foreign exchange. Drought of 1969 to 1975 coupled with continuous increase in animal and human population stressed the need for more cropland and thus gum production has been dwindled in this part of the gum belt which gave rise to serious problems of degradation of vast areas of gum belt and also the reduction in the yield of agricultural lands, as yield from hashab trees (*Acacia senegal*) was no longer in the traditional agricultural cropping system. Moreover, the gum belt which constitutes a natural buffer zone between the desert proper in the north and the agricultural crop land in the south has deteriorated upto an alarming state and as a consequence of which the whole ecosystem of the region has been highly unstable from the agricultural and livestock production point of view.

Acacia senegal(hashab tree) plays an important part in the balanced agricultural practices and also in the socio-economic set up in the Kordofan region. The farmers and villagers have realised the multifarious benefits from the hashab trees as these provide them additional income from gum collection and moreover, tree canopy intercepts the raindrops and prevents runoff and soil erosion and also enrich the soil fertility as their roots fix nitrogen in the soil.

These benefits have also induced the farmers to work their holdings in quadrants - one quarter is set aside for old productive hashab (*Acacia senegal*), second quarter for young productive hashab, third quarter for intercropping with hashab transplanted seedlings under Agro-Forestry system and fourth quarter under pure agricultural crops. As and when they realise that their fourth quarter is loosing its fertility, they switch over to transplanting it with hashab seedlings. Then they fell the old hashab trees from the first quarter of their holdings and use that land for cropping. This would give them additional income in the form of building materials, materials for tool handles, agricultural implements, fuelwood, charcoal, etc. The only expert guidance to be provided to the farmers is about the planting techniques, soil working, weeding and after care, such as protection from biotic interferences, accidental fires, pests and deceases.

Tree seedlings are planted in strips of 20 rows i.e., 100 m width across the wind direction to commence with leaving 50 m. wide strips for establishing grasses and shrubs. The subsequent tree strips will be of 10 rows i.e., 50 m width parallel to the first row of trees. Again 50 m width is left for grasses and shrubs, and again tree strips are planted at 10 m wide parallel to the 2nd tree strips and continued further. These tree rows act as shelter-belts apart from stabilizing the sand dunes. Tree seedlings are planted in pits of 45^3 cm. Planting seedlings in strips is recommended to these areas mainly because:

- Having phased the stabilisation work for the project period, working it out from the lower side all along the length would check the wind velocity and shifting of sand particles uphill would be considerably reduced.
- The sand dunes which are being considered for stabilisation work are mainly longitudinal dunes spreading lengthwise more than the width and hence it has been felt desirable to tackle them all along their length to start with strip by strip.
- This method would give more stability to the micro-windbreaks, if need be, to be laid in the upper zones because of tree plantings done at lower levels would act as shelterbelts.
- Water tankers could move easily all along the length than move uphill with the load of water. The open strips left in between the tree rows for grasses and shrubs could be used for the movement of water tankers.

Drier Tracts of Chile (South America) : In Chile, whose desert conditions are mainly confined to Northern region adjoining to Peru, extreme temperatures during summer and winter (day and night) do not rise above 30oC or go lower than $0^{o}C$. Chile has an estimated 4,270 km of territorial length. The Great Northern Chile is composed of the first region with 58,072 km^2 and the second region with 125,306 km^2. The typical features are desert landscape with abundant mineral resources, mainly silver and complementary copper and gold. Agriculture is limited to two fertile valleys. Average annual rainfall is negligible. Though the land is arid, the entire region is cut by deep, dry alluvial gorges. The sector bears a network of dead water courses

The Tamarugal Pampa which owes its name to *Prosopis tamarugo* is in the plain sloping lands varies in elevation from 300 to 1200 m. The characteristic face of this land is; desert and salt. *Prosopis tamarugo* belongs to the family of Mimosaceae order Leguminosae. It is native of the first region of Chile. Its average height is 15 m, trunk diameter ranges from 50 to 80 cm and crown diameter from 15 to 20 m. Tamarugo has a double root system - tap root penetrating to a depth of 7-8 m in loamy soils and secondary roots which hardly go upto 1.5 m depth. The tree becomes productive within 7-8 years of age. This species can survive and even thrive in soils of high salinity and low fertility. The species usually need a yearly rainfall minimum of 250 mm but can adapt to areas, where mean annual rainfall is as low as 75 mm or even less. They can easily withstand prolonged period of drought and still produce abundant pods.

The pods were used as food material by the prehistoric human beings in the western hemisphere. But even these days, the pods are source of protein and carbohydrates for many north and south American desert dwellers. The food value is comparable to that of barely and maize. Most of the livestock in Hawaii, Peru, Chile and Argentina are maintained on pods of this *Prosopis* species.

The plants grow easily from seed and regenerate from root suckers or runners, so their survival rate is high. In certain favourable soils, their tap roots go as deep as 10-20 m but they have a considerable network of secondary roots. Experiments conducted on *Prosopis tamarugo* revealed that species is capable to absorb atmospheric moisture through its leaves and transmit it to the roots where it is stored as water. This explains why and how the tamarugo tree thrives in areas where ground water lies forty or more meters deep and where there is no contact of water to the root zone.

With the onset of rains in the month of June, transplanting of nursery raised seedlings is done. In the Tamarugal Pampa, where salt crust is mainly found upto 40-60 cm depth, and below that better soil layer is found, pits are generally dug 80 cm wide by 1 m length. Depth of pit depends on the saline layer which must be reached before, as the planting pit is actually dug after striking the good soil layer below the salt crust. Pits of 30 cm depth by 20 cm diameter are dug for planting seedlings. Before planting the seedlings, irrigation is applied to the planting pit so as to wet the pit as far down as possible. On an average 11 watering at 10 litres per watering is provided for the establishment period. Once new shoots start sprouting, watering is done once is 20 days.

Arid Lands of Brazil (South America) : The Brazilians advocate the spacing of 2 m x 2 m or 3 m x 3 m for wood production and 5 m x 5 m, if it is for silvipastoral plantation. For production of pods, 10m x 15 m or 15m x 15m spacing is advocated. Under planting of cactus (*Opuntia ficus indica*) with *Prosopis chilensis* is also carried out. This species, (*Prosopis chilensis*) was introduced in Brazil in the forties and acclaimed to be the most promising tree species for the driest regions in the north east, where annual precipitation is below 100 mm. Cactus is used as fodder and planted at 2 m x 0.5m in between the *Prosopis* spp. trees. In many parts they sow seeds of maize and buffel grass (*Cenchrus ciliaris*) in between the tree rows and harvest very good yield. The average yield of *Prosopis* pods is 10-15 kg per tree and 60 tonnes of cactus (11.2 tonnes of dry weight) per hectare per year and 16 tonnes of buffel grass per hectare per year.

Certain Important Guidelines For Afforestation

- Tree planting should be done after the onset of a good soaking shower. All planting operations should be completed within the shortest period as soil moisture is the main limiting factor for the success of the plantation especially in drier regions. This would also facilitate the seedlings planted to take advantage of the subsequent rainfall.

-The seedlings should have long and well developed tap roots and seedlings should be of 45 to 60 cm high.

-Coiled roots should be straightened at the time of planting.

-Care should be taken to see that the collar zone of the plants are completely covered by the soils.

-Depth of the pit should be more than the root portion of the seedling.

-After planting the seedlings in the pits, the soil around the seedlings should be pressed firmly.

-After planting a saucer shaped depression around the plant having 15 cm deep and 1 m diameter in plain areas and a crescent shaped ridge of 15 cm high may be provided on sloppy areas to collect and store rain water.

-The species should be able to produce coppice shoots and viable seeds for further propagation.

- During summer seasons, all precautions must be taken to protect the plantations from accidental fire incidence.

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PROPAGATION TECHNIQUE OF RAISING TOP FEED SPECIES THROUGH TISSUE CULTURE

N.L. Kackar and Manjit Singh

Introduction

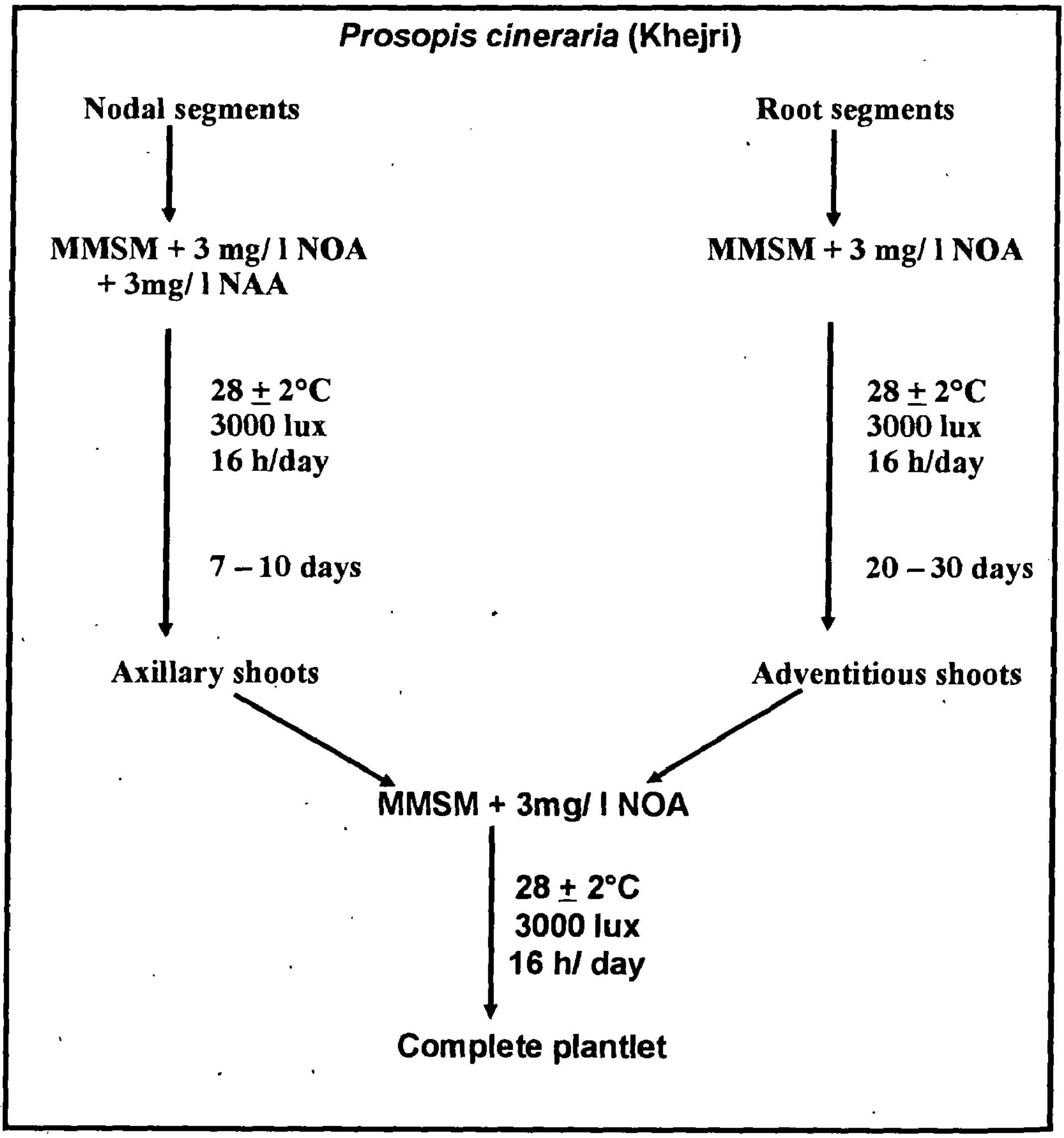
In arid regions trees mean life. Any silvipastoral system , in addition to correct choice of top feed tree species, will require genetically superior populations and modern silvicultural treatment. Surveys of natural population and half sib progeny trials of arid zone trees like *Prosopis cineraria, Tecomella undulata, Acacia senegal* etc. have revealed that progenies show lot of heterogeneity for morphological traits (Kackar 1988, Jindal *et al.*, 1985,1992). Conventional approaches of genetic improvement for obtaining varieties producing homogeneous population is likely to take long time. Biotechnological approaches like mass multiplication of selected genotypes through tissue culture, i.e. micropropagation of elite trees, may prove to be quick and efficient mean to obtain uniform stands of good quality trees. Despite the slow start, tissue culture propagation of forest trees is gaining momentum and a large number of hard-wood and softwood species have been micropropagated. Research on tissue culture of hard wood forest trees has been in progress for over a decade in many research institutions in India. The tree species used in these studies include desert and arid zone trees, leguminous trees and those used for timber, fuel, fruit and industry. The first reports of success in the micropropagation of mature elite forest trees, production of triploids and regeneration of plantlets from tree protoplasts, were from Indian laboratories (Anon, 1989). General technique of micropropagation includes selection of mother plant which is to be multiplied, and initiation of culture by selecting appropriate explant. The most crucial stage is however shoot multiplication. It may be achieved through callusing, adventitious bud formation or enhanced axiliary branching. Research work on micropropagation of arid zone top feed tree species like *Prosopis cineraria, Salvadora oleoides* and *Tecomella undulata* is in progress at this institute.

Prosopis Cineraria (khejri)

Among indigenous arid zone tree species of Thar desert, no other species excels *Prosopis cineraria*. This multipurpose tree, however, suffers from relatively slow growth. The required expanse of its stands in the afforestation programmes is felt by all but this lacuna is brought on the fore while deliberating for the choice of species (Solanki *et al.* 1992). During surveys vast variation was observed (Kackar *et al.*, 1986a,b; Singh *et al.*,1993) indicating the magnitude of exploitable genetic potential for its improvement. In fact during trials some trees attained height of more than 7 metre in seven years as compared to the population mean of 3.5 metre (Solanki *et al.* 1992). Air layering technique was developed for clonal propagation of superior genotypes (Solanki *et al.*,1984,1986) and used for establishment of clonal seed orchard. This technique, however, may not be suitable to meet the demands of large number of plantlets of superior genotypes required for afforestation programme. Methods for *in vitro* regeneration and multiplication of this species have been developed using shoot and root segments as explant (Kackar *et al.* 1991,1992).

Nodal segments from actively growing branches of five year old elite tree when cultured on modified Murashige and Skoog, medium containing 3 mg/l each of napthoxy acetic acid and napthyl acetic acid produced axiliary shoots within 7-10 days. These shoots when cultured on modified MS medium containing 3 mg/l of NOA developed tap roots in 25-30 days. The shoots from *in vitro* cultured plantlets could be further cut into 3-5 nodal segments, each of which produced complete plantlet on modified medium containing 3 mg/l NOA (Kackar *et al.*, 1991).

Root segments from 2-4 month old seedlings and also from 5 year old elite tree could also be used successfully for micropropagation. 1.0 -1.5 cm long root segment when cultured on modified MS medium containing 3 mg/l NOA produced adventitious shoots, their number being more in explants from seedlings (5-20 shoots) than from adult tree (3-8 shoots). These shoots when cultured on the same medium produced complete plantlets (Kackar *et al.*, 1992).



Salvadora oleoides (Jal)

In India *Salvadora* spp. are widely distributed in saline patches of arid regions (Gupta and Saxena 1968). It has marked tolerance to aridity and salinity. Seeds of this species have high amount of non-edible oil (having high lauric acid content) and is used in soap industry as a substitute for coconut oil. One of the reasons for shortage of edible oil in our country is that such oils are diverted towards non-edible industries. There are over 100 million ha. of waste-land in India , 7.5 million ha of which consist of saline and alkaline soils. If a portion of these tracts can be covered with elite *Salvadora* trees it will be a major benefit both in wasteland development and to the non-edible oil industry as it has been emphasized at various levels that *Salvadora* spp are one of the potential source of non-edible oil.

The work on micropropagation of *Salvadora* persica has been carried at National Chemical Laboratory, Pune using nodal segments as explant (Mascarenhas *et al.* 1987). Work on regeneration of *Salvadora* oleoides. has been initiated at this Institute using immature embryos from unripe fruits (Kackar and Solanki 1992). Unripe seeds were collected in the month of August, they were surface sterilized with 0.1 per cent mercuric chloride and the embryos were excised under aseptic condition. These embryos when cultured on MS basal medium containing each of 3 mg/1 napthyl acetic acid (NOA) and naphthalene acetic acid (NAA) produce 3-4 shoots. These shoots when subcultured on modified MS media containing 3mg/1 of napthoxy acetic acid (NAA) produce 3-4 shoots. These shoots when subcultured on modified MS medium containing 3 mg/1 of NOA produced roots within 20-30 days and continued to grow. These growing shoots were again cut into 2-3 single node segments and subcultured on the same medium produced complete plantlets. Using this procedure we can multiply the plantlets by 5-7 folds (Kackar and Solanki 1992).

In our studies various approaches like adventitious shoots and axiliary shoots have been used. In general, adventitious shoot formation. directly form excised organs is considered less reliable than axiliary bud proliferation, but it is more dependable approach than the callus method for clonal propagation (Anon., 1989). Biotechnological methods can be successfully exploited for large scale production of superior trees derived through genetic improvement - all being exact duplicates of the original. This is bound to increase the economic yields of the forests. It may not be possible to achieve the same results using conventional methods in the short time. One objection which is often raised is that clonal forestry will lead to annihilation in the event of a disease outbreak. This problem can be overcome by using number of unrelated superior genotypes.

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REPRODUCTIVE BIOLOGY AND BIODIVERSITY IN TOP FEED SPECIES

Manjit Singh

Introduction

With the explosive increase in world population, there is increasing pressure on the dry lands which, with their semi-arid fringes constitute one-third of the land area of the globe. Among the consequences of desertification, major emphasis has been put on soil degradation and destruction while genetic erosion has received comparatively little attention. Genetic diversity, constantly subjected to a process of selection and adaptation to the always changing conditions of the earth, constitutes the world's genetic resources. Although the survival of man and his home, the Earth, depends on genetic diversity, this resource is being rapidly destroyed or depleted (Esquinas-Alcazar 1985).

It is common belief that arid lands have a large amount of genetic diversity, but this needs to be substantiated, and the distribution, kind and potential use of these genetic variants need to be analyzed. Populations of many species from deserts and extreme arid lands are divided into genetically isolated units that may be evolving rapidly and separately in response to environmental constraints (Esquinas-Alcazar 1985). Ratio of total number of genera to species in Indian desert is 1:1.9, which is rather low in comparison to a corresponding ratio for whole India (1:7) (Bhandari, 1978). Arid intermediate regions are laboratories in which many new adaptive complexes of plant groups are produced, while the extreme arid regions become museums in which some extreme adaptations and sometimes relict species are preserved. Selection pressures, in this case desertification, are bound to change the population structure and gene frequencies. Approximately three-quarters of the arid lands of the world are in the process of desertification. As desertification proceeds, valuable germplasm disappears. In extreme cases of desertification, populations are likely to show less diversity but would be more selectively adapted to stressed environments. The conservation of genetic resources goes far beyond the salvation of species. The object must be to conserve sufficient diversity within each species to ensure full availability of its genetic potential for the future (Esquinas-Alcazar, 1985). The degree of genetic variability and its mating system will have an important bearing on method of collection, sample size, etc.

Plant Genetic System

The patterns in which gametes unite to pass genes from one generation to the next is termed the mating system. In the past, species were often characterized as inbreeders or outbreeders, self fertile or self sterile. Now it is well known fact that mating system is not a fixed, species specific constant, but is rather a dynamic entity, varying in time and space and affected by a large number of biotic and abiotic factors. These include degree of self compatibility, population density, variation in phenology and climatic variables (Stern and Roche, 1974). The mating system is an important determinant of plant population genetic structure (Clegg, 1980). It is the genetic link between generations and determines the initial zygotic frequency distribution of each generation. Individuals of a highly outcrossed species generally have higher levels of heterozygosity than those of self fertile species. Inbreeding can also induce gametic phase disequilibrium even among loci on different chromosomes (Allard, 1975; Mitton *et al*, 1981).

A knowledge of the population genetic structure of a species is important for a number of reasons. In genetic conservation, for example, estimates of the amount of genetic diversity within population, and the range and distribution of this diversity among populations is necessary in order to devise an optimum sampling strategy. The mating system of a species affects the genetic structure of populations- the distribution of genotypes and the dynamics of this structure in relation to evolutionary forces (Ritland and Jain, 1981). In addition, estimation of many genetic parameters on which breeding strategies are based makes use of an assumption of random mating which may not be valid (Squillace, 1974). In fact in arid zone trees climatic vagaries, low population size etc., will make complete random mating almost an improbability.

Several methods have been employed in the study of mating systems of forest trees. With the advent of gel electophoresis, allozyme polymorphism have been commonly used for examining the mating systems of trees, because they provide many marker loci and alleles per locus, increasing the statistical precision of estimates (Moran and Brown, 1980). Both single locus model and multi-locus models have been developed to estimate mating system parameters from allozyme data. The use of enzyme polymorphism is highly advantageous since isoenzymes are usually co-dominantly expressed and many independent loci can be assayed simultaneously on the same individual allowing a large amount of information on the mating system to be obtained (Jain, 1979).

Genetic Variability and Reproductive Biology in Trees of Thar Desert

In Indian arid and semi-arid regions *Prosopis* species like *P. cineraria* and *P. juliflora*, *Acacias* like *Acacia nilotica, A. senegal, A. tortilis* and other tree species like *Tecomella undulata, Azadirachta indica*.are among the commonly used timber and fuelwoods. Some of these species alongwith others like *Ziziphus* species, *Calligonum polygonoides, Salvadora* spp. *Capparis decidua* have served as the most important renewable energy source in rural areas since generations. With rapid increase in population, the stress on these limited forest biomass resources has increased tremendously. We have already over exploited the natural resource for short term gains. And now for our long term survival, it is obligatory on our part to devise and implement a reasonably sound conservation strategy. For effective conservation strategy of a species, it is important to understand extent and pattern of genetic variability in natural populations. Decisions about sampling frequency, sample size etc., are affected by variances within and between populations, level of heterozygosity, allelic polymorphism etc. and mating system of individual tree species. We here present the information collected on genetic variability in indigenous arid zone tree species of Thar desert and their reproductive biology.

Prosopis cineraria

P. cineraria is an important multi-purpose tree species of Indian Thar desert. This species shows considerable variability in natural stands in western Rajasthan, height ranged from 4.6 to 20.0 m; forking height 1.2-4.6 m; diameter at breast height (D.B.H) 0.14-1.5 m; collar diameter 0.16 to 1.6m,branches per tree 2 to 9 and canopy dia 1.2 to 9.1m; pod length 6.4-18.0 cm; seeds/pod 3-19. Coefficient of variation in these traits ranged from 26 - 64 % (Kackar *et al.* 1986a, b).

Wide range of variability was observed in percentage of crude protein, reducing sugars and total sugars of pods in trees even from the same provenance. The total range (%) over all provenances was 8.05- 15.05 for crude protein, 0.83-4.67 for reducing sugars and 6.04-15.83 for total sugars. Studies on crude protein content of various progenies revealed significant differences among progenies indicating the genetic basis for this diversity.

In *P. cineraria* both vegetative and sexual reproduction can be observed in natural stands. Vegetative reproduction occurs through coppicing. In arid zones, where climatic conditions are harsh it is but natural that a tree species should have all possible modes of reproduction. Our experiments have shown that this species can be vegetatively propagated through air layering (Solanki *et al.*, 1986). This approach has been used to collect some promising genotypes and a clonal seed orchard has been established. We have also successfully micropropagated this species *in vitro* using nodal segments as well as root segments from juvenile and mature plants as explants.

In *P. cineraria* flowering occurs during March to May. Many insects including honeybees and thrips can be seen on the inflorescences during this period. There are on an average 76 flowers per inflorescence. However, only 2 % of these turn into pods. The dispersal of seed is through animals. In nursery, problem of seed dormancy is overcome by scarifying the seeds with sulphuric acid for five minutes. Seeds collected in the end of May or first week of June can be planted immediately in nursery after this treatment and two-month-old seedlings so produced can be successfully transplanted in field. In our trials we have obtained about 90% establishment and at present there are more than 3000 trees representing 142 genotypes in our germplasm collection or progeny trials (Solanki *et al.*, 1991).

The information on mating system, pollinators and detailed reproductive biology is scanty. The degree of outcrossing rates can have an important bearing on conservation strategy both *in situ* and *ex situ* as well as genetic improvement of the species under consideration. The conventional methods for obtaining this information in trees may require decades. Recent biochemical studies, particularly those on isoenzyme polymorphism, have raised high hopes for comparative analysis of variation patterns in different groups of plants and their degree of outcrossing. Studies on peroxidase isoenzymes of 52 seedlings representing single plant progenies of six trees have clearly shown that there is variability both within and between single plant progenies at more than one loci demonstrating the outcrossing nature of the species (Solanki *et al.*, 1992a).

Loss of biodiversity is the direct consequence of deforestation. It need not be over emphasized that promotional activities for afforestation will get a boost if genetically superior stocks are made available. *P. cineraria* is a slow growing tree species. Observations and analysis of data from progeny trials and seed orchard show that there is ample genetic potential available in natural stands. Fast growing types can be selected by even following simple selection. For example, in seed orchard the best tree attained height of more than 7 m in 6 years. In natural stands trees may take more than 15-20 years to attain this height.

Tecomella undulata

Tecomella undulata (Rohida) belongs to family Bignoniaceae which is known for many woody perennials with large size attractive coloured flowers. Their seeds are very light and papery and easily get wind dispersed. In Indian arid zone it is locally called as "Marwar Teak" or Desert Teak because of its wood quality. Presently it is one of the most important desert timber tree species. Last three decades have witnessed large scale export of its carved furniture. This factor has caused a heavy demand for quality wood. Thus indiscriminate felling continued and at present the desert tract has almost exhausted large bold and healthy plants. Consequently the population of this species decreased drastically and it is now listed as threatened species (Saxena, 1993).

In Western Rajasthan Rohida (*T. undulata*) in generally recorded on sandy plains, undulating hummocky plains and undulating interdunal plains with deep to very deep sandy soils. There are two distinct concentration zones of high density of Rohida. (1) District Barmer and (2) Sikar . In Barmer District tehsil Chohtan, Barmer and north Bhakasar show high density of Rohida (20-60 plant/ha) on flat and hummocky interdunal areas. This is a low rainfall tract (150-250 mm) but the soil moisture in lower depth is always present round the year and perhaps this factor helps in providing high tree density of Rohida and Khejri. Rohida is always a common associate of khejri (*P. cineraria*) community in these areas. Low dunes and longitudinal ridges of these three tehsil, of Barmer district are also occupied by this species with 10-20 plants/ha.

Mean, range, standard deviation for various quantitative characters of. *T. undulata* have been studied (Solanki *et al.*, 1993). Tree height ranged from 12.8 m to 20 m with mean value 5.78 m. Forking height 0 to 4.2 m with 1.63 m mean. Branches per tree ranged between 1 to 15. Basal diameter and D.B.H ranged from 7.1 to 136.8 cm and 3.8 cm to 130.4 cm, respectively. Maximum coefficient of variability was observed for basal diameter (61.3%) followed by D.B.H (59.2%) and minimum for leaf size 1.19 to 6.08. Peak flowering period is from end of February to middle of March. The flowering duration varies from 59 to 103 days for individual tree and upto 135 days for the whole population. It has been observed that almost all the flower buds appearing in November, December and January fell before or after opening. Only a few of the flowers developed in February set fruits. Fruit set varied from 0.64 per cent for selfing to 3.94

per cent in cross pollinated plants indicating the presence of self compatibility. Apomixis, an important mechanism for fixing heterotic advantage, was found to be absent. (Jindal *et al.*, 1985). Wide range of variability was observed in 198 trees studied. Maximum coefficient of variability for tree height, DBH, basal diameter and canopy diameter were observed in Barmer district. (Jindal *et al.*, 1987).

Tree height of eleven half sib plant progenies established in 1984 was recorded for six years. Progenies showing good growth in the initial stages were not necessarily performing in subsequent years. There were significant differences among the progenies over all the six growth years. Estimates of family heritability, single tree heritability and genetic gains from family and mass selection indicated that the gains were low with both the methods. As components of variance tend to stabilize after fourth year of growth, selection done in the earlier years may not be rewarding. Low values of heritability and genetic gains from family and single tree selection suggested that there is need for other selection procedure for higher genetic gains for the tree height (Jindal *et al.*, 1992). In *T. undulata* flowering like that in *P. cineraria* is asynchronous and occurs during November to February In natural population flowers of red, yellow and intermediate colours are found. In the progeny trial comprising of eleven half sib plant progenies established at CAZRI, Jodhpur during 1984, besides variation in of height, diameter at breast height (DBH) there was segregation for flower colour in ten progenies, suggesting the outcrossing nature of this species. Our observations showed that birds like purple sun bird (*Nectarinia asiatica*) visit the flowers for nectar and may be acting as pollinators.

Acacias

A senegal is an important fuel and gum yielding tree on rocky habitats. An exploratory survey was undertaken during 1984. Maximum variability was found in Barmer district. In 52 trees enough variability could be observed in various pod characters like pod length (4.2- 10.3 cm), seeds/pod (2.8-7.0) and 100 seed weight (7.40-18.88 g). Variation in different traits has also been observed in progenies of 13 plus trees established in 1985 at Jodhpur, Bhopalgarh and Jaisalmer. At present there are about 700 trees in field representing 18 single plant progenies.

A. nilotica sub sp. *cupressiformis* is found in Pali district and its concentration is very high around Sadri. During survey variation in height, DBH and compactness of crown was observed. Seed from eleven plus trees has been used to establish progeny trial of this sub species during 1991. Our earlier studies on single plant progeny indicate that this sub species can perform well under Jodhpur conditions and there is segregation with respect to compactness of crown. *A. nilotica* collections were also made from eleven provenance in Gujarat and a replicated trial was established during 1990.

Twelve progenies of *A. tortilis*- an exotic fast growing multipurpose tree species - were evaluated under arid (Jodhpur) and semi-arid (Pali) conditions. Components of variance for height tend to stabilize by third year (Solanki *et al* 1992b). Provenance trial of *A. tortilis* sub sp. *raddiana*, has also been established during 1988-89.

Acacia albida is widely distributed throughout the dry zones of Africa and parts of the Middle East (Fagg, 1992). This species has a particular potential for community forestry in dry areas (Palmberg 1981). In Sahelo-Sudanian zones *A. albida* is regularly associated with most intensively cultivated lands. According to Pelissier (1979), *A. albida* stands are critical to the lives of farmers dependent on rainfed cereal agriculture and breeding of domestic animals. Since last two-three decades information has been generated on agroforestry, silviculture, and various other aspects, but it was only during last decade or so that concerted research efforts were made on genetic resources and stock improvement (Bonkoungou,1992).

Provenance trial of *A. albida* was established at Central Arid Zone Research Institute, Jodhpur during 1988. There were significant differences among the seven accessions for tree height over all the seven years since their establishment. Mean provenance height after seven years was more than 4 m in all the accessions (Table 1). Accession having maximum height during first year of establishment is also having maximum mean height after seven years of establishment. Flowering in 16 trees was observed for the first time in 1993-94 when trees were six year old. These trees were not from any specific provenance but were representing all the provenances.

Table 1. Mean height of seven accessions of *A. albida* transplanted in July 1988

	Mean Height (m)						
Acc no.	1988	1989	1990	1991	1992	1993	1994
EC 232578	0.23	0.84	1.95	3.05	3.65	4.40	4.68
EC 232579	0.26	0.94	2.14	3.36	4.05	4.41	4.99
EC 232581	0.37	1.15	2.14	3.34	3.91	4.70	5.02
EC 232582	0.25	0.80	1.63	2.91	3.54	4.45	4.97
EC 232583	0.27	1.01	2.06	3.29	3.93	4.76	5.03
EC 232584	0.26	0.75	1.50	2.52	3.02	3.72	4.01
EC 232585	0.28	0.80	1.63	2.75	3.28	4.01	4.30
Mean	O.27	0.90	1.86	3.03	3.63	4.35	4.71

From the foregoing discussion it is evident that trees are important constituents of arid zone ecosystem and cater to many needs of desert dwellers. Variability for almost all the silvicultural characters is available in the indigenous trees of Thar Desert and there is a possibility of selection of plus or elite trees keeping in view of the objectives and needs of particular zone. However, considering the long life span and extreme climatic conditions, systematic efforts through proper planning and testing of the material at multilocations are required so that genetic potential is realized to a maximum.

Most of the diversity collected during surveys or procured from other sources is in the form of progenies/accessions in the field. The conventional approach of germplasm collection and conservation in the form of single plant progenies or clones cannot be extended too far due to limitation of land and manpower. There is need for adopting other conservation strategies like low temperature storage of seeds, pollen storage, *in vitro* collection and conservation etc. Dilemma can be whether to store genetically improved stocks or just natural populations. The problem becomes simpler if we actually know about the exact extent of genetic variability and try to preserve the same levels in genetically improved stocks.

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INTRODUCTION OF TREE SPECIES FOR INDUSTRIAL USE IN SILVIPASTORAL SYSTEMS

S.K. Jindal

Introduction

The introduction of perennial woody species on pasture land or vice versa offers many advantages at low cost. The silvipastoral system operates in a region where agroforestry crop farming system is not feasible, owing to low rainfall and lack of fresh water. The integration of forest (timber, food or fodder producing ones) and woodland management with pastoralism as the main occupation, is a good example of the silvipastoral use of land. The proper use of fodder trees can add nutrients to soil, fix atmospheric nitrogen, lower the soil surface temperature, reduce soil moisture evaporation, contribute animal feed during lean period and also provide more effective year round use of labour (Shankarnarayan, 1984).

There has been considerable interest in using more productive renewable natural resources of the arid and semi-arid zones which make almost 40 per cent of the Third World's land surface. In this article tree species which are reported to tolerate arid or semi-arid conditions, suitable for silvipastoral systems and have potential as raw materials for industrial i.e. non-food use are mentioned. These species yield one or more of the following commodities.

- Essential oils for use in flavourings, fragrances etc.
- Firewood
- Gums and resins for use as adhesives including those which may be used in food stuff
- Oilseeds-non food uses i.e. technical oils used in surface coatings for lubrication etc.
- Pesticides
- Pharmaceuticals - as a source of drug or their precursors
- Tanning materials
- Waxes

Choice of Woody Species

Many factors are required to be taken into consideration when selecting woody species for a silvipastoral or an agro-silvipastoral system. Robinson (1983) insisted on the importance of (i) the location (on communal lands, on private pastures, on non-appropriated lands near rivers etc.), (ii) the management (watering, planting, protection, shaping, pruning, lopping, distribution, classes of age etc.) and (iii) the purpose.

Management of Tree Species

Multipurpose trees: Multipurpose trees could be grown as widely spaced individuals, in small groups or rows, but should not be in closed stands if they are required to yield fruits and browse as well as wood. Multipurpose might mean 'multimanagement', some trees might be lopped for browse, others pruned for fruits, others allowed to grow tall for shade and ground cover; trees for different purposes might be planted on different patches of soil; fruit trees may become multipurpose if poorly managed; some trees might be culled for fuel and continuously replaced; and old trees might be girdled to obtain a last crop of fruits before felling.

Fodder trees: Trees grown for browse, fodder or mulch should be coppiced, or if animals are grazed beneath them pollarded.

Fuelwood trees : For fuelwood trees, the wood should have a high specific gravity, and the trees should be spaced to produce stems and branches of the desired diameter in the shortest time.

Timber trees : Wide spacings and the pruning of basal branches improves the timber quality and shortens the time to maximum mean annual increment.

Purpose of the Trees

When the main target is to increase *fodder* availability, a broad choice of species is to be advised to reduce risks of inappetability or even toxicity, and the account should be given to the time, the parts consumed by the animals, and how their nutritional value changes along the year.

If *shading* the animals is the main objective, the places where animals are most of the time throughout the year during the day should be known, in order to start planting shading trees where shade is the most needed. Trees are in fact not always the only solution for shading, for example sheep may be shaded by shrubs. The age of the animal is also to be taken into consideration: lambs are more affected by heat than rams.

Environmental considerations should not be neglected. For example woody plants may become nesting grounds for grain eating birds which could attack neighbour cereals.

Opportunity costs are also important for example what is the impact of woody plants if introduced close to crop lands.

Resources in man-power: Zero grazing requires a lot of man-power to cut and transport fodder, pruning branches is less demanding and free grazing/browsing requires no man power at all.

Flexibility of the pastoral management e.g. are other fodder resources available during the period of planting and do young woody plants require protection?

For arid zone tree species as far as possible, should have some or all of the following characteristics.

- It should be drought hardy and fast growing
- It should be compatible with local flora and be able to grow under different agro-climatic regions of soils (saline, alkaline, rocky refractory sites).
- There should be profuse coppicing to save an additional expenditure on replanting of the area after felling.
- The tree species should have easy establishment
- It should produce good quantity of viable seed for further propagation, and

- It should require very little after care.

Introduction of Exotic : Plant introduction from isoclimatic regions of the world is an important part of any afforestation and/or tree improvement programme. At CAZRI, 115 species of *Eucalyptus*, 65 species of *Acacia* and 82 miscellaneous species of 44 genera from Australia, Israel, U.S.A., U.S.S.R., South Rhodesia, Chile, Peru, Sudan, Kenya, Arizona, Venezuela, Mexico etc. have been introduced.

Out of 65 *Acacia* species introduced from Australia, Israel, Rhodesia, Kenya and Sudan the most promising ones identified are *Acacia tortilis, A. raddiana, A. senegal, A. planiform, A. ciliata, A. aneura, A. tortilis, A. leucophloea, A. salicina, A. nilotica* and *A. catechu*. Among these *A. tortilis* has been adjudged the best for arid zone which has established its superiority over others in various habitats, viz., deep sandy soils, sand dunes, rocky refractory sites, sandy loam shallow soils overlying hard calcareous pan beneath.

Exotic v/s Indigenous Species : Choice of species rests between tree vegetation from natural vegetation native to the area or introducing species from other isoclimatic zones. Introduction of exotic species at times seems attractive as it is possible to achieve gains in a short time and genetic improvement of local species is more time consuming. So foresters tend to opt exotics rather than exploiting the local tree species. The experiences with some of the introduced tree species show that the initial gains are at times forfeited by the subsequent problems created by them. "Good" plants may become "bad" or vice versa. *Prosopis juliflora*, which is bad in Texas is appreciated to colonize eroded lands in Mauritiana, where it provides a valuable fodder where no forage was available; around some villages of Niger and Upper Volta, where it has introduced as a source of fodder, it became a pest creating impenetrable bush, when not cut earlier for fuelwood. In India also, it is proving to be useful in some parts of India (Rajasthan and other wastelands) and as a weed in other parts (parts of Gujarat etc.). *Lantana camara*, well relished by goats, but largely dispersed by birds has become an invader of thousands of hectares of excellent grasslands of Kenya greatly reducing their carrying capacity. Thus it is important that pros and cons of introducing exotics should be thoroughly weighed and wherever possible, priority should be given as far as possible to the indigenous tree species. Work at CAZRI has shown that there is large genetic variability and if exploited properly by simple breeding tools it can give high returns.

-large variation for fruit yield per tree, DBH, tree height etc. in *Azadirachta indica* (Jindal and Satyavir, 1994); for tree height, clear bole length etc. in *Tecomella undulata* (Jindal *et al.* 1987)

- Heritability of most of the traits is high and good results can be obtained by simple selection in *Prosopis cineraria* (Solanki *et al.* 1984).

Now what should be done? Whether to grow indigenous or exotic tree species. Always use the plant which in a given environment, best fulfils the needs of the people as they have identified them. Of course the conservation of the genetic resources is must, but it is rarely the main argument used by the pro-indigenous,when exotic are the best.-They should be used. 100% of the production of soya in the U.S.A. are provided by six varieties of Asian origin, more than

50% of wheat in Canada comes from Kenyan germplasm, all fodder sorghum cultivated in S France derivates from germplasm collected in the Sudan and in W. and N. Africa (Baumer, 1988). So the choice of species should be based on clear goal in mind and a tough screening of both indigenous and exotic species should be made before arriving at final conclusions i.e. before selection of the species. It should be tested thoroughly for its adaptability, utility for fuel, fodder, fibre and quality and suitability to the soil and climate of the various locations. Soil preferences, water requirements, uses etc. of most of the species are known particularly for their habitats.

A review of the woody species in agroforestry for fodder was made by Torres (1983). But a lot of incertitudes remain which would justify urgent research, as pointed out by IUFRO (Carlson and Shea, 1987). *Prosopis* spp illustrate it.

Prosopis sp. plants are drought resistant, N-fixing and acceptable. In the Pacific coast of Latin America, fruit of *P. chilensis* was used as food and fodder before arrival of the Europeans, the species is still cultivated there on poor soils with a rainfall as low as 250 mm/year. According to Bene *et al* 1977, one hectare may produce upto 4 t of pods/year, which contain 9% proteins, 47% non-nitrogenous extract, 6% fat and 25% cellulose. Their fodder value is close to barley. Flour which can be grinded is used to prepare a rich food which may be eaten raw and preserved for several weeks. As, in some areas where one quarter of the family returns is spent in buying fuel to cook only one warm meal a day, the quality of the food is obvious. The wood of P. species has a high calorific value and is hard enough to be used for poles, pegs, building, furniture. The root system is strong, so the production of leaves and pods may be used from the third or fourth year and in some cases after two and a half years. Nectar is much appreciated by honey bees.

But a difficult problem is the true identification of species and varieties. As far as the Sahelian and Sudano-Sahelian regions are concerned, the best adapted species are not yet known for certain (Poulsen, 1979). According to Burkart (1976), *Prosopis juliflora* (Swartz) D.C. is a distinct species from *P. chilensis* (Mol). Stuntz., but for others it is a synonym of *P. chilensis* var. glandulosa (Torr). Standl., the variety glandulosa of *P. juliflora* so common in Texas and in California is sometimes considered as a distinct species. This is to illustrate the complexity and the confusion in the taxonomy.

An adult khejri tree (*Prosopis cineraria* (L.), Macbride) may give upto 5 kg per year of air dried pods with a rainfall of 350-500 mm. From 10 to 30 years of age the tree will give 2- 3 kg per year (Mann and Saxena,1980). The species is rarely destroyed by the Indian farmer who is well aware of all its advantages: fodder, fuel, small timber, protection against wind, improvement of soil fertility. The farmers cultivate a lot of crops under the khejri : millet, sorghum, mustard, wheat, guar, moong (*Vigna radiata*), cowpea (*V. sinensis*).

On deep alluvial soils, the number of khejri per hectare varies from 20 to 40 giving a 4-10% cover. On very deep soils of the districts of Nagaur, Ganganagar, 40-120 trees per hectare are kept with a rainfall ranging from 150-350 mm and even upto 150 trees south of Sikar where rainfall is around 400 mm. In the western parts of Rajasthan where rainfall ranges from 80-180 mm (around Jaisalmer), only 10 trees per hectare are found in the natural rangelands.

For arid areas, preferred indigenous tree species are *P. cineraria, A. senegal, Ziziphus sp., Tecomella undulata, Salvadora oleoides* and *S. persica*. These tree species, however, are extremely slow in nature. For better rainfall areas of arid zone, are *Azadirachta indica* and *Albizia lebbeck.*

Herlocker *et al.* (1981) reported the results of planting trials carried out during 1976 and 1980 in several altitude zones. Twenty seven species, over half of which were exotic, were tried with considerable success in the sub-humid zone, but only limited success was achieved with a few drought tolerant species in the arid zone where an initial period of watering was possible. The most successful of the introduced, drought tolerant species were *Prosopis chilensis, Parkinsonia aculeata, Melia azedarach, Azadirachta indica* and *Cartrica papaya.* Among the indigenous species planted in arid conditions are *Acacia senegal, A. tortilis* and *Salvadora persica* had been the most successful although slow in their growth. An important characteristics of *Prosopis* and *Parkinsonia* is their relative unpalatability which enables them to survive in an environment where goats may prevent the growth of the most small woody plants. Tree species of industrial uses for silvi-pastoral systems are given in Table 1 and 2.

Table 1. Raings for various uses, annual rainfall required and ratings for drought resistance for various tree species suitable for silvipastoral systems

Tree species	Ratings for tree for various uses				Annual rainfall (mm)		Drought resistance	
	Fodder	Fuel	Timber	Growth rate	Minimum	Maximum	During Planting	Mature tree
1. *Acacia albida*	8	7	7	6	300	1800	8	10
2. *A. aneura*	3	5	3	4	200	500	9	10
3. *A. leucophloea*	6	5	5	4	450	1500	6	9
4. *A. nilotica*	7	10	8	6	350	2000	8	9
5. *A. salicina*	2	3	4	5	125	550	8	9
6. *A. senegal*	5	7	6	3	200	625	8	10
7. *A. tortilis*	5	7	8	7	100	1000	10	10
8. *Ailanthus excelsa*	6	3	3	9	400	850	7	8
9. *Albizia amara*	7	7	4	8	500	1150	7	8
10. *A. lebbeck*	4	6	5	7	300	2500	8	8
11. *Anogeissus pendula*	5	7	3	4	425	575	7	8
12. *Azadirachta indica*	6	5	6	6	750	1150	7	8

13	*Bauhinia variegata*	8	5	3	7	500	4500	6	6
14	*Butea monosperma*	4	6	5	5	500	4500	6	6
15	*Cassia siamea*	4	7	6	8	500	700	6	7
16	*Celtus australis*	5	3	3	6	250	800	5	6
17.	*Colophospermum mopane*	8	6	4	8	150	800	8	10
18	*Commiphora wightii*	7	6	2	3	500	850	7	10
19	*Dichrostach-ys cinerea*	6	4	3	6	200	700	8	10
20.	*Emblica officinalis*	4	4	3	5	400	2500	6	8
21.	*Ficus bengalensis*	6	4	4	7	500	4000	6	7
22.	*Grewia tenax*	8	5	4	6	200	1000	5	7
23.	*Hardwickia binata*	9	8	8	6	250	1500	7	8
24.	*Leucaena leucocephala*	10	8	7	10	350	200	5	6
25	*Melia azedarach*	5	7	5	8	350	2000	5	6
26.	*Parkinsonia aculeata*	1	5	3	8	200	1000	8	10
27.	*Prosopis cineraria*	10	8	8	3	75	800	8	10
28.	*P. juliflora*	5	9	8	9	150	750	10	10
29.	*Salvadora oleoides*	4	5	5	4	180	1000	8	10
30.	*S. persica*	3	4	4	5	130	900	8	10
31.	*Tecomella undulata*	3	5	10	6	150	500	8	10
32.	*Wrightia tinctoria*	5	4	3	5	400	1200	6	7
33.	*Ziziphus mauritiana*	6	8	7	6	125	2225	6	10

Source : Hocking, 1993

Ratings of trees for various uses: the higher the number (range 1 to 10), the better it is and higher the quality for that uses.

Drought resistant ranking by minimum rainfall: the higher the more droughts resistant is the species.
1. least drought hardy, 10 = most drought hardy 34.

Table 2. Industrial uses of tree species suitable for silvipastoral systems		
S. No.	Species	Industrial uses
1.	*A. albida*	Wood in older trees is of large dimensions and is of great value for household and farm implements and utensils. It is relatively soft and easy to work. Bark contains about 25% tannin and various parts of the tree are used for medicinal uses
2.	*A. aneura*	Wood is hard, heavy and durable. Seeds contain about 25% protein and used as a grain legume
3.	*A. leucophloea*	Wood is moderately heavy (721 kg/m3), strong hard and tough . It is coarse in texture and the grain is irregularly interlocked. It is used for making agricultural implements, carts, cart wheels, oil mills and for turnery. Good fire-wood, 4886 K. Cal/kg
4.	*A. nilotica*	Useful for timber, firewood, charcoal, tannin and gum. 15-20 year old plantation yields about 6 tonnes of air-dry bark which is one of the best tanning material of North India . The timber is very strong (830 kg/m3), very durable when well seasoned. It is favourite wood for agricultural implements, hammers, crushers, oil pressers, persian wheels, carving , turnery. It is excellent firewood and charcoal, calorific value of dry sapwood is 4800 K. Cal/kg, of heartwood 4950 K. cal/kg, of charcoal about 6800. Gum is used in the manufacture of matches, inks, paints and confectionery. Medicinal uses: bark as an astringent which cures cough, bronchitis and piles. Gum is said to cure leprosy, urinary discharge and biliouness, and is useful in diabetes. Extracts of pods, leaves, bark are used for dyeing cotton, silk and leather.
5.	*A. salicina*	The wood is hard and heavy, heartwood making a fine quality timber used for furniture .
6.	*A. senegal*	Gum: used for finishing silk and crepe, in inks, paints and polishes. Timber used for making cart and persian wheels, sugar cane crushers, agricultural implements
7.	*A. tortilis*	Good fuelwood, calorific value 4400 K. cal/kg. Wood is moderately heavy and strong and is used for fence posts, agricultural implements and small articles.
8.	*Ailanthus excelsa*	Timber of class suitable for match boxes, but not quite satisfactory for match industry.
9.	*Albizia amara*	used as firewood

10.	*A. lebbeck*	Wood is used as timber of panelling
11.	*Anogeissus pendula*	Excellent firewood, 5300 K.Cal/kg. Produces the best charcoal in the Aravalis. Gum is edible and medicinal.
12.	*Azadirachta indica*	Fruits yield oil used in the manufacture of soap; bark, leaves and fruit used in traditional Indian medicines and as an insecticides, Extracts of bark recently used in toothpastes etc.
13.	*Bauhinia variegata*	Used as firewood, several parts have medicinal values, flowers are laxative, bark is astringent and is used for treatment of diarrhoea.
14.	*Butea monosperma*	Leaves are used to make 'Dona' for serving eatables, Green pods are used as vegetables. Gum is used for medicinal use.
15.	*Cassia siamea*	Wood is used as fuel, charcoal is of excellent quality. Bark is occasionally used for tanning.
16.	*Celtus australis*	In Africa, the leaves and fruits are eaten in soups and salads.
17.	*Colophospermum mopane*	Wood is very hard, heavy and quite durable, poles are used in hut construction, fence posts. It is an excellent fuel.
18.	*Commiphora wightii*	Oleo-resin extracted is used for medicines, perfumery, preparing agarbattis, as incense etc.
19	*Dichrostachys cinerea*	Wood is used for fuel and makes high quality charcoal. Various parts are used in Africa for various medicinal purposes.
20.	*Emblica officinalis*	The bark, leaves and fruits are in native medicines. Mainly grown for fruits which are used for pickles, preserves or candies.
21.	*Ficus bengalensis*	Infusion of bark is tonic and is used in dysentery, diarrhoea and diabetes.
22.	*Grewia tenax*	Good fuel. Branches used for making walking sticks, decoction of the wood is used as a remedy against cough.
23.	*Hardwickia binata*	Timber is used for cart wheels, plough shares and making bearings . Excellent fuel and gives very good charcoal.
24.	*Leucaena leucocephala*	Wood can be used for fuel or making charcoal and for paper pulp, fibreboard etc. Seeds used for decorative purposes in craft work.
25.	*Melia azedarach*	Wood is extensively used for toys, boxes, sporting goods, house building, boat building, ploughs and furniture.
26.	*Parkinsonia aculeata*	Wood is used for making charcoal
27.	*Prosopis cineraria*	Pods used in various foods (such as curries), branches and main stem are used for fuel and to give a high quality charcoal. The plant is used in Indian medicine for rheumatism.
28.	*P. juliflora*	Bark exudes gum which is edible. The bark is used for tanning. Wood is used for fuel, fence posts and occasionally for conversion into charcoal. Flowers yield nectar and honey.
29.	*Salvadora oleoides*	Seeds contain about 40% oil and is used for soap making and varnish

30.	*S. persica*	Seeds contain 35-45% oil and excellent for making soaps and it makes a good substitute for coconut oil and is a potential industrial substitute. The wood is white, easy to work and takes a good polish.
31.	*Tecomella undulata*	Wood is hard and is used for making furniture and is as valuable as *Tectona grandis*. Due to the presence of lapachol, the wood is resistant to fungal and insect attack. The wood is excellent for firewood and charcoal, and it burns slowly with a fierce heat.
32	*Wrightia tinctoria*	Dye is extracted from the leaves, wood is used for making toys, match boxes, printing blocks. The tree yields cream coloured latex. The seeds yield deep red, semi-drying oil which has medicinal value.
33.	*Zizyphus mauritiana*	Good for firewood and charcoal,. Calorific value of the wood is 4878 K.Cal/kg. Wood is heavy, hard (650 kg/m^3),used for bed-legs, tent-pegs, house buildings, agricultural implements.

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SEED PRODUCTION IN GRASSES AND TREES

M.S. Yadav and Manjit Singh

Introduction

To counteract pressure of ever increasing livestock population on the available natural resources in the desert, especially vegetation pasture development and afforestation is necessary and for this ample quantity of good quality seed is required. Inadequate supply of good quality seed is one of the major constraints in pasture development programmes. It is more so important because the forage grass crops have been grown substantially for vegetative purpose and as such they are shy seeder with low productivity. Secondly they are not allowed to come to maturity and are either cut or grazed at vegetative stage.

At present very little arrangements exist in our country for the production and distribution of genetically pure good quality seeds in an organised manner. A major portion of demand of pasture seed is met from low quality spurious seeds. As per the estimates made by National Wasteland Development Project of Indian Grassland & Fodder Research Institute, Jhansi, a large gap exists between the requirements and availability of range grasses and legume seeds per year (Table 1).

Table 1.Requirement and availability of range grasses and legumes seed per year

Particulars	Requirements (t/yr)	Availability (t/yr)
Range grasses and legumes for tropics	3000	450
Range grass and legumes for temperate climate	2000	200

Seed Production in Grasses

Problems

- Very little efforts have been made to generate high yielding varieties of pasture grasses. In general, high fodder yielding varieties are poor in seed yield. Varieties with high forage production potential coupled with high seed yield are rarely available as a consequence of which production could not be an attractive enterprise.
- Maintenance of seed purity in individual plants is difficult because of its perennial and tussocky nature.
- Seed maturity is scattered due to unsynchronised tillering.
- Seed production is highly susceptible to adverse weather conditions, i.e., heavy rainfall, wind storm and drought.
- The seeds of most of the pasture grasses do not have any alternate sale value.

Seed Production Technology

Seed production is a highly specialized activity and can be profitable only by adopting the following points.

Suitable Locations

Dry climate is conducive for higher seed setting, whereas in humid tropics the rainfall is higher and wind storms are common, the seed does not ripe fully and there is loss of seed due to shedding, hence the selection of suitable location for individual crops is of prime importance.

Method of Planting

Seed rate and spacing: The individual plant should get enough space, sunlight and nutrition to produce healthy and bold seed in large quantities. Over crowding retards plant growth and development, resulting in poor seed yield. It is, therefore recommended that seed crop must be planted in spaced rows with a comparatively lower seed rate (Table 2), as compared to crop grown for forage production. The general practice of sowing of forage crops through broadcasting should be avoided as the sowing in rows facilitates inter cultures and rouging.

Weeding: Two weeding are essential for the proper growth of plants,and first done after fifteen days of sowing. At this stage annual weeds compete with the sown crop. Second weeding is followed at the initiation of flowering, *Cenchrus ciliaris/setigerus* grasses recorded 100 per cent increase in yield by weeding alone.

Removal of off types: In order to produce genetically pure seed it is necessary to remove plants not conforming to the characters of variety. In cross pollinated grasses, such plants should be removed before flowering. In self pollinated and apomictic, rouging should be done before the collection of seeds.

Seed collection: Most of the grasses flower in the month of July-August. There is continuous process of tillering. Tillers which emerge first will flower in the month of August but tillering process continues till August and such tillers come to flowering in Sept. Therefore, grass seeds start maturing in the month of September. and continue till October. Seed maturity is influenced by rains, if there is low rainfall (below 250 mm) seeds will mature in September, if there is normal rainfall (250-400 mm) with proper distribution, seed maturity is delayed by one month. Now it may be highlighted that flowering and seed maturity ranges from 20th August to 30th October.

Seed collection is done manually by hand picking of spikes (Fig. 1). The seed shedding is a major problem and even with a light jerk seeds will fall down. Mature seeds should be collected. The upper portion of the spike matures first and immediately it should be collected and lower

Table 2. The optimum seed rate and spacing of different pasture grasses

Species	Seed rate (kg/ha)	Spacing (cm)
Lasiurus sindicus	5.5	50 x 75
Cenchrus ciliaris	4.0	50 x 50
Cenchrus setigerus	4.5	50 x 50
Panicum antidotale	2.5	50 x 75
Dichanthium annulatum	2.0	50 x 50

portion should be collected at its maturity. Average seed yield of some important grasses is *Lasiurus sindicus* - 20 kg/ha, *Cenchrus ciliaris* - 60 kg/ha, *Cenchrus setigerus* - 100 kg/ha, *Panicum antidotale* - 70 kg/ha, and *Dichanthium annulatum* - 30 kg/ha.

Cleaning of seed: During the process of seed collection spike rachis and few leaves are mixed with the seed. After seed collection, rachis and leaves are separated manually. This inert matter decreases the quality and should not be permitted more than 2 per cent.

Drying and storage of seed: Seed is covered by the glumes and bristles which contain moisture. As soon as thee seed is collected it should be dried on threshing floor in open sun for three days. After drying seed should be filled up in gunny bags. For storage of seed, sufficient space is required because one gunny bag contains only 8 to 10 kg seed. Seed is stored at room temperature which should not exceed to 37 °C.

Effect of Fertilizers on Seed Production

Application of fertilizers to pasture grasses increases forage production and seed yield. Application of 20 kg N/ha to *Cenchrus ciliaris* pastures resulted in 83.1% increase in dry forage yield and 112.6% increase in seed yield. Faroda (1974) did not observe significant effect of P_2o_5 on the forage yield of *C. ciliaris.* But Puri *et al.*, 1977 and Raj (1990) reported increased yield of *D. annulatum, C. ciliaris* and *S. hamata* after application of 60 kg P_5/ha.

Qualitative Aspects of Pasture Grass Seed

The seed needs to be of proven and desired quality so as to maintain it during the course of its multiplication cycles. The seed quality traits comprise genetic purity, physical purity, seed moisture, seed germinability and health. The minimum standard of these traits are prescribed for different crops and categories of seeds. These standards need to be met before granting certification tag. These standards are field standards and laboratory standards. The field standards are met through field inspections by the monitoring team. In this inspection, it is ensured that the prescribed isolation distance is maintained as well as the field is free from off-types and weeds. The field inspection controls the genetic as well as physical purity. The samples as prescribed are drawn from lots and are sent to notified seed laboratories for analysing for seed moisture and germination per cent.

Categorisation of Seeds

In accordance with the position of the particular class of seed in the chain of seed multiplication, the degree of monitoring and precision observed for purity made in the cultivation as well as the seed standards it qualifies, the seeds are classed as Nucleus, Breeder, Foundation, Certified and Truthful labelled seeds.

Nucleus seed: This is the purest form of seed produced by the breeder with highest degree of precision. Single plant/earhead/pod which have the desired genetical build up, are grown in single progeny rows. The rows which are slightly different are rejected. The seeds of all the approved lines are bulked and used for production of breeder seed.

Breeder seed: Breeder seed is a seed or vegetative propagating material which is directly controlled by the originating or in certain cases, the sponsoring breeder or institution and which provide for the initial or recurring increase of foundation seed. Drawal of prescribed number of samples from each lot and growing with check rows of nucleus seed of the same variety is desired under "Grow-Out Test" to know the genetic purity of the produced seed.

Foundation seed: Foundation seed is seed stock so handled as to most nearly maintain specific genetic identify and purity and that may be designated or distributed by an agricultural experiment station. Foundation seed is multiplied from breeder seed. Minimum isolation distance for production of foundation seed in *C. ciliaris, L. sindicus, D. annulatum* and Napier grass is 20 metres.

Certified seed: It is the last category of seed which can not be used for further multiplication but used for forage production only. The seed is produced as per prescribed standards by the registered growers, State Departments, State Seed Corporation, Regional Stations, etc. Isolation distance in this case is 10 metres.

Seed Certification

Seed certification is a legally sanctioned system for quality control of seed multiplication and production which in this country consists of the following control measures;

An administrative check on the origin of propagating material for the purposes of determining varietal purity.

Field inspection: An evaluation of the growing crop for obtaining data on trueness to varietal purity, isolation of seed crop to prevent cross pollination, mechanical admixtures and disease dissemination; and crop conditions as regards diseases, objectionably weed and admixtures. Supervision of agricultural and commercial operations of harvesting, storage, transport and processing with a view to preserving the identity and quality of lots.

Sample inspection: An evaluation of planting quality by a laboratory test of representative sample drawn by the certification agency that aims at determining the percentage of germination, moisture content, weed-seed content, admixture and purity.

Bulk inspection: An evaluation of the lot for the purpose of checking homogeneity of the bulk as compared with the sample inspected.

Control plot testing: Samples drawn both from the source seed and the final seed produced can be grown in the field alongwith standard samples of the variety in question.

Pre-requisite for Certification

1. Only tagged seed of one category of seed should be used for multiplication. Certification tag is required at the time of monitoring. However, in the case of breeder seed production this requirement is not there. It may be produced from breeder seed stage. The cultivars needs to be notified.

2. The *field standards*: The required minimum isolation distance should be there. The seed crop must be free from off-types, diseased plants, objectionable weeds and inseparable crop plants. The minimum seed certification standards are given in Table 3.

Table 3. Specific crop standards for certification (certified seed)

Factors	Anjan grass
Pure seed*	80.0%
Inert matter +	20.0%
Other crop seeds +	0.5%
Total weeds seeds +	0.5%
Objectionable weed seed +	0.2%
Germination *	30.0%
Moisture +	10.0%

* - Minimum
+ - Maximum

3. Disease free crop.

4. Seed plot monitoring and inspection by authorised team for this registration is required. There are five crop stages of inspection.

   - Inspection at the time of sowing.
   - Inspection during pre-flowering/vegetative stage.
   - Inspection during flowering stages.
   - Inspection during post-flowering and pre-harvest stages.
   - Harvest time inspection.

5. Seed samples from lots as prescribed and its laboratory analysis for moisture content, germination, and physical purity.

6. Grading and processing.

7. Packing and placing tags.

Seed Production at CAZRI

Being a pioneer institution in grass seed research, CAZRI is actively engaged in breeder seed production programme. We are the only agency in India producing breeder seed of grasses. Regularly every year the seed production of Sewan grass (*Lasiurus sindicus*), Runyadar Dhaman (*Cenchrus ciliaris*), Moda Dhaman (*Cenchrus setigerus*), and Karad (*Dichanthium annulatum*) is being taken up in more than 50 hectare area at Regional Research Stations, Pali, Jaisalmer, Bikaner, Bhuj and C.R. Farm, Jodhpur. The institute has developed many new high yielding varieties of grasses, i.e., Marwar Anjan and CAZRI-358 of *Cenchrus ciliaris*, Marwar Dhaman, and CAZRI-296 of *Cenchrus setigerus* and CAZRI 30-5 and CAZRI 317 of *Lasiurus sindicus* for grazing lands of western Rajasthan. The average breeder seed production from 1986 to 1993 was 27 q/year.

Seed Production In Trees

The situation of demand and supply of quality seed of tree is not much different than that of grasses. The productivity of silvi-pastoral system can be increased significantly by correct choice of tree/shrubs species and by using genetically improved seed. Realising that the mistake of using poor quality seed cannot be rectified easily in case of trees and the investment made in genetic improvement will repay many times the initial cost, work was initiated at this Institute on genetic improvement of multipurpose tree species in 1983 and the programme covers species like *Prosopis cineraria, Tecomella undulata, Acacia senegal, A. nilotica* var. *cupressiformis, A. tortilis, A. tortilis* subsp. *raddiana* and *A. albida*.

Indigenous trees, many of which are important constituent of silvi-pastoral systems, are highly heterogeneous in quality and seeding ability. Seed production in trees is affected by age, genotype and environment. Variation in seed production was observed in *P. cineraria* and *A. tortilis*. In four-year old 35 trees of *A. tortilis*, the coefficient of variation for seed yield per tree was 116.9% (Jindal *et al.*, 1990). In *P. cineraria*, on average a 30 year old tree produces 2-3 kg seed under 350-400 mm annual precipitation. Our observations show that seed production was highly variable over years. This has led to many beliefs and natives predict rainfall in the subsequent months on the basis of amount of flowering and pod formation in *P. cineraria*. Sufficient variability in seed and seed related characteristics has been observed in all the species under study. In some trees pods or seed form the part of economic yield as well. For example pods of *P. cineraria*, fresh or preserved, are used as vegetable, seeds of *A. senegal* also form part of vegetable. The significance of pod and seed production in such tree species in a genetic improvement programme automatically gets enhanced. During surveys natural variability has been collected and preserved as germplasm accessions or progeny trials (Solanki *et al.*, 1992).

Prediction equations for seed production by a tree have been formulated in some cases. In *P. cineraria* studies show that pod production could be predicted from diameter at breast height (dbh) and seed can be predicted from pod weight. In *A. tortilis*, total seed weight could be predicted from total pod weight. The seed related traits were not significantly associated with morphological traits in this species and these traits could not be used as predictors. In *P. cineraria* in even aged stands, 100-seed weight is significantly associated with tree height, collar diameter and dbh, this association however gets masked in natural populations possibly due to variable age and location (Singh *et al.*, 1991). 100-seed weight also has positive association with progeny height in nursery. Thus selection for seed weight alongwith total seed production by a tree may lead to better germination and establishment in nursery. The other seed related traits like pod length, seed number, etc. were not significantly associated with morphological traits implying that independent or simultaneous selection can be made for these traits.

For production of genetically superior seed, it is necessary to bring together plus trees spread over large areas. The intermitting of such trees is likely to give better quality seed. For this, vegetative propagation techniques have been developed for *P. cineraria* (Solanki *et al.*,

Fig. 1 Manual seed collection of *Cenchrus ciliaris*

Fig. 2 A seed orchard of *Prosopis cineraria*

1984). A clonal seed orchard of *P. cineraria* comprising of 200 plants raised through air layering has been established. Seed production in such trees is early and due to bushy nature of plant, the harvesting of seed is also easy.

To get information on genetic parameters related to seed production and other traits, progeny-provenance trials have been established in all the species on which work has been undertaken. Seed orchards of *P. cineraria* (Fig. 2), *T. undulata* and *A. tortilis* have also been established. In most of the species, there were clear cut differences in morphological and seed related traits within and between progeny.

Knowledge of mating system, i.e., degree of outcrossing is necessary for production of genetically superior seed and can have an important bearing on the number of genotypes to be included in a seed orchard. Unfortunately baring some generalizations there is no information available on mating system of indigenous tree species. Efforts are being made to collect and document information relating to this. In *P. cineraria* flowering is asynchronous and takes place during March-May. Pod formation occurs during May-June. The average number of flowers/inflorescence is 76 and out of these only two per cent develop into pods. The surplus flowers appear to be a mean and attracting pollinators and a reserve which is so essential in such climates where extensive losses can occur due to abiotic and biotic factors (in some trees gall forming pests can lead to complete loss of pods). On an average in 12% of the inflorescences no pod formation was observed. Out of the rest, pod formation was mainly observed in distal and middle region of the stalk of inflorescence. Only 5% of the pods were found in basal region. Similar observations was also made in *A. senegal*. It is intriguing that why an arid zone species should opt for distal pods and spend extra resources on thickening and strengthening of support tissue and increased translocation. There was no difference in pods/inflorescence in upper and lower region of ten trees of *P. cineraria* studied. In the developing pods there were marked differences between trees for the number of ovules developing into normal seeds and it varied from 43%-86%. *P. cineraria* is a self compatible, non-apomictic species. Pod formation in selfing in bagged inflorescences, was, however, extremely low. In isolated trees in natural stands, pod production appeared normal, though pod size and seeds/pod was less. It appears that pollinators are essential for normal production of pods. Pollination appears to be mainly by honey bees. Similarly studies in *T. undulata* showed that flowering is asynchronous, only 0.93% of open pollinated flowers develop into pods, it is self compatible, non-apomictic (Jindal *et al.* 1985) and is pollinated mainly by birds (purple sun bird-*Nectarinia asiatica*.).

It is evident that we need to have broad genetic base in seed orchards for production of genetically superior seed. At the same time it is important to have information on the pollinators which may also be getting affected by over exploitation of vegetal resources. In seed orchards, besides superior genotypes, it will be necessary to go for various cultural and management operations for better growth and health of plants.

Seed certification of tree has not get the desired attention even though it has been realised that its importance is more in case of trees than annuals as due to long life span of trees the mistake of using poor quality seed cannot be rectified soon. Instead of random seed collection, emphasis is now being given to collect seed from plus trees, or established plantation or seed orchards. Seed collection in trees requires some innovative approaches as many times tree density is low, seed is on higher branches, seed is available when climate condition are adverse e.g. *P. cineraria* or seed is papery (e.g. *T. undulata*). For convenience the seed collection is used even though almost invariably it is the fruit which is harvested from the trees. There are a great variety of methods and equipments available for collection of seeds/fruits and the choice depend on a number of factors; relative size and numbers of natural disposal units and characteristics of fruit, tree, slad, site, etc. The fallen seeds/fruits are obtained by hand picking, screening the soil below the mother tree, spreading sheet below tree or by using vacuum seed harvester, etc. When seed from individual trees is required than approaches like shaking the tree using a pale or rope can used. Whenever practically possible, direct hand plucking from trees in the high way of obtaining genetically pure seed.

Seed production can be enhanced by supplemental mass pollination, using growth hormones, checking gall forming insects and other resident pests. Pressure on demand for good quality seed can also be reduced by better post harvest care and improved nursery technique. It is important to ensure that seeds are collected and cured at an early/appropriate stage. Seed storage after chemical treatment may reduce the damage due to insects. In nursery system techniques like scarification may significantly improve the germination rates. For direct seeding/aerial seeding, pelleting may also prove to be of utility as it is possible to fungicides, insecticides, organic fertilizers, etc.

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ALTERNATE LAND USE SYSTEMS FOR SUSTAINABLE DEVELOPMENT

R. P. Singh

Introduction

Indian agriculture is beset with varied and complex problems. Growing population pressure and dwindling renewable natural resources are the issues of serious concern for sustainable development. Degradation of the environment is a serious problem world-wide and poses a threat to sustainable development.

In the Indian context, land degradation low productivity per unit area, unassured income of dryland farmers, are the major problems that loom large. Deforestation and overgrazing with consequent soil erosion, drought, flooding, silting of reservoirs, loss of biodiversity, loss of soil fertility and structural integrity of soil, and a reduction in shelter from the sun and wind for people and their livestock stand in the way of sustainable development. An assessment and appreciation of the problem can be gauged from the following facts :

- The average plantation: deforestation ratio of 76 countries, including India, is 1-10.
- In India, the per capita cropped land and forest land availability is less than 0.2 ha and 0.1 ha, respectively.
- About 70 per cent of the cultivated area in India is rainfed. Eighty five per cent of total cultivated rainfed area in India is degraded.
- Only 6 m ha out of 67 m ha under forest are real forests, as assessed by National Remote Sensing Agency.
- About 94.0 m ha of non-forest area in the country has been identified as wasteland of which 64 per cent is drought prone.
- According to National Remote Sensing Agency, cultivable wastelands occupy 32.8 m ha, which could be brought under tree or grass cover through improved technology.

The above facts call for planting more trees and putting larger areas under grass cover. Above all, there is need for alternate land use systems matching diverse environments which can with stand the vagaries of climate whilst at the same time providing rural people with the basis of income, food, fuel and shelter in the long run.

In countries like India, where land is scarce and labour is in plenty but less productive, coupled with scarce capital and high interest rates, alternate land use systems are an ideal option (Singh and Osman 1995). There is predominance of marginal and small farmers representing 75 per cent of the total holdings of less than 2.0 ha. Small and fragmented land holdings have some inherent constraints to increased productivity, the principal being lack of resources and impoverished soils. Alternate land use systems are more appropriate in areas where subsistence farming in practised in fragile ecosystems. In additions, alternate land use systems help in efficient utilization of resources like land and labour.

Alternate land use systems (ALUS) can be defined as a perennial systems/practice adopted to replace or modify the traditional land use. They aim at matching the land capability class, generating more assured income with minimum risk through efficient utilization of available resources. These systems posses more potentiality and flexibility in land use than the traditional crop production systems.

Sustainable Land Use

Sustainable land use is that which achieves production combined with conservation of the resources on which that production depends, thereby permitting the maintenance of productivity (Young, 1989). Simply stated:

Sustainability = Productivity + conservation of resources.

Soil is an important resource. For sustainability, not only soil has to be conserved, but the whole range of resources on which production depends, will have to be conserved. In essence, the primary requirement for sustainability is to maintain soil fertility.

The objective of sustainable land use is the continuation of production over a long period. This essentially calls for forms of land use that will not only allow maintenance but sustain production at higher levels than at present (Young, 1989).

Why Alternate Land Use Systems?

It is recognized that not all lands are suitable for crop production. Class I lands which have the least or no constraints to crop production offer the best in terms of productivity, profitability, and sustainability of crop production. Such lands are, however, very limited. Class II and class III lands require input and management skills of crop production which are beyond the capacity of a resource-poor farmers. Further, crop production in rainfed and dry areas, irrespective of class of lands, is more often fraught with the risk of either crop failure or low productivity and income. classes V and above (class VI, VII and VIII) are not suitable for crop production.

Crop production is a seasonal activity. Further, it meets only a part of the multiple need of the farmers, i.e. food, fibre, edible oil and to some extent fodder, but it does not meet his requirements of timber, fuel, and shelter.

More assured income, efficient utilization of resources like land, labour, water capital, and time, coupled with meeting the multiple farm and family need. of farmers, are best met through alternate land use systems.

Different Versions of ALUS

Any farm enterprise other than crop production is usually referred to as alternate land use system. Fodder production for raising livestock is a part of crop production system and therefore it does not come under the ambit of alternate land use system.

Tree farming wood lots, pasture and grassland systems, leyfarming, and agroforestry systems are different versions of alternate land use systems, Strictly speaking, making use of laterite/lateritic soils for brick making is an alternate land use, but since it is not an agricultural system, so is the case with land use for recreation and amenity, and the conservation of wild life.

Among the alternate land use systems, agroforestry is one. which is most common and appropriate for most of the situations because it is a multiple land use system which has potentials for a sustainable development. Agroforestry offers a sustainable balance of productivity between wood and feed, besides an increase in total productivity per unit area of land.

Agroforestry – *The Principal Alternate Land use*

As an alternate land use system, we will consider Agroforestry in more details than other systems, for the obvious reasons explained above. The concepts of Agroforestry are very well elucidated by Nair (1991), and the same are subjoined:

Agroforestry

- Is a collective name for land-use systems involving trees combined with crops and/or animal on the same unit of land;
- Combines production of multiple outputs with protection of the resource base;
- Places emphasis on the use of indigenous, multipurpose trees and shrubs;
- Is particularly suitable for low in-put condition and fragile environments;
- Involves the interplay of socio-cultural values more than in most other land-use systems;
- Is structurally and functionally more complex than monoculture.

There are three basic types of agroforestry systems:

1. Agrisilviculture (crops and trees)
2. Silvopastoral (pasture/animals+trees)
3. Agrisilvipastoral (crop + pasture/animals+tree)

Within an agroforestry systems, there can be more than one agroforestry practice. These are listed below:

1. Agrisilvicultural systems (crops-including shrub/vine/tree crops-and trees)

   i) Improved fallow, ii) Taungya, iii) Alley cropping (hedge-row intercropping), iv) Multilayer tree gardens, v) Multipurpose trees on crop lands, vi) Plantation crop combinations, vii) Homegardens, viii) Trees in soil conservation and reclamation, ix) Shelterbelts and windbreaks, and x) Fuelwood production.

2. Silvopastoral systems(trees+pasture and/or animals)

   i) Trees on rangeland or pastures , ii) Protein banks, and iii) Plantation crops with pastures and animals.

3. Agrisilvipastoral systems(trees+crops+pasture/animals)

i) Homegardens involving animals, ii) Multipurpose woody hedgerows, iii) Apiculture with trees, iv) Aquaforestry, and v) Multipurpose wood lots.

An agroforestry practice is a distinctive arrangement of components in space and time. Earlier, Young (1989) gave the following classification of agroforestry practices.

Agroforestry Practices

Mainly Agrisilvicultural (trees with crops)

Rotational

- Shifting cultivation
- Improved tree fallow
- Taungya

Spatial mixed

- Trees an cropland
- Plantation crop combinations
- Multistorey tree gardens

Spatial zoned

- Hedge row intercropping (alley cropping), also agrisilvipastoral
- Boundary planting
- Trees on erosion control structures
- Windbreaks and shelterbelts
- Biomass transfer

Mainly or Partially Silvopastoral (Trees with Pastures and Livestock)

Spatial mixed

- Trees on rangelands or pastures
- Plantation crops with pastures

Spatial zoned

- Live fences
- Fodder banks

Tree component predominant

- Woodlots with multipurpose management
- Reclamation forestry leading to multiple use

Other components present

- Entomoforestry (trees with insects)
- Aquaforestry (trees with fisheries)

Advantages and Implications of Agroforestry

Jarvis (1991) puts the advantages and implications of agroforestry as follows:

1. The value of trees on farms may considerably exceed than offered by woodlots and plantations.
2. Trees serve as windbreaks and shelterbelts, delineate boundaries and provide shade, ornamentation and seclusion around homesteads.
3. They supply not only poles, stakes, timber and fuel, but also, depending on the country, cash crops, fodder, fruits and nuts, dyes, gums, resins, fibres and medicines.
4. Fodder and food trees can help provide balanced diets during dry seasons when other foods are scarce.
5. Trees, with their deep rooting systems, exploit moisture and nutrients from greater depth in the soil than do arable and pastoral crops, and so make better use of available resources. Furthermore, these deep roots reduce the leaching of nutrients from soil following heavy rains.

Considering the environmental costs of flooding and erosion, the economic merits of agroforestry outweigh all alternate land use systems.

Land Capability Classes cum Need-based Alternate Land Use Systems

There are eight well recognized land capability classes. Classes I, II, III, and IV lands are fit for all agricultural uses including crop production, grassland/pasture development, forestry, etc. as per the capability and need. Class II to IV lands have progressively increasing hazards for cultivation Classes V, VI, VII and VIII lands are not suitable for agriculture. Land use according to its capability is set out in Table 1.

Considering two broad classes of land, i.e. arable and non- arable, the following alternate land use systems are suggested:

A. For arable lands

- Alley cropping
- Agri-horticulture
- Intercropping with NFT's (Agrisilvicultural)

Table 1. Appropriate alternate landuse systems for different classes of land

Land use capability classes	Suitable system/practice
I	Crop production, intensive cultivation
II and III	Moderately intensive cultivation, alley-cropping Agrisilviculture (agri-horticulture)
IV	Ley farming, restricted cultivation
V and VI	Silvopastoral system (horti-pastoral)
VII	Low-density, long-rotation plantation
VIII	Recreation, wild life, watershed protection

B. For non-arable lands

- Silvopastoral system/Horti-pastoral
- Pasture management
- Ley farming
- Tree farming

A brief discussion of each of the above systems follows:

Alley Cropping

Alley cropping: Alley cropping is an agroforestry practice which emerged as an alternative to shifting cultivation in humid tropics. It is a system in which food crops are grown in alleys formed by hedgerows of trees or shrubs. The primary purpose of alley cropping is to maintain or increase crop yields by improvement of soil fertility (through legume tree component and mulching) and micro-climate. Hedge rows on contours also serve as vegetative barriers.

Four aspects of hedgerow management, viz; choice of crops, alley width, cutting height, and frequency/interval of cutting have been researched by CRIDA, Hyderabad, in greater details. The experiences with regard to each of these are presented below.

a) Based on three years experimental results (1984 to 1986), it was seen that yield reduction was higher (61 to 62%) in pigeonpea and castor than sorghum (48%) and pearl millet (30%).

b) Alley widths between 3 to 4 meters are severely competitive with crops, more so in a drought year. Irrespective of the crop, the decline in yield was more in case of narrow (3.6 m) row widths than in wider (7.8 m) row widths, the per cent reduction being more in case of castor and pigeonpea.

c) Hedge row heights of 100 and 150 cm are severely competitive with crops, in regard to light and moisture. Shading at anthesis/grain formation affects the productivity of crops in alleys adversely. Hedgerow cutting height of 15 cm was found advantageous, resulting in an yield advantage of 14% in case of pearl millet.

d) Intervals of 40 to 50 days and cutting heights of 75 and 150 cm yielded as much as 50 per cent more foliage than a 15 cm cutting height.

Management of the crop grown in the alleys has not received due attention and so is the case with microclimate and tree-crop interaction studies.

Tree-crop Interactions in Agroforestry Systems with Particular reference to Alley Cropping : *Micro-climatic interactions in agroforestry systems*: When two species are grown in mixed stands, competition for limited resources is inevitable. Intercropping is a conspicuous feature of low-input agriculture in the tropics which are characterized by abundant sunlight, strongly seasonal but unreliable rainfall within seasons, and usually deficient nutrients (Monteith, 1991). There is a close resemblance between intercropping and agroforestry systems where annual crop species are grown in close association with trees (preferably nitrogen-fixing legumes).

In alley cropping systems based on *Leucaena leucocephala* which proved successful in the humid tropics of Nigeria failed in the semi-arid tropics of India (Hyderabad) because the tree component offered severe competition for water (Singh *et al.*, 1986). At ICRISAT centre, interaction of agroforestry components with atmosphere were studied with respect to 1) interception of radiant energy, 2) the interception of rainfall, 3) saturation vapour pressure deficit (VPD), and 4) temperature, in a system where pearl millet was grown between hedges of *Leucaena leucocephala*. The main advantage of the alley system lay in intercepting more light throughout the year and therefore producing more biomass. Temperature and humidity within the alleys differed little from values in the open but wind speed was substantially less. (Monteith *et al.*, 1991). The main disadvantage of the system in terms of pearl millet production was therefore competition below ground rather than above. In Table 2 are set out the values of intercepted (total) solar radiation, above-ground biomass and intercepted radiation per unit biomass, as affected by seasons and sole/intercrops of millet and *Leucaena leucocephala*.

Table 2. Values of intercepted (total) solar radiation, above-ground biomass and intercepted radiation per unit biomass

	Intercepted radiation	Biomass ($t\ ha^{-1}$)	$(gMJ^{-1})^{e}$
Rainy season (July-Aug. 1986)			
Sole millet	581	4.7	0.81
Alley millet	300	3.1	1.03
Sole *L. leucocephala*	520	4.0	0.77
Alley *L. leucocephala*	510	4.0	0.77
Total alley system	810	7.1	0.88
Dry season (Sept. 1986-June 1987)			
Sole *L. leucocephala*	1270	1.5	0.12
Alley *L. leucocephala*	1160	1.7	0.15
Year (July 1986-June 1987)			
Total alley system	1970	8.8	0.45

Source. Monteith, Ong, and Corlett (1991).

It is seen that for the rainy season as also for the whole year, the agroforestry systems is clearly more productive than either species grown alone.

Studies have shown that rainfall interception ranged from about 10% at the smallest population of 400 trees/ha to over 40% at 10,000 trees/ha. *Leucaena* in the alley crop would be expected to intercept about 20% of incident rainfall. (Monteith *et al.*, 1991). Regarding temperature, it was noted that initially, the foliage of millet within alleys was about 1°C warmer than in a sole stand of millet (less wind) but by the end of the season it was 0.5 to 1°C cooler (less radiation). Larger deferences were observed in soil temperature. The soil temperature in the alleys was about 1°C warmer, to begin with, but at the end of the millet season, this figure dropped to -2 to -4°C, the lowest figures were recorded close to the hedge where shading was heaviest.

There are several important lessons that can be learnt from the experience with alley cropping in the ICRISAT. The advantages in terms of microclimatic interactions (interception of radiation, wind speed, VPD, and temperature), are relatively unimportant compared with the adverse effects of interception of rainfall and below ground interactions (Ong *et al.*, 1991). Reduction in soil erosion under a tree canopy or leaf mulch are of minor importance compared to the competition for water between well established roots of trees, and crops (Singh, 1989). One redeeming feature, however, is that the principles of complementarity in resource utilization hold good for both intercropping and agroforestry systems and these should form the guidelines for the development of new agroforestry systems.

Above and Below Ground Interaction in Agroforestry systems : The beneficial effects of ecological interactions between trees and crops are well documented. These are:

- Leguminous trees have a beneficial effect on soil fertility through nitrogen fixation, greater organic matter production, and recycling of nutrients. (Young, 1986).
- A combination of annual crops and trees raised biomass production because differences in rooting depth enable uptake of more water and nutrients (Huxley, 1983).
- The presence of trees acts as a protective barrier against soil erosion or as windbreak (Wiersum, 1984).

In much of the semi-arid and arid tropics, almost all crop residues, and organic matter are consumed by livestock (Sandford,1989), and tree pruning are too valuable as fodder to be used as mulch (Singh *et al.*, 1986). There appears to be little prospect of appreciable advantages from tree/crops interaction via soil fertility or environmental benefit should be obtained from a greater utilization of physical resource (Ong *et al.*, 1991)

The basic concepts of intercropping and agroforestry are about the same. In intercropping, the most common mechanism for higher productivity is the temporal sharing of physical resources (i.e., using species of different durations so that they demand resources at different times during the season (Willey *et al.*,1987). According to this concept, the combined *L. leucocephala* and sorghum represent an ideal 'temporal' system. At this stage, it is necessary to point out the major difference between intercropping and agroforestry. In intercropping, both species are sown together at the onset of the rainy season and as such competition for resources builds up gradually, while in case of agroforestry the tree component (e.g., *L. leucocephala*) develops a well established root system and a rapidly developing canopy by the second year. In such a situation, the adverse effects of competition greatly outweighs the benefit from temporal differences in development and growth.

In agroforestry, there is 'spatial' sharing of below, ground resources (water and nutrients), since the system represents a combination of a deep rooting species and a shallow rooting species. Other potential benefits of below-ground interactions could be-nitrogen transfer from nitrogen fixing trees and improvement of soil physical characteristics. Adverse effects of below-ground interactions may result from competition for water, allelopathy or pest build up (Ong *et al.*, 1991)

A modified version of the the root barrier technique was used to separate the below-ground interaction in alley cropping in semi-arid India (Hyderabad), where the total dry matter of crops in the alleys was severely reduced by the presence of *L. leucocephala*. Before the rainy season, a shallow root barrier was installed to a depth of 0.5 m on both sides of *L. leucocephala* hedges which restricted the lateral roots in the horizontal horizons while allowing them to explore the soil fertility below 0.5 m. The four treatments consisted of sole millet (SM), sole L. leucocephala (SL), millet/*L. leucocephala* alley cropping (LM) and LM with root barrier (LMB). In the LM treatment, the reduction in total dry matter by the production of millet was larger adjacent to the 2 - year old *L. leucocephala* hedges and overall reduction was 40% of SM. A similar approach to separate the below-ground interaction was reported by Singh et al., 1989 who used a wider alley width (10m) and taller hedge sown (3-4m). In their study, the *L. leucocephala* was four years old and the adverse effects of competition had extended beyond 3 m in the alley. In the experiment, three important dryland crops (sorghum, cowpea, and castor) were grown in the alleys. Durations to maturity were 70 days for cowpea, 90 days for sorghum and 150 days for castor. Competition from *L. leucocephala* was greater where crop duration increased. The root barrier was installed to 0.5m as in the previous example. The root barrier almost completely removed the adverse effect on both cowpea and sorghum, but only partly in castor. The yield in the middle of the alley was unexpectedly enhance possibly because of the residual benefit of a hedgerow removed two years earlier. In addition to this observation, light, temperature, humidity and wind speed were measured by an automatic data logger. The results suggested that modification of microclimate is relatively unimportant compared to below-ground interactions, (Singh *et al.*, 1989).

In the humid tropics, substantial improvements in crops yield in agroforestry systems were reported where tree prunings were used as mulch or as green manure (Kang et al., 1985). In a study of the effects of pruning intensities in alley cropping with maize and cowpea on Alfisol in Nigeria, shading reduced maize yield from 4.4 t^{-1} ha to 0.76 t^{-1} ha (Duguma et al.,1988). In semi-arid India, it is also widely believed that shading by trees is responsible for poor yields of associated crops, although the evidence presented here clearly indicates that the real problem is competition for moisture. It should, however, be recognized that alley cropping is a very sound technology for improving the fertility of degraded low-activity clay soil in the tropics, and the key to its success lies in the use of prunings as green manure or mulch (Ong *et al.*, 1991).

Soil-Plant Interactions in Agroforestry Systems : Szott *et al.*, (1991) believe that there is need for greater consideration of basic soil/plant interactions and processes which affect sustainability and performance of agroforestry systems and how these processes vary with soil type.

Let us consider some of the constraints to plant production in humid, sub-humid and semi-arid tropics. In the humid tropics, the main constraints are chemical in nature: low exchangeable base contents, low nutrient reserves, high aluminum toxicity, low phosphorus availability, and mild acidity. Steep slopes and shallow soil depth are the chief physical constraints. In the subhumid and semi-arid tropics, moisture availability is the over-riding constraint to plant production, besides low nutrient reserves, aluminum toxicity and soil acidity Many semi-arid systems are nitrogen and phosphorus limited as well. In determining the sustainability of agroforestry systems, it is necessary to consider native soil fertility and the quantities of nutrients lost through periodic harvests. The potential of agroforestry systems to increase nutrient stocks on acid infertile soils is highly limited as against more fertile soils in which nutrient release from weatherable minerals is larger and roots are able to exploit larger soil volumes. Homegardens and silvopastoral systems - the two agroforestry systems considered more sustainable - are mainly found on base-rich Alfisols, Audisols and Entisols (Sanchez, 1987) and that in both the systems biological yield, and hence nutrient removals, tend to be low (Szott *et al.*, 1991).

It must be recognised that successful agroforestry systems are nearly always practised on inherently fertile soils. Most agroforestry alternatives to shifting cultivation are more exhaustive with regard to nutrients. In order to make the alternative systems biologically sustainable, it is necessary that nutrient inputs or recycling should be larger or nutrient losses must be substantially reduced.

On acid, infertile soils (Oxisols, Ultisols, Dystropepts, Psamments and Spodosols), the potentials for increasing nutrient inputs and reducing losses is limited by border. Here too, some constraints exist, principal of which are moisture stress through out the semi-arid tropics, high phosphorus fixation in Audepts, erosion hazard in some Entisols and Alfisols, and shrinking and swelling in Vertisols.

Much work needs to be done on processes regulating nutrient release from litter and soil organic matter (Szott *et al.*, 1991).

Agroforestry for Soil Conservation: Earlier approach to soil conservation was mainly concerned with control of soil erosion, and centred upon rates of soil loss. Conservation measures on arable land were directed at reducing runoff through earth structures. Greater attention is now given to the effects of erosion on soil properties, fertility and crop yields. Soil erosion causes substantial loss in crop yields and loss of production. The adverse effect is more conspicuous on highly weathered tropical soils. Major causes of such yield reduction are loss of organic matter and nutrients and in dry areas, loss of runoff and lowering of available water capacity. In this context, agroforestry practices which combine maintenance of soil fertility with control of soil loss are of particular interest. Aspects of agroforestry that deserve attention are .

- The potential of agroforestry for erosion control should be considered jointly with that of maintenance of soil fertility.
- Particular attention should be given to the capacity of tree litter to maintain soil cover.
- It is important to develop agroforestry systems with the potential for sustainable land

Agri-horticulture System

It is basically an agrisilviculture system in which fruit trees replace other woody tree species. In this system, short duration arable crops are raised in the interspaces of fruit trees. The system mainly focuses on higher returns per unit area. The system works best in medium to deep soils with good water holding capacity. Individual farm ponds and supplemental watering in the off-season will certainly improve the scope of fruit farming in drylands. Studies involving ber (*Ziziphus mauritiana*) and short duration legumes revealed higher returns than their respective sole crops. Horsegram and clusterbean gave an additional gross returns of Rs.3,000/- and Rs.1,900/- per ha, respectively. The gross returns from ber was Rs.7,320 ha, besides 1.2 tons of fuel wood obtained from pruning. There are quite a few fruit tree species which can be made use of in the system. These are jamun (*Syzigium cumini*) custard apple, guava, mango, sapota, aonla, etc. In order to make the system successful and paying it is necessary to :

- Carry out regular pruning so as to permit taking an intercrop.
- Follow a judicious fertility management programme
- Interplant short duration legumes and avoid cereals, as far as possible.

Agrisilviculture System (Intercropping with NFT's)

In semi-arid tropics, it is not possible to have a residual build up of organic matter and, therefore, it is important to replenish organic matter supplies every year. Nitrogen fixing tree species offer immense possibilities of supplementing the nitrogen requirement of crops grown in association, besides providing rich organic matter and atmospheric nitrogen, improving soil structure and preventing land degradation. Inclusion of top-feed N-fixing tree species in crop stands, help mitigate the fodder scarcity in years of drought. Most of the common N-fixing tree species are *Acacia, Albizia, Calliandra, Hardwickia, Dalbergia, Erythirina, Glyricidia, Inga, Leucaena, Parkinsonia, Pongamia, Prosopis, Sesbania,* etc.

In an experiment on intercropping of arable crops with N-fixing trees carried out at Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, it was revealed that there was a marginal increase in yield of sorghum and castor when grown in association with *Acacia albida, Acacia ferruginea* and *Prosopis cineraria,* whereas both the crops failed when intercropped with *Leucaena leucocephala*. Crop failure in *Leucaena leucocephala* points to importance of canopy management for successful undercropping.

A classical example of crops benefiting when grown under tree canopies is presented by Peter Poschen (1986) in Eastern Ethopia. Maize yield under the tree was 3.4 t/ha as against 1.9 t/ha in the 'open', the figures for sorghum being 2.13 and 1.57 t/ha, respectively, representing a 76 per cent increase for maize and 36 per cent increase for sorghum.

There are evidences that soils under the trees were richer in organic matter and nutrients than those in the surrounds without a tree cover. For *Acacia albida*, 50 to 100% increase in organic matter and nitrogen under the canopy are known, together with increased water holding capacity (Felker, 1978). Aggarwal (1980) working at Central Arid Zone Research Institute, Jodhpur, found higher available nutrients (N, P and K) under tree canopies of *Prosopis cineraria* and *Prosopis juliflora* than in adjacent open land (Table 3).

Table 3. Available nutrients beneath trees

Available nutrients (kg/ha)	Under *P. cineraria*	Under *P. juliflora*	Open field
N 0-15 cm	250	203	-
15-30cm	193	121	196
P 0-15 cm	22	10	8
15-30 cm	10	5	4
K 0-15 cm	633	409	370
15-30 cm	325	258	235

Horti/Silvo-pastoral System

Grasses and legumes associated with hardy fruit trees/top feed species is the panacea for non-arable and culturable wastelands. In horti-pastoral system, there is integration of fruit trees with pasture/grass. In a system where fruit trees are replaced by top-feed tree species, it becomes silvopastoral system. In a continuous grazing system, custard apple is an ideal choice as it is not browsed by livestock and it is drought hardy too. Fruit trees like bergo very well with pasture, as it provides good quality foliage during the lean period, April-May. *Aonla* is best suited for alkali and water-logged soils. In the choice of top-feed tree species, due consideration should be given to fast growing, highly palatable, multipurpose species having good coppicing ability.. In addition, the tree species should have the ability to withstand browsing, trampling and intensive lopping, besides being resistant/tolerant to drought and extremes of climatic conditions Suitable top-feed tree species and pasture grasses and legumes for different rainfall situations and soil types are provided in the book (pp. 388-389) entitled, 'Sustainable Development of Dryland Agriculture in India' (Ed. R.P. Singh, 1995). Of the many species of grasses and legumes tried, special mention need be made of *Cenchrus ciliaris* which was found promising for most of the situation, and *Stylosanthes hamata*, among legumes, which was found specially suitable for semi-arid tropics of India. The species stylos, is valued for its persistence, nutritive value and palatability.

Silvopastoral system: In a long term study carried out at CRIDA, Hyderabad, the performance of *Leucaena* + *Stylosanthes hamata* was found better (Stylo 4.2 t/ha/year DM) than *Leucaena* + *Cenchrus ciliaris* (*Cenchrus* 2.5 t/ha/year DM). The traditional sorghum crop in a similar soil (0-20 cm soil depth) seldom yielded a biomass of 2 t/ha/year. *Leucaena* trees were felled after eight years, 700 trees/ha, which yielded 35 t/ha of biomass.

In arid regions, silvopasture is the most important and common land use. *Prosopis cineraria* and *Ziziphus mauritiana* are grown both in association with crops as well as on field boundaries. Studies carried out at CAZRI, Jodhpur, have shown that better returns could be obtained from silvopastoral system of *A. tortilis* grown at 10 x 5 m spacing with *C. ciliaris* compared to growing pure trees or pure grass. *Hardwickia binata* and *Calophospermum mopane* proved promising when grown at wider spacing of 10 x 10 m.

Lot of work has been done on various aspects of silvopastoral system at IGFRI, Jhansi. It has been reported that *Cenchrus ciliaris* when grown in association with *A. tortilis* and *Leucaena leucocephala* could produce 3.5 t/ha/annum of dry forage without significantly affecting the growth of tree species. Wood production of the order of 7 to 8 t/ha/annum was obtained at a rotation of 13 years in the silvopastoral system. In a silvopastoral management system followed in the semi-arid Bundelkhand region, it was revealed that besides getting an average annual production of 3 to 5 t/ha of dry forage, an aerial biomass production of 66 and 52 kg could be obtained from *H. binata* and *A. amara*, respectively, each grown at 4x4 m spacing.

In and around Agra, representing a ravinous situation, both *Cenchrus ciliaris* and *Dichanthium annulatum* were grown successfully under the canopy of *Acacia nilotica* giving an average annual forage production of 2.5 t/ha. At Dehradun, in *Chrysopogan fulvus* and *Eucalyptus hybrid* silvopastoral system, grass gave an average yield of 3.4 to 3.9 t/ha/year, when grown at 5x5 m spacing. *Dalbergia sisoo* and *C. fulvus* system gave much higher production.

Pasture Management

Native pastures are highly degraded. Their improvement and management involves a set of technical and social interventions. The important technical interventions are: identification and introduction of suitable grass and legume species, using suitable establishment techniques, fertilization of the pasture lands, regulating the grazing pressure and using an optimum stocking rate, use of rotational grazing system if feasible, and increasing the grazing period through introduction of top-feed tree species.

Various options are now available for adoption, according to production objectives and agro-climatic situations. Some of these options are set out in Table 4.

Tree Farming

It is said that crop production is for the plains having good soil and assured rainfall, while trees are for hills, degraded soils and drylands, where greater risk of crop failure exists. Trees have a comparative advantage over crops, withstand as they do, the extremes of climate. More and more farmers are not resorting to tree farming because of lack of timely availability of labour. Studies carried out at Bijapur have shown that the strips of *Casuarina* and *Leucaena* collected several times less runoff, as compared to control (no trees), thereby conserving the meagre resources of marginal lands, other benefits of tree farming are through nitrogen fixation, leaf fall, turnover of fine root biomass and recycling of nutrients.

High density plantations (10,000 trees/ha) and short rotation intensive culture of 3 to 5 years, were found to be economically sound practice for deep soils of Nellore and Prakasam districts of Andhra Pradesh. In these districts, 50 per cent of rainfed area is occupied by *Casuarina* and *Leucaena* tree species.

Table 4. Farming systems options for different agro-climatic situations

Rainfall (mm)	Soil type	Farming systems	Suitable tree/grass legume species
Less than 500	Shallow (0-30 cm)	Tree farming	*Prosopis, Acacia aneura, A. nilotica, A. tortilis and Pithecelobium dulce*
	Medium (0-45) cm)	Pasture Mgmt.	*L.sindicus* (light textured soils), *C. setigerus, Sehima nervosum, Stylosanthes scabra, Clitorea ternatea*
500-700	Shallow	Silvopastoral system	*A. nilotica, Colophospermum mopane, Dalbergia sissoo, Hardwickia binata, Cassia sturtii, Albizia amara, Leucaena* sp., *Cenchrus ciliaris, Dicanthium annulatum, Macroptilium atropurpureum*
	Medium	Hortipastoral system	Custard apple, Ber, Jamum, Aonla,Tamarind, woodapple, Bael, *Cenchrus ciliaris, Panicum antidotale, Urochloa mosambicensis, Stylosanthes hamata, Macroptilium atropurpureum, Clitoria ternatea.*
More than 750	Shallow	Leyfarming or Silvopastoral system	3 years *Stylosanthes* and 4th year arable crop
	Medium	Leyfarming or Horti-system	*Ley-farming as in B-above. Mango, Guava, Sapota, Aonla Stylosanthes hamata/ Macroptilium atropurpureum*

Source : Singh and Osman, 1995.

In marginal and degraded soils, low-density and long rotation tree plantation system should be emphasized, with intensive care given in the first two years. Tree farming in open grazing lands should emphasize 'neem' (*Azadirachta indica*) and Australian babool (*Acacia auriculiforms*) which are damaged the least by livestock. Tree spaces considered suitable for areas having different annual rainfall are listed in Table 5.

Ley Farming

Studies on ley farming were carried out with Stylosanthes hamata as the legume pasture ley and was rotated with the two principal dryland crops, viz; sorghum and castor, of the region. Soil fertility and grain yield as influenced by ley farming are presented in Table 6.

The three years ley with stylo resulted in a nitrogen build up of 35 kg/ha over normal rotation. The two years of ley resulted in a nitrogen build up of 20 to 30 kg/ha, whereas one-year ley did not contribute to any appreciable soil nitrogen bulled up. The yield advantage of three years ley was perceptible in as much as it gave an additional grain yield of about 2 t/ha over the control (no Stylo).

Table 5. Tree species considered suitable for different rainfall situations

< 500 mm	500-700 mm	> 750 mm
Acacia nilotica	*A. nilotica*	*A. nilotica*
Acacia aneura	*A. ferruginia*	*Albizia amara*
Acacia tortilis	*Albizia amara*	*Azadirachta indica*
Acacia albida	*Azadirachta indica*	*Casuarina equisetifolia*
Colophospermum mopane	*Casuarina equisetifolia*	*Dalbergia sissoo*
Prosopis cineraria	*Cassia sturtii*	*D. latifolia*
Prosopis juliflora	*Dalbergia sissoo*	*Gmelina arborea*
Pithecellobium dulce	*Dalbergia latifolia*	*Grewia optiva*
	Leucaena latifolia	*Grevillea robusta*
	Leucaena leucocephala	*Hardwickia binata*
	Tamarindus indica	*Melia azedarach*
	Terminalia sp.	*Populus* sp.
		Sesbania sp.

Source: Singh and Osman, (1995)

Agroforestry: Its Development as a Sustainable and Productive Land Use System

Erskine (1991), while reviewing the prospects of agroforestry as sustainable, productive landuse system for low- resource farmers in Southern Africa, has suggested a number of resource situations which hold promise for potential adoption of agroforestry technologies. ''Of particular interest is agroforestry's potential to increase output per unit on agricultural lands not being optimally utilized at present; in rehabilitating many of the area's marginal land area degraded by overcutting of trees and shrubs or inappropriate agricultural practices; and in easy pressures between agricultural lands and forest lands''. The above resource situations hold good for India as well.

If the potential contribution of agroforestry to sustainable development is to be realized, the following constraints and policy issues must be carefully examined. These include:

- Inappropriate government policies or legislation that constrain tree growing and harvesting by farmers, particularly insecure land tenure and the inadequate development of agricultural and afforestation rural development policies.
- The lack of incentives for tree planting, such as inadequate access to seedlings, low confidence in or lack of awareness of appropriate land use systems, and inadequate access to markets.

Table 6. Soil fertility and grain yield as affected by ley farming

Rotation	Average N (kg/ha) Before	Average N (kg/ha) After	Grain yield of sorghum (kg/ha)
Castor-sorghum-castor-sorghum	109.76	81.54	1802
Castor-sorghum-stylo-sorghum	112.89	97.21	2549
Castor-stylo-stylo-sorghum	125.40	98.28	2899
Stylo-stylo-stylo-sorghum	144.75	106.13	3912

Source: Korwar (1984).

- Weak, poorly trained, understaffed and underfunded extension services.
- Inadequate communication and co-ordination among agricultural, forestry and livestock personnel.
- The absence of site-specific research needed to adapt agroforestry principles to the wide range of social and ecological conditions encountered in developing areas.

These constraints and policy issues aptly hold good for India. The government departments involved in rural extension work have to be persuaded and sensitized that planting of trees on farms is a farming system and a social issue rather than a forestry issue. Erskine (1991) suggests that the most effective way of achieving this objective is for forestry specialists to be fully integrated into the agricultural extension service.

Economics of Alternate Land Use Systems

A detailed comparative economics of various alternate land use systems tried at the CRIDA, Hyderabad, is set out in Table 7. The choice among them lies with the farmer's production objectives in relation to land capability class, rainfall and market considerations.

Alley cropping and agri-horticulture systems are an ideal option for better sites having least constraints to production. Hortipastoral and Silvopastoral systems are best suited for marginal and non-arable lands. Silvopastoral system will be highly paying if it is integrated with

Table 7. Comparative economics of different alternate land use systems

	Farming system	Average cost (Rs./ha)				Average returns/yr (Rs./ha)				value cost ratio	Annuity at 12% (Rs./ha
		1	2	3	4	1	2	3	4		
1.	Alley cropping										
	Fodder system	2000	1800	1800	1800	6000	6425	6425	6425	3.39	4441
	Mulch system	2000	1800	1800	1800	6000	6350	6350	6350	3.36	4388
2.	Agro-horticulture system Ber-clusterbean/horsegram	5811	1600	2500	2500	2500	2500	3500	12000	2.69	5146
3	Horti-pastoral System Custardapple/Guava-Stylo	5240	1739	1739	750	-	875	875	5000	2.28*	2475**
4.	Silvopastoral system *Leucaena-Stylo*	2500	750	750	2500 8th year	-	875	875	14000	1.50**	582**
5.	Ley-farming Stylo-sorghum (4th year)	900	300	300	1500	-	1250	1250	6000	2.22	1150
6.	Pasture Mgmt. sheep rearing	875	2776	976	976	-	1800	1800	1800	1.28*	3.35
7.	Tree farming *Leucaena* sp.	2500	500	500	10000 (10th year)	-	-	-	40000 (10th year)	2.10	1181

* Highly fluctuating market price, ** Returns will be higher if integrated with livestock

Notes:

1. Number of lambs 1.7 sheep/year. Cost of sheep Rs,350/- having body weight of 29 kg.
2. Rs. 400/t of fuel wood
3. Cost of Stylo legume, Rs.0.25/kg dry matter

improved breeds of milch animals. Hortipastoral system could be a more stable system on medium deep soils and with right choice of fruit tree and forage species. Leyfarming will be advantageous in areas prone to soil erosion, endemic diseases and perennial weeds. Tree farming appears to be more paying in areas located near by cities/paper mills. High density and short rotation intensive culture is possible only in better sites. Comparative economics of each of the systems is presented in Table 7.

Conclusions

Of the many alternate land use systems available today, alley cropping agroforestry system is one system which has received the highest consideration of scientists working in the semi-arid tropics. Microclimate benefits accruing from the system are of little consequence, as compared to the below ground competition for water, which is a scarce resource in the semi- arid tropics, total biomass production per unit area not withstanding. Contrary to general belief, successful agroforestry systems are nearly always practised on inherently fertile soils.

Agri-horticulture and silvopastoral management systems are very relevant, viable, and sustainable for the semi-arid and arid environments, respectively.

Much research needs to be done on agroforestry systems, in particular, on processes which govern productivity, litter production, recycling of nutrients etc. Above all, policy issues relating to incentives for tree planting and grassland might need serious consideration of the government and planners.

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TRADITIONAL AND IMPROVED SILVIPASTORAL SYSTEMS IN ARID AND SEMI-ARID REGIONS OF INDIA

S.K. Sharma

Introduction

Silvipastoral system is an alternate landuse system in which trees or shrubs are grown in association with pasture or livestock or both and there exists both ecological and economical interactions between trees and other components. This technology is of special significance in Indian context, because of inbalance in land man ratio, very high rate of deforestation and land degradation. In fact, this technology checks land degradation on one hand and provides much needed products viz, food, fibre, fodder, fuelwood, timber, medicine etc. on the other hand.

Ruminants like buffalo, cattle, goat and sheep are an extremely important resource in the arid and semi-arid regions of India. However, their productivity level by and large is extremely low, because of low quality and seasonal nature of forage supply. The problem becomes more acute in dry seasons. In such a situation, forage based silvipastoral systems could be of promise. Therefore, in arid and semi-arid regions it is important that careful selection of shrub and fodder trees which can withstand harsh arid environmental conditions should be done.

Silvipastoral systems have potential to check soil erosion through their well knit root systems of grasses as well as woody species in fragile sandy and alluvial landforms like ravine lands. In the following text an attempt has been made to highlight the results of silvipastoral studies in arid and semi-arid regions of the country with special emphasis on choice of tree, shrub and pasture species, productivity of different silvipastoral systems.

Traditional Silvipastoral Approach

Although the term silvipasture is new, the practice of having trees in the farm fields for their top feed value has been in vogue traditionally among the farmers of western Rajasthan. They have encouraged and protected the population of Khejri (*Prosopis cineraria*) and Bordi (*Ziziphus nummularia*) in their crop fields to lop them in winter (December) for top feed and fuelwood.

In states where animal husbandry plays an important role to provide sustained economy to the people, forest grazing has remained a source of their livelihood from times immemorial. At the beginning of this century our forests were rich in diversity of vegetation i.e. tree, shrub and grass cover. The grazing pressure was low with minimum deforestation activity in the forest. But in last 3-4 decades there has been rapid increase in human and livestock population, and forest cover of the country depleted very fast due to ever increasing demand of fuel, fodder, timber, minor forest produce etc. Moreover people of drought prone states are forced to migrate their grazing animals to the forests and grazing lands of the adjoining states. These migratory animals put additional grazing pressure on the forest cover beyond their carrying capacity and result in land degradation. This severe problem of migratory animals could be minimised by improving the productivity of our community grazing lands, marginal eroded land through scientific management and introduction of multipurpose tree, shrub species (MPTS) and improved pasture species in silvipastoral system.

The farmers have long recognised the fertility building characteristics of trees and their symbiotic effects for good crop growth and higher yields (Fig 1). But there was no scientific approach to it because trees were permitted to grow at random in the fields and no attention was paid to compatibility and choice of trees and pasture species for greater yields.

Growing of *Acacia* species in agricultural fields is a traditional and well established practice of semi-arid and sub-humid tropical zones. Many *Acacia* species are grown extensively in and around agricultural fields through out India. Some other very important tree species are grown in semi-arid and sub-humid tropical zones, for example, *Borassus flabellifer, Tamarindus indica, Ceiba pentendra, Leucaena leucocephala, Prosopis juliflora* and many others. These species particularly *Borassus flabellifer, Tamarindus indica* and *Prosopis juliflora* play an important role in the economy of the farmers and the local communities. No information about the practices is available. Research effort is virtually none, therefore research needs are not identified (Tejwani, 1994).

Growing of woodlots of *Casuarina equisetifolia* is an old practice, popular with the farmers of Andhra Pradesh, Tamil Nadu, Karnataka and Orissa. It is adopted on lands which are too poor or not suitable for profitable agriculture. It is now being practiced on good agricultural lands in association with agricultural crops, due to good economic returns from woodlots. Growing of woodlots of Eucalyptus species and *Poplars* on farm lands in Punjab, Haryana, Gujarat and U.P. is the result of the farmer's response to the market economic conditions (Tejwani, 1994).

In traditional farming system farmers had encouraged plantation of those multipurpose tree species along their field or community grazing land boundaries which usually grow in their fields and did not affect their crops. Nowadays top priority is being given to educate rural people about traditional and new MPT species for plantation on bare field boundaries and farm approach roads. Traditional tree and shrub species in arid and semi-arid areas suitable for silvipastoral system are *Prosopis cineraria, Tecomella undulata, Acacia nilotica, Albizia lebbeck, A. amara, Calligonum polygonoides, Acacia jacquemontii, Clerodendrum phlpmidis* and *Ziziphus nummularia* etc. Farmers are likely to adopt easily these trusted species along their field boundaries and later on other important indigenous and exotic woody species could be introduced into the system.

Forage Production in Afforested Area

Grass cover in afforested areas play an important role in sustenance of grazing animals particularly in drought years. These forest areas support variety of grass communities and associations in their understorey grass cover depending upon the climatic and landform conditions. Grass cover of India has been discussed in detail by Dabadghao and Shankarnarayan (1973). Common forest tree species of arid and semi-arid regions of India comprise of *Prosopis cineraria, Tecomella undulata, Salvadora oleoides, Acacia nilotica, Albizia lebbeck, Azadirachta indica, Holoptelia integrifolia, Pongamia pinnata* etc. But there have been very limited scientific studies on compatibility of forest tree species and their understorey grass cover, species composition, forage production and optimum number of trees, shrubs in a rangeland. The results of studies conducted at different research farms of Central Arid Zone Research Institute, Jodhpur are discussed in brief below.

Studies on floristic changes in grass cover under different tree species by Aggarwal *et al.* (1976) revealed that the growth characteristics of most of the annual and perennial species in respect of their number, density and dry matter production were much better under *Prosopis cineraria* plantation than other tree species (Table 1).

Table 1. Number of plant species, density and dry matter production per metric square under different tree species

Tree species	No. of species		Mean plant density		Dry matter production/
	Annuals	Perennials	Annuals	Perennials	
Acacia senegal	8.6	1.8	313.2	48.8	285.7
Albizia lebbeck	8.9	1.4	344.8	55.6	229.2
Prosopis cineraria	11.4	3.5	476.8	136.0	402.9
Prosopis juliflora	5.9	1.5	136.0	31.6	251.9
Tecomella undulata	10.6	3.4	379.6	96.4	273.5
SEm	0.8	0.4	30.7	14.5	38.0
C.D. at 5%	2.2	1.1	87.5	41.2	99.7

Ahuja *et al.* (1978) and Sharma *et al.* (1980) studied forage production under afforested tree species which are commonly found in arid and semi-arid parts of western Rajasthan. The growth and primary productivity of grasses in understorey vary in different years and locations due to fluctnation in intensity and pattern of ranfall. Maximum forage production was recorded in good rainfall year with even distribution (1973) and least in drought year (1974). However, forage yield in another good rainfall year (1975) was less than that of 1973 due to uneven distribution of rainfall during August, followed by heavy rains during September which extended upto October and it affected the production of grass. Contribution of perennial grass was maximum during 1975 when rainfall extended upto middle of October 1975, thereby providing large span of growth period. During 1973 precipitation period was limited upto the middle of September. This restricted the growth period of perennial grasses but proved ideal for the ephemeral species. The forage under *P. cineraria, Tecomella undulata* and *Albizia lebbeck* did not differ significantly, but the forage production under *Acacia senegal* was very low (Table 2).

Improved Silvipastoral System

In the present mechanised farming system, improvement in traditional silvipastoral system to increase the productivity and carrying capacity of the grazing land is possible through choice of suitable high yielding pasture grasses and top feed tree, shrub species. Top feed species should be compatible and in optimum density for balanced production from understorey and upperstorey of the system. Some important high yielding perennial grasses are *Cenchrus ciliaris* (Anjan), *Cenchrus setigerus* (Dhaman), *Lasiurus sindicus* (Sewan), *Dichanthium annulatum*

Table 2. Air dry forage yield (t/ha) under different tree species

Year	Rainfall(mm)	Air day forage yield (t/ha) in				
		Albizia lebbeck (3.37)*	*Prosopis cineraria* (6.75)	*Tecomeela undulata* (4.62)	*Acacia senegal* (18-25)	Meam Meam
1972	363.1	0.53	0.61	0.45	0.16	0.43 (96.5%)**
1973	641.3	2.59	2.81	3.36	1.81	2.65 (37.8%)
1974	244.3	0.59	0.54	0.36	0.15	0.41 (96.8%)
1975	661.9	1.00	2.22	1.73	0.64	1.68 (89.3%)
Mean		1.41 (66.5%)**	1.55 (78.9%)	1.48 (57.0%)	0.69 (53.8%)	1.28 (68.2%)
C.D. at 5% (tree sp.)		0.319				
C.D. at 5% (years)		0.303				

*Mean number of trees per plot
**Percent contribution of perennial grass

(Karad), *Panicum antidotale* (Gramno), *Panicum turgidum* (Murat), *Sporobolus marginatus* (Kharaio grass). Shankarnarayan (1983) recommended tree and shrub species suited for dry tropics peninsular India, plains in Bundelkhand, Maharashtra, Gujarat, Rajasthan and south west Haryana. These are *Acacia chindra* (Lal Khair), *Acacia cupressiformis, Acacia tortilis* (Israeli babool), *Albizia amara* (Lalleo), *Hardwickia binata* (Anjan tree), *Prosopis cineraria* (Khejri, Jand), *Pterocarpus santalinus* (Raktchandan), *Ziziphus nummularia* (Bordi, Jharberi), *Colophospermum mopane* (Mopane), *Dichrostachys nutans* (Nutan tree) and *Acacia aneura* (Mulga). Most of these species are of fodder and fuel value. The choice of the species will depend upon the local soil and climatic conditions.

Tree-pasture Interaction

Woody Species Survival : In silvipastoral studies involving three tree species (*Acacia tortilis, Colophospermum mopane* and *Leucaena leucocephala*) and a grass (*Cenchrus ciliaris* CAZRI 358) were sown in alluvial soil of Central Research Farm, Jodhpur in 1977. The establishment of tree seedlings was in the order of *A. tortilis* (98.5%), *L. leucocephala* (68.1%) and *C. mopane* (26.7%).

In IDRC silvipasture operational research project conducted at three different locations in Bundelkhand region representing undulating terrain (C.R. Farm, IGFRI, Jhansi), eroded plains (Datia in Madhya Pradesh) and ravinous salt affected area (Dhirpura, 16 km from Datia), five fodder cum fuel trees viz., *Acacia tortilis, Albizia lebbeck, A. amara, Leucaena leucocephala* and *Hardwickia binata* were grown in association with pasture grasses and legumes like *Cenchrus ciliaris, Sehima nervosum, Chrysopogon fulus, Stylosanthes hamata* and *Macroptilium atropurpureum*. Survival rate of tree species at six, five and four years plantations at above mentioned three locations respectively was observed as follows. At site first the survival percent for different tree species varied from *Acacia tortilis* (66.2%), *Hardwickia binata* (52.0%), *Leucaena leucocephala* (47.5), *Albizia amara* (41.9%) and *A. lebbeck* (13.4). At site II survival rate in descending order was *Acacia tortilis* (90.2%), *A. amara* (66.6%), *Dalbergia sisoo* (46.0%), *L. leucocephala* (25.0%) and *A. lebbeck* (4.3%). While at site III the trend of survival was *A. tortilis* (81.0%), *Dichrostachys cineraria* (72.0%), *A. amara* (64.8%), *A. lebbeck* (45.1%) and *D. sisoo* (31.8%) (Anonymous, 1988).

In a recent trial survival percent of *Z. nummularia* and *G. tenax* in association of *C. ciliaris* after three years of establishment was recorded 99.6 and 87.9% at Pali and 61.1 and 72.2 per cent at Kailana, respectively (Sharma *et al.* 1994).

Shrub-Tree Density: Yield of under-storey grass cover and of the browse (Pala) were influenced by varying densities of the community grazing land covered by the shrub canopy (Table 3). The relationship between the shrub density and grass cover yield was broadly inverse at Pali (Kaul and Ganguli, 1963). It was found that the medium stocked density with 14 per cent area of the community grazing land covered by shrub-canopy was optimum for high forage production.

Table 3. Average yield of leaf fodder (Pala) and grass in *Zizyphus* shrubland

Per cent density of Zizyphus nummularia	Yield of leaf fodder (kg/ha)	Yield of grass (kg/ha)	Combined yield (kg/ha)
18	150	540	695
14	125	875	1000

In *Acacia tortilis - Cenchrus ciliaris* system at C.R. Farm, Jodhpur different spacing treatments (i.e. 10x5 and 10 x10m) had no significant difference in forage yield. But significant variations in forage yield (0.2 to 1.6 t/ha) were observed during different years (Table 4) by Muthana *et al* (1985).

Table 4. Dry forage yield (kg/ha) in silvipastoral system during different years

Treatments	1977	1978	1979	1980	1981	1982	1983	1984
Annual rainfall (mm)	353.3	354.9	758.1	232.3	316.6	417.2	512.6	231.2
S1 (10 x 5m)	1252	668	1358	668	482	458	1537	831
S2 (10 x 10m)	999	567	904	389	350	433	1564	871
S0 (Pure Pasture)	1602	535	1140	712	527	222	991	830
SEm for years		± 90.0		SEM for spacing + 85.7				
C.D. at 5%		283.5		'F' test Non significant				

Pasture production of *Cenchrus ciliaris* and a mixture of *Chrysopogon fulvus* grown in association of *Hardwickia binata* and *Albizia amara* planted in 4x4 and 4x6 m spacing was studied in semi-arid condition of Jhansi (Deb Roy, 1988). Forage production from *C. ciliaris* and mix species pasture in closer spacing was 2.6 and 3.3 t/ha under *H. binata* and 2.7 and 3.1 t/ha under *Albizia amara*. Forage production in wider spacing from above two pastures was higher under both tree species canopies i.e. 3.0 to 3.2 t/ha under *H. binata* and 3.3, 3.7 t/ha under *A. amara*. In another silvipastoral study involving two spacings (4x4 m and 6x6 m) of two fodder trees (*Acacia tortilis* and *Leucaena leucocephala*) and two grasses *Cenchrus ciliaris* and *Cenchrus setigerus*) from Jhansi, forage production from *C. ciliaris* was higher than *C. setigerus*. Highest forage yield (4.3 t/ha) was obtained from *C. ciliaris* under *L. leucocephala* plantation at closer spacing (4x4 m). In *A. tortilis* plantation, however, wide spacing (6x6m) favoured high forage yield (4.2 t/ha). Wider spacing favoured yearly increment in height (82.4 cm) of *A. tortilis*. Apart from firewood and leaf fodder yield an extra dry grass yield (4.3 t./ha) was obtained (Deb Roy *et al.* 1980).

Muthana *et al* (1977) studied spacing and coppicing effect of top feed species in silvipastoral system. Close spacing reduced the forage component in the system and grown up trees canopy also adversely affected the forage yield. This is clear from the forage yield data recorded from coppiced and non coppiced plots (Table 5).

Table 5. Effect of different spacings and coppicing of *Acacia tortilis* on fuel and pasture production

Spacings	Fuel wood (kg/ha)		Forage yield (kg/ha)	
	Coppiced	Uncoppiced	Coppiced plot	Uncoppiced Plat
6. 0x6.0m	392	140	2356	596
4.5x4.5m	44	90	348	171
3.0x3.0m	536	48	78	39

Close (10x2.5 m) and wide (10x4 m) spacing of *Grewia tenax* and *Ziziphus nummularia* in association of *C. ciliaris* pastures at arid (Kailana) and semi arid (Pali) locations did not reflect forage yield variations (Fig 2). However, forage yield varied year to year from 0.8 to 1.9 t/ha at Kailana and 0.4 to 6.5 t/ha at Pali (Sharma *et al.*, 1994).

Tree-Grass Compatibility : In *A. tortilis - C. ciliaris* system the growth of *A. tortilis* seedlings was initially suppressed upto the first three years period. When the tree seedlings were raised in combination with *C. ciliaris* grass. After third year the plants picked up better growth rate, indicating that the plants had developed deeper root system and made the best use of the soil moisture available at lower soil strata. The mean annual increment (MAI) of *A. tortilis* trees was higher in without grass plots as compared to grass plots from initial planting stage to the third year growth period. After that the trend of tree growth with grass was observed higher (Muthana *et al.* 1985). Similar trend of jujube species establishment in *Cenchrus ciliaris* pasture and forage yield variation was observed in comparatively dry sandy rangelands at Samdari (Barmer district) by Sharma and Vashishtha (1985). Maximum mortality

Fig. 1 *Prosopis cineraria* + *Cenchrus ciliaris* - An ideal silvipastoral system for alluvial soil

Fig. 2. *Ziziphus mauritiana* + *Cenchrus ciliaris* - An improved silvipastoral system

i.e. 80.5% in *Ziziphus nummularia* and 60.4% in *Z. rotundifolia* was recorded in the first year of the establishment. The growth of jujube species was severely affected in the established buffel grass (*C. ciliaris*) pasture.

Silvipastoral studies involving four tree plantations i.e. *Acacia tortilis, Azadirachta indica, Albizia lebbeck, Holoptelia integrifolia* and four grasses i.e. *Cenchrus ciliaris, C. setigerus, Dichanthium annulatum* and *Panicum antidotale* revealed no significant differences in grass yield under above plantations at Pali (Muthana and Shankarnarayan 1978). Dry forage yield (average of two years, i.e. 1975 and 1976) in *D. annulatum* was 2.8 t/ha, followed by *C. ciliaris* (2.5 t/ha) and *P. antidotale* (2.2 t/ha). Among the tree *Azadirachta indica* attained maximum height (2.18 m) followed by *Acacia tortilis*. In general, trees attained maximum height in *Cenchrus setigerus* plots followed by those of *C. ciliaris*.

Effect of Khejri tree (*Prosopis cineraria*) on the productivity of range grasses growing in its vicinity was studied by Shankar *et al* (1976). Within a 2 m perimeter of khejri canopy, significant improvement in the khejri canopy, height, tussock diameter and forage yield of *C. ciliaris* was noticed. As the distance increased beyond 2 m, the crop improvement of khejri gradually tapered off.

Lopping Practices and Browse Yield: Studies on lopping intensity (Bhimaya *et al.*, 1964) revealed that heavy intensity of lopping adversely affected the growth of khejri. Further recurrent lopping reduced the leaf fodder yield irrespective of lopping perhaps due to successive reduction in the overall surface of new shoots. Need for a period of rest between two loppings of khejri is, therefore, prima facie obvious for sustained yield of loong (leaf fodder of khejri). It has been suggested (Commonwealth Agricultural Bureau Report, 147) that in arid areas lopping of *Acacia spp.*, particularly *A. nilotica* (ex. *A. arabica*) should be regulated on a cycle of 4 years with restriction on lopping of thicker (diameter of 1.9 cm and above) branches. In Madhya Pradesh and Tamil Nadu lopping of *Hardwickia spp.* was permissible only in times of scarcity (Shankar, 1988).

Sharma and Gupta (1981) studied the effect of seasonal lopping on the top feed production and growth of *P. cineraria*. They observed that winter was the ideal season for lopping, as it improved plant height and bole diameter of the tree as compared to trees lopped in rest three seasons i.e. spring, summer and monsoon. In similar studies on harvest of *Ziziphus nummularia* bushes in different seasons, the maximum top feed (Pala) 292 g/plant and shoot biomass 1170 g/plant was recorded in winter harvest as compared to other seasons (Saxena and Sharma, 1981).

Fully grown (over 30 years of age) *P. cineraria* with well spread crown is reported (Muthana, 1980a) to produce 25 kg air dried leaves, 5 kg pods, and 2 kg seeds in one year in 300 to 400 mm rainfall zone and a moderate sized plant (20 to 30 years age group) yields one kg seed. Complete lopping (lopping of entire tree) is reported (Kaul and Gyan Chand, 1977) to yield higher (58 to 72 kg/tree) than the lopping of the lower two third (28.48 kg/tree) and the lower one third (19.73 kg/tree) of the crown. There was no significant difference between two third and one third lopping treatments (Bhimaya *et al*, 1964). In another silvipastoral study in arid and semi arid locations with two top feed species viz. *Grewia tenax* (Forsk), Piori and *Ziziphus nummularia* (Burm.f.) wt. planted in *C. ciliaris* pasture in 1988 with two different spacings (10 x 4 and 10 x 2.5 m). Growth of top feed species in semi arid location at Pali was much faster than arid rocky and slopy location of Kailana (Jodhpur). Top feed species at Pali reached harvest stage after 3 years of growth. Top feed production from *G. tenax* under wide and close spacing ranged from 0.03 to 0.11 t/ha from without pasture plots and 0.03 to 0.09 t/ha from pasture plots, similarly top feed from *Z. nummularia* varied from 0.03 to 0.04 t/ha. There were not much variations in top feed yield from close and wider spacing plots (Sharma, *et al.*, 1994).

Fuel Yield in Silvipastoral System

Afforested dunes in western Rajasthan produced 15 to 20 t/ha firewood in 200 to 300 mm rainfall zone (Bhimaya *et al* 1960). The firewood yield from *Prosopis juliflora* plantation was estimated at 15 t.ha at the end of 5 years (Kaul and Ganguli, 1964). Wide variations in yield with respect to the age and habitats of *P. juliflora* were noticed (Bhimaya *et al.*, 1967). Differences in the fuel yield between the habitats generally followed the pattern of rainfall i.e., increase towards the east.

Studies on fuel yield of *P. cineraria* revealed that for a diameter range of 12.4 to 25.7 cm. the fuel yield ranged from 85 to 479 kg per tree with an average yield of 230 kg per tree of 20 cm mean collar diameter (Kaul and Jain, 1967). Kaul (1965) reported an average yield of 19 kg per tree firewood from *Calligonum polygonoides* at maturity (7 years old). Yield of 100 to 110 t/ha have been obtained from *Casuarina equisetifolia* raised in coastal Andhra Pradesh and managed under clear felling of plants with rotation age varying from 7 to 10 years (Rao, 1967). Away from the coastal area where water table and humidity were usually low, the yield varied from 25 to 65 t/ha (Ghosh, 1977).

Full grown tree canopy in established silvi pastoral system helps in many ways like change in micro-environment (Ramakrishna &shastri, 1977 a,b Improving soil fertiloty status (Singh and Lal, 1969, Aggarwal *et al.*, 1976) and reduction in sodium contents of the soil (Sharma *et al.*, 1995).

Recent studies (Chinnamani, 1992) in mahi ravine lands in Gujarat have revealed that prodected silvi pasture cover is best in erosion control than other agrecultural crops (Table 6)

It may be concluded from above discussion that silvipastoral system is ideal for those degraded waste and ravine lands which are not fit for cultivation and need immediate attention for their reclamation. Another important thing is to recognise the importance of our native tree and shrub species which are well compatible for silvipastoral system.

Table 6. Runoff and soil loss in revines of Vasad

Particulars	Average run off (mm)	Soil loss (t/ha/yr)
Natural fallow	16.5	0.02
Silvipasture	1.0	0.00
Agricultural crops	12.0-25.0	2.20-4.8
Denuded ravines	15-30	16-30

These studies bring into sharp focus the need for optimisation of tree density and the canopy cover in silvipastoral system. Critical appraisal of the tree grass compatibility is essential for making the silvipastoral system a viable proposition (Sharma and Venkateswarlu, 1990).

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HORTI-SILVI-PASTURE SYSTEMS FOR ARID ZONE

B.B. Vashishtha and R.N. Prasad

Introduction

The resource-poor farmer behind the plough is the most neglected person in the rural societies of India. Simple and high input packages designed for monocrop systems do not fit well either with the complexity and diversity of resource poor farming systems or with their poor access to agricultural services and risk prone environment. The bulk of this risk prone environment of hot Indian arid zone (61%) is contained in western Rajasthan. Livestock population of the arid zone of Rajasthan is about 23 million (Ahuja, 1994), equivalent to about 12 million Adult Cattle Units (ACU). Total human population in this arid zone was 13.4 million in 1981 which has increased to 17.4 million in 1991. Food and forage are the basic requirements for the health of desert dwellers and their animals. In the arid region of Rajasthan, the estimated forage availability (dry matter) from range land, top feeds, crop residues etc, is about 15.41 million tonnes against the total dry matter requirement of 17.46 million tonnes for the existing livestock population, showing a short fall of 2.05 million tonnes (Sharma, 1994). Similarly, the consumption of fruits in the daily diet of rural mass is almost negligible as against the recommended requirement of 60 g fruit per day (Chadha, 1993). However, animal husbandry being major source of income, the availability of fodder in adequate quantity is all the more important. Due to erratic rainfall pattern and continuous drought for many years, monoculture of either crop, or forage, has failed the test of time, compelling to switch over to mixed farming system for sustainable livelihood. Drought hardy fruit crops can survive and provide income to the farmers even under severe drought. Silvicultural plantations would check the drift of sand, provide forage, fuel and timber wood and would help in creating favourable micro-climatic conditions. To manage the arid lands in judicious way, a combination of horticultural crops, silvicultural plantations and fodder crops is the need of the day. This gave rise to the concept of horti-silvi-pastoral system of farming-a symbiotic affinity which leads to the higher production of fruit, fodder, fuel and timber wood per unit area.

Selection of Species

In an integrated horti-silva-pasture system, selection of fruit plants, tree/bush plants/grass-legume is to be done keeping in mind the geo-physical characters of the soil, climatic conditions and last but not the least, the farmers choice. As far as possible, multipurpose species would be ideal choice under the given conditions.

(a) Fruit Trees : The selection of fruit trees would depend upon the agro-climatic conditions and availability of irrigation facilities. There are arid areas where some irrigation facilities are available. The fruit crops suitable for different locations have been listed in the Table 1.

(b) Tree Species : Recognising the importance of trees as top feed during lean periods, it is useful to know the important top feed species alongwith their palatability and nutritive value for arid region, Ganguli et al., (1964) identified 16 top feed species alongwith their palatability and

Table 1. Fruit plants for different agro-climatic conditions

Arid (less than 500 mm rainfall	500-700 mm rainfall	Partially irrigated
Cordia myxa (goonda)	*Syzygium cumini (jamun)*	*Citrus aurantifolia (lime)*
Capparis decidua (ker)	*Tamarindus indica (tamarind)*	
Ziziphus mauritiana (ber)	*Feronia limonia (wood apple)*	*Punica granatum (pomegr-anate)*
Moringa oleifera (drumstick)	*Manilkara hexandra (khirni)*	*Psidium guajava (guava)*
Annona squamosa (custard apple)	*Aegle marmelos (bael)*	
	Emblica officinalis (aonla)	
Carissa carandus (karonda)	*Morus alba (mulberry)* *Grewia subinaequalis (phalsa)*	

nutritive value. According to them the palatability ratings for leaves of different top feed species in the order of preference are *Acacia tortilis, Prosopis cineraria, Salvadora oleoides, Ziziphus nummularia, Acacia senegal, Albizia lebbek, Anogeissus rotundifolia, A. pendula, Calligonum polygonoides, Azadirachta indica, Grewia tenax, Gymnosporia spinosa, Prosopis juliflora* and *Tecomella undulata.* These top feed species occur in distinct habitats and remain green in hot weather period. However, those with poor palatability may be over utilized by stock to meet their requirements (Shankarnarayan, 1984). The FAO (1977) panel of experts on forest resources, recognised the importance of exploring and conserving the resources of species that can meet one or more of these non-timber uses, particularly for arid zones. They are listed in Table 2.

(C) Pasture: To provide balanced nutritive fodder to the animals it is advised to have both grasses and legumes in the pasture. The selection of the species would however depend upon the soil and climatic conditions. Based on the edaphic factors suitable grasses can be classified as under (Bhati, 1984).

- Sand dunes and sandy plains: *Lasiurus sindicus, Panicum antidotale, Saccharum bengalensis, Cenchrus ciliaris.*
- Sandy loam and sandy clay loam: *Dichanthium annulatum, Heteropogon contortus.*
- Sand stones and rocky sites: *Sehima nervosum, Dichanthium annulatum.*
- Well drained sandy alluvial soils: *Cenchrus ciliaris, Cenchrus setigerus.*
- Low lying saline soils: *Sporobolus marginatus, Chloris virgata.*

Above classification is based on the edaphic factors but the selection of grass species will also depend on the rainfall.

Table 2. Trees species and their uses

Name of species	Uses
Acacia albida	*Fodder, fuelwood, farm forestry*
A. aneura	*Fodder, fuelwood, shelterbelts, soil stabilisation*
A. saligna	*Fuelwood, shelterbelts, soil stabilisation*
A. ligulata	*Fuelwood, shelterbelts, soil stabilisation*
A. nilotica	*Fodder, fuelwood, farm forestry*
A. salicina	*Fuelwood, shelterbelts, soil stabilisation*
A. senegal	*Fuelwood, farm forestry*
A. tortilis	*Fuelwood, farm forestry*
Azadirachta indica	*fuelwood, shelterbelts, farm forestry*
Calligonum polygonoides	*Soil stabilisation*
Eucalyptus camaldulensis	*Fuelwood, shelterbelts*
E. gomphocephala	*Fuelwood, shelterbelts, soil stabilisation*
E. brockwaeyi	*Fuelwood, shelterbelts, soil stabilisation*
E. microthece	*Fuelwood, shelterbelts, soil stabilisation*
E. tereticornis	*Fuelwood, shelterbelts*
Gleditsia sp.	*Fodder, fuelwood, shelterbelts, soil stabilisation*
Leucaena leucocephala	*Fodder,fuelwood,farm, forestry, soil stabilisation (For semi-arid only)*
Prosopis cineraria	*Fodder, fuelwood, shelterbelts, soil stabilisation*
Tamarix aphylla	*Fuelwood, shelterbelts, soil stabilisation*
Ziziphus sp.	*Fodder,Fuelwood, soil stabilisation*

Management

The management of trees, fruit crops and pasture grasses will involve planting all the three components in such a way so that there is no competition for light, nutrition and water. The tree species should be planted on the periphery of the orchard which would act as shelterbelt and wind break. While planting trees/shrubs for shelterbelt, selection of species should be on the basis of height. The tall species should be planted on the boundary, the middle row should consist of shrub, having low height and again the third row should be of tall species. These should also be staggered rather than in a straight row. The wind velocity will be minimised and would minimise the damage caused by hot and cold winds prevalent in the arid region.

The choice of the tree/shrub species will be governed by the rainfall conditions. In rainfall zone of 300-400 mm, *Acacia tortilis, Prosopis cineraria, Tecomella undulata* can be selected as tall species whereas *Colophospermum mopane, Ziziphus nummularia, Calligonum polygonoides*

Table 3. Tree/shrub, fruit plants and grasses for horti-silvo-pastoral system in different rainfall zones

Rainfall (mm)	Trees	Shrubs	Grasses	Fruit crops
150-300	*Acacia tortilis*	*Ziziphus nummularia*	*Cenchrus ciliaris*	*Cordia myxa*
	Acacia senegal	*Calligonum polygonoides*	*Lasiurus sindicus*	*Capparis decidua*
	Prosopis cineraria			*Ziziphus mauritiana*
	P. juliflora			
	Ziziphus rotundifolia			
	Dichrostachys glomerata			
	Tecomella undulata			
300-500	*Acacia tortilis*	*Ricinus communis*	*Cenchrus ciliaris*	*Cordia myxa*
	Acacia nilotica Sub sp. indica	*Ziziphus nummularia*	*C. setigerus*	*Z. mauritiana*
		Casia auriculata	*Panicum antidotale*	*Moringa oleifera*
	Tecomella undulata		*Dichanthium annulatum*	*Annona squamosa*
	Ailanthus excelsa		*Sehima nerovosum*	*Carissa carandus*
	Prosopis cineraria			
>500	*Acacia nilotica*	*Cassia auriculata*	*Dichanthium annulatum*	*Sizygium cuminii*
	ar.cupressiformis	*Cassia anguistifolia*	*Sehima nervosum*	*Tamarindus indica*
	Butea monosperma		*Chrysopogon fulvus*	Feronialimonia
	Acacia catechu		*Iseilema laxum*	Manilkara huxandra
	Madhuka latifolia			*Morus alba*
				Ziziphus mauritiana
				Cordia myxa

etc. can form less highest bush component. Table 3 gives detail of tree/shrubs, fruit trees and grasses for different rainfall zones.

The distance of planting of tree/shrub should be in such a way so that it forms an effective shelter belt. The tree should invariably be planted at a distance of 4-5 m whereas shrubs at 2-3 m.

Fruit plants require more care. The selected cultivars of fruit plants should be planted at appropriate distance which would enable the pasture to grow in between rows of the fruit trees. The distance of planting of various fruit crops is given in Table 4.

Table 4. Distance of planting of fruit crops in square system

Fruit crops	Distance (m)
Ber (jujube)	6-7
Pomegranate	5
Cordia myxa	8
Indian gooseberry (aonla)	8
Custard apple	6
Carissa carandus	6
Sizygium cuminii (jamun)	10
Tamarindus indica (tamarind)	10
Feronia limonia (wood apple)	10
Manilkara hexandra (khirni)	10
Aegle marmelos	8
Mulberry	6

In horti-silva-pasture system, silvicultural plantation (trees/bushes) to be planted as shelterbelt and fruit trees can be planted simultaneously. The sowing/planting of grass should be taken up one or two years after planting the trees/shrubs and fruit plants. Research work conducted with jujube-buffel grass (*Cenchrus ciliaris*) at Range Management area, Samdari, (Barmer district) revealed that establishment of jujube species was very poor initially with high mortality. It was due to competition for moisture with grass because both were drawing moisture from upper layer. The grass completed its vegetative and reproduction phase within 3 months and utilized moisture faster than jujube. It was concluded that to avoid such competition, the grass should be planted two years after the jujube plantation (Sharma and Vashishtha, 1985).

The planting of fruit trees should be done during rainy season. In case of budded plants, in-situ budding should be invariably followed. The root stock should be raised and can be budded after one year. The plants raised through cutting, layering etc. should be planted during rainy season and irrigated for establishment during first year. The fruit plants should be well trained during initial three years so as to provide them a definite shape suiting to the farming system. In case where the animals like sheep and goat are allowed for grazing in the pasture, the budding should be done at the height of 1 meter and the plants should be trained so that the animals do not harm the fruit trees. In case of jujube or ber, the leaves can be fed to the animals after the harvest of fruits is over. The plants of pomegranate should be trained on single stem and branching should be allowed at one meter height.

Nutrition: The fruit plants should be provided required nutrition. The requirement of N, P and K will depend upon the species and age of the plant. The doses of N, P and K are constant after 6 year of age of the plants. The doses of nitrogen should invariably be given in 3 splits and that

Table 5. Nutrition for fruit crops (More than six year of age)

Fruit crops	FYM (kg)	N (g)	P_2O_5 (g)	K_2O (g)
Mango	75	600	200	250
Citrus fruits	75	500	200	250
Ber	50	500	200	150
Pomegranate	50	500	200	150
Aonla	75	500	280	225
Sapota	75	500	240	300
Annona	20	450	150	250
Bael	40	400	250	250

of phosphorus and potash should be given once a year. Table 5 provides the general recommendation of nutritional requirements of various fruit crops.

Plant protection: Fruit plants are attacked by various pests and diseases. In addition to the polyphagus insects pests and disease, there are some specific pests and disease of fruit crops, which need management. Ber is attacked by fruit fly (*Carpomyia vasuviana*) which can be controlled by two sprays of any systemic insecticide (metasystox, rogor, dimecron etc.) 0.03% active ingredient. The first spray should be done when the fruits are in 'pea stage', followed by second spray three weeks later. It is also attacked by powdery mildew (*Oidium sp.*) which can be controlled by spray of 0.1% Karathan. Black or brown spots on pomegranate fruits are due to anthracnose disease which can be controlled by the repeated sprays of copper fungicide (0.2%) viz. fytolon, blue copper, blitox etc. Lime fruits are spoiled by citrus canker, caused by *Xanthomonas citri* bacteria. This disease spreads more during rainy season and can be checked by repeated spray of streptocyclin (50-100 ppm depending upon the intensity of disease).

While planting/sowing grass or pasture legume, leave 50cm species from the basin of the fruit plant on each side. This will reduce the competition for nutrients and water in both the components. Grass extends its runners every year which may reach the basin of fruit plant therefore the suggested distance from basin to be maintained every year.

In an ongoing experiment on horti-pastoral system at CAZRI, Jodhpur, *Cenchrus ciliaris* was introduced in an established orchard of jujube in year 1993, in between rows of 6 m distance. During third year, 32.9 q/h grass was harvested with 25 kg/h grass seed in addition to 29 kg/tree ber fruits. There is no adverse effect on ber yield with the introduction of grass. Korwar *et al.* (1988) conducted work on horti-pastoral system at Hyderabad (Andhra Pradesh) taking guava and custard apple as fruit crop and *Stylosanthes hamata* and *Cenchrus ciliaris* as grasses. Plant height of guava was more (1.78 m) with *C. ciliaris* whereas in custard apple it was more in control (Table 6). The yield of *C. ciliaris* in first year was 5-9.6 t/ha.

The horti-silvi-pastoral system can produce more biomass per unit area. This sytem also meets the basic requirement of Three F'S" i.e fruit, fuel and fodder for the rural masses of arid

Table 6. Growth parameter of fruit trees (18 months old) and yield of dry grass in horti-pastoral system

Pasture species	Guava		Custard apple		Yield of dry grass
	Plant height (m)	Diameter at knee height (cm)	Plant height (m)	Basal dia. (cm)	(t/ha)
S. hamata	1.67	1.81	1.04	2.45	
C. ciliaris	1.78	2.04	0.98	2.15	5.0-9.6
Control(No pasture)	1.61	2.24	1.08	2.78	-

+ Stylo not harvested in the first year
Source: Annual Progress Report, CRIDA, Hyderabad, 1987.

region. Not much work has been done on this multidimensional aspect and there is need to conduct intensive research on multilocation to generate information for this composite system. This system will not only provide the judicious use of available land resources but will also generate additional employment opportunities for rural people.

Future Thrusts : Following areas need intensive studies for location specific horti-silvipasture system.

- Delineation of plants/trees/shrubs/grasses, legumes for upper storey, understorey and basal storey for different agro-climatic zones of arid and semi arid regions.
- Evolving suitable plant geometry for this system.
- Developing efficient plant architecture of upper storey and understorey trees to avoid competition among them without causing any harm to basal storey.
- Studies on the symbiotic/asymbiotic effects of all the three components on the yield of final product of the system.
- Standardization of location specific agrotechniques for all components.
- Last, but not the least, work out cost benefit ratio of the system under given set of conditions.

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PROBLEMS AND PROSPECTS OF DEVELOPMENT OF SHRUB/LEGUME BASED PASTURES IN INDIAN ARID ZONE

T.K. Bhati

Introduction

The hot arid tropical zone of India covers about 12 per cent of the country's geographical area, and occupies over 3.2 lakh sq. km of land located in parts of Rajasthan (61%), Gujarat (20%), Andhra Pradesh and Karnataka (10%), and Haryana and Punjab (9%). The human (19.4 m) and livestock (23 m) population in this region is very high and there is a shortage of forage by 46.4% (Paroda *et al.*, 1980). Although a large stretch of land (10 m ha) is available for development of pastures in Arid Rajasthan alone but the present average productivity (0.35 t/ha) of these lands is very low. If not properly developed and scientifically utilized, these lands will continue to accentuate the process of desertification and soon may lead to serious environmental problems even for other parts of the country. CAZRI based on its over four decades of research has come out with full package of pasture establishment and utilization techniques for various sub-agro-climatic regions pertaining mainly to pasture grasses like *Cenchrus ciliaris, Cenchrus setigerus, Lasiurus sindicus, Dichanthium annulatum* and *Panicum antidotale* (Daulay and Bhati 1989). Although at this Institute research work on adaptability and grazing behaviour of some of the pasture legumes viz. *Clitoria ternatea, Lablab purpureus, Indigofera spp.* has also been conducted. Several exotic pasture legumes viz., *Macroptilium atropurpureum* (Siratro), *Lotononis bainesii, Desmodium intortum, Centrosema pubescens, Stylosanthes hamata, S. scabra, S. viscosa, S. guianensis* were also studied for their adaptability in this tract. Except *M. atropurpureum* non had shown much promise.

Fortunately nature has gifted these challenging areas with highly productive and useful species of pasture legumes and shrubs. There is great scope of optimal integration of legume components with pastoral grasses to increase the productivity, nutritive value, grand growth phase and palatability, on these pastures. Besides the pasture legumes can also fix the atmospheric nitrogen in the soil, thereby improving the productivity of grass component through biological N-fertilization. Although it is recognized that these grasses respond to N-fertilization (Bhati and Mathur, 1984) yet they can not be applied due to socio-economic considerations.

A. Experimental Findings

Experimental findings of some of the studies carried out at this Institute (Bhati *et al.* 1987) on various aspects of legume/shrub grasslands viz., germination, nodulation, compatibility, establishment and animal grazing are presented below for better comprehension of this important area of research.

Germination: Amongst pasture legumes the germination percentage of one year old seed of *Stylosanthus humilis*, (16.0%) and *Indigofera cordifolia*(19.0%) were very poor as compared to *Atylosia scarabaeoides* (87.0%), *Lablab purpureus* (72%), *Macroptilium atropurpureum* (79%) and *Clitoria ternatea* (65.0%).

Nodulation: *L. purpureus, C. ternatea* and *M. atropurpureum* nodulated very profusely (Table 1) in the field conditions. The per cent soluble sugar (2.09 and 3.62%), dry weight of nodules (122.15 and 38.67 mg/plant) were higher in *L. purpureus* and *C. ternatea* respectively, thereby, revealing their better nitrogen fixing ability.

Table 1. Abundance and chemical composition (%) of nodules in pasture legumes

Pasture Legume	No. of effective nodules /plant	Freshwt. of nodules /plant	Dry. wt. of nodules/ plant	Moisture %	Soluble sugar %	Nitrogen %	Starch %	Reducing sugar %
Atylosia scarabaeoides	9.84	19.23	16.48	16	3.04	36.54	1.28	0.05
Indigofera cordifolia	6.88	4.44	2.44	45.04	-	56.70	-	-
Lablab purpureus	29.2	423.00	122.15	71.92	2.09	41.79	0.27	0.07
Macroptilium atropurpureum	11.6	74.0	21.6	70.81	1.65	53.27	1.79	0.10

Compatibility : Investigations carried out to assess the feasibility of grass-legume association revealed that L. *purpureus* failed to regenerate while *Clitoria ternatea* continued to persist in association with perennial grasses viz. *L. sindicus* and *C. ciliaris* even during IIIrd and IVth years of establishment. Higher yields of forage were recorded in *L. sindicus* and *C. ternatea* (2:1) combinations.

Soil and Water Conservation : Protection from biotic factors and adoption of improved soil and water conservation measures (gully control, staggered contour trenches, vegetative barriers etc.) could result in increase in the density of several naturally occurring shrubs in rocky degraded grasslands (Table 2). The increase in density was highest (872%) in *Ziziphus nummularia* and was least in *Grewia tenax* (187.5%).

Table 2. Increase in the density of natural woody perennials under protection and soil and water conservation measures after 5 years (1988-1993)

Woody perennial	Density (No.of plants/30 ha)		
	Initial (1988)	Final (1993)	% Increase
Capparis decidua	103	315	205.8
Maytenus emarginata	41	221	439.0
Acacia jacquemontii	10	76	650.0
Prosopis cineraria	9	65	622.2
Commiphora wightii	15	137	813.3
Lycium barbarum	36	193	436.1
Grewia tenax	8	23	187.5
Ziziphus nummularia	44	438	872.8
Total	266	1458	448.12

Legume-Shrub Grasslands : (A) *Primary and secondary productivity*: Preliminary studies on the role of shrubs in pasture lands was conducted by Kaul and Ganguli (1963) and they observed highest production (1.0 t/ha) on the natural grasslands of which 14% area was covered with *Z. nummularia* shrub. Sharma and Vashistha (1980) also reported highest forage yield (1.2 t/ha) in *C. ciliaris* + *Z. nummularia* (210 p/ha) pasture. As a step forward in 1982-83 a full fledged research programme for evaluation of shrub/legume based pastures under animal grazing system (mixed flock of sheep and goat) was initiated at Jodhpur (av. rainfall 357.6 mm) with *C. ternatea* as a pasture legume and *Z. nummularia* as a shrub in varying proportions with *C. ciliaris* [A. 1:0 (pure grass), B. 1:1 (grass:legume), C. 2:1 (grass: legume), D. 1:1 (grass: shrub), E. 2:1 (grass:shrub)] on a paddock of 0.75 ha size for each treatment (Bhati *et al.* 1987). The grazing was initiated in the third year of establishment with 4 ram-lambs (Av. body wt. 96 kg/animal) and 4 he-goats (av. body wt. 68 kg/animal) per paddock and was continued for three growth seasons. The forage and seed productivity in different pastures during establishment phase (1982-84) are presented in Table 3. The observations clearly revealed that the pasture No. B to E besides giving acceptable levels of grass yield also produced concentrates for the animals. However, introduction of grazing in 1984 resulted heavy pressure specially on legume component and resulted in complete mortality of *C. ternatea* in pasture No. B and C. As such it appeared that the pasture legume although good for stall feeding may perhaps not be able to sustain the animal grazing pressure in arid zone conditions. Contrary to legume, *Z. nummularia* could sustain the heavy browsing pressure of animals well and no mortality was observed. The live weight gain and wool/hair production was higher in the pastures having these components

Table 3. Forage (t/ha) and seed (q/ha) productivity of legume/shrub pastures in establishment years (1982-84)

Type of pasture	Forage yield (t/ha)					Seed yield (q/ha)				
	1982	1983	1984			1982	1983	1984		
	Grass	Grass	Grass	Legume /Shrub	Total	Grass	Grass	Grass	Legume /Shrub	Total
A. *C. ciliaris*	1.40	1.40	2.78	-	2.78	1.10	1.62	2.76	-	2.76
B. *C. ciliaris* + *C. ternatea* (1.1)	1.31	1.42	1.14	1.07	2.21	0.95	0.96	0.96	1.82	2.88
C. *C. ciliaris* +*C. ternatea* (2:1)	1.42	1.31	1.49	0.46	1.95	1.04	1.32	1.42	1.34	2.76
D. *C. ciliaris* + *Z. nummularia* (1:1)	1.00	0.95	0.83	0.17	1.00	0.60	0.85	0.93	1.50	2.43
E. *C. ciliaris* +*Z. nummularia* (2.1)	1.20	0.90	1.62	0.17	1.79	0.80	1.45	1.18	0.89	2.07

(Table 4). Since all the three years (1984, 1985, 1986) have been the drought years the animal grazing could not be continued on year long basis and in lean periods animals were fed from outside fodder resources. It is therefore suggested that we should develop a three tier system involving top feed tree species, shrubs/legumes and grass component in suitable proportion for

Table 4. live weight gain (kg/ha) and wool/hair (kg/ha) production from sheep and goat for legume/shrub pastures

Pastures	Lie weight gain (kg/ha)						Wool/ hair production (kg/ha)			
	Ram lambs			He - goat			Ram lambs		He - goat	
	Dec. 84 to June 85	Oct. 85 to Dec. 85	Sept. 86 to Jan. 87	Dec. 84 to June 85	Oct. 85 to Dec. 85	Sept. 86 to Jan. 87	Dec. 84 to June 85	Oct. 85 to Dec. 85	Dec. 84 to June 85	Oct. 85 to Dec. 85
A. *C. ciliaris*	18.5	3.0	3.0	22.0	4.5	10.0	4.5	2.9	0.85	0.95
B. *C. ciliaris* + *C. ternatea* (1.1)	19.0	-	-	20.0	-	-	5.0	-	1.25	-
C. *C. ciliaris* + *C. ternatea* (2:1)	19.5	-	-	22.0	-	-	4.1	-	1.20	-
D. *C. ciliaris* + *Z. nummularia* (1:1)	25.0	13.0	9.0	23.5	16.0	11.5	4.2	3.2	1.3	1.05
E. *C. ciliaris* + *Z. nummularia* (2.1)	24.5	16.0	4.5	24.0	170	16.0	4.75	3.1	1.35	1.25

year long grazing and sustainability of animal production from these lands. In fact it can be an important area of pasture research programme.

Table 5. Establishment cost (Rs/ha) of different types of pastures

	A		B		C		D		E	
Particulars	82 - 83	83 - 84	82 - 83	83 - 84	82 - 83	83 - 84	82 - 83	83 - 84	82 - 83	83 - 84
Clearing	45.00	-	45.00	-	45.00	-	45.00	-	45.00	-
Fencing	1040.00	-	1040.00	-	1040.00	-	1040.00	-	1040.00	-
Soil working	258.00	-	258.00	-	258.00		258.00	-	258.00	-
Digging of pits	-	-	-	-	-	-	297.00	-	297.00	-
Seeds/Seedlings	90.00	-	95.00	-	97.50	-	1161.00	640.00	811.50	560.00
Sowing	105.00	-	105.00	183.00	105.00	-	57.00	-	57.00	-
Transplanting	-	-	-	-	-	-	210.00	135.00	315.00	315.00
Watering	-	-	-	-	-	-	135.00	180.00	135.00	180.00
Hoeing and weeding	180.00	369.00	180.00	369.00	180.00	333.00	180.00	270.00	180.00	225.00
Total	1718.00	369.00	1723.00	552.00	1725.50	333.00	3383.00	1225.00	3961.50	1280.00
Total establishment cost over 2 years		2187.00		2275.00		2058.50		4608.00		4241.50

B. Economic Evaluation

(i) Establishment Cost: Establishment of shrub based pastures was found costlier than the pure grass pasture because of the added cost of shrub establishment. The total expenditure towards the pasture establishment was Rs. 2187.00, 2275.00, 2058.50, 4608.00 and 4241.50 for pasture numbers A, B, C. D and E respectively (Bhati *et al.*, 1987). Abnormal rainfall pattern in the establishment phase (1982-83, 1983-84) also added to the cost particularly in *Ziziphus* based pastures (Table 6). Further the establishment costs were calculated on hectare basis which are never applicable to grazing lands as they are usually of larger size (10 hectares and beyond). Therefore the establishment cost will reduce accordingly making them more profitable propositions as the size of pastures increase..

Table 6. Year wise grass monetary returns (Rs/ha) from legume/shrub grasslands

Pasture	1982 - 83	1983 - 84	1984 - 85	1985 - 86	1986 - 87
A. *C. ciliaris pure*	832.50	3520.50	1139.30	312.75	412.50
B. *C. ciliaris* + *C. ternatea* (1:1)	456.00	930.30	1125.00	-	-
C. *C. ciliaris* + *C. ternatea* (2:1)	241.50	1919.40	1125.10	-	-
D. *C ciliaris* + *Z. nummularia* (1:1)	51.75	1425.43	1295.40	881.50	600.00
E. *C ciliaris* + *Z. nummularia* (2:1)	238.50	1652.80	1309.55	994.45	600.00

ii) Gross Monetary Returns: The monetary returns from these pastures were estimated on the basis of forage, seed, green leaf (*'Pala'*), bushwood (fire wood), manure, wool/hair and live weight gain. Although based on 5 years of estimations pure pasture of buffel grass gave higher returns (Rs. 6226.50/ha) but the returns were also satisfactory from shrub-based pastures i.e. D (Rs. 4250.08/ha) and E (Rs. 4795.30/ha). Again the yield of shrub component is also bound to increase over time. Hence these pastures are expected to give better returns in long run. Further as reflected in Table 4 the live weight gain and wool production were also conspicuously higher in these pastures and this trend will continue to turn them more and more profitable with the passage of time. The year wise monetary returns from these pastures are given in Table 6. In 1985 and 86 the returns were calculated only on the basis of animal productivity and it clearly reflected the superiority of these pastures over pure grass pasture. Since the prices of wool and meat were low during these years i.e. Rs. 25/kg and 22/kg respectively as reflected in low monetary returns over previous years where higher seed price (Rs. 25/kg for grass, Rs. 5/kg for legume) reflected in high returns.

Conclusions

From the foregoing discussion it is evident that nature has bestowed arid regions not only with highly productive and useful species of pasture grasses but also of legumes and shrubs. If properly dovetailed with pasture grasses these legumes/shrubs can help in 1. improvement in pasture productivity and quality, 2. enhanced palatability and grazing period, 3. improved soil fertility and productivity, 4. efficient soil and water conservation and ultimately; 5 socio-economic stability through enhanced livestock productivity and quality. Although *Z. nummularia* has been identified as suitable shrub in association with pasture grass *C. ciliaris* (1:2), but there are many indigenous and exotic (*Dichrostachys nutans*, *Colophospermum mopane* etc.) shrubs which need to be evaluated for their suitability in development of shrub based pasture systems befitting different agro-climatic situations in the desert. Similarly there are several pasture legumes which need to be investigated for their compatibility and proportion with pastoral grasses both under stall feeding and grazing management. At last it can be concluded that active people's participation is of paramount importance in development and management of these systems on community/private grazing lands.

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IMPORTANT LEGUMINOUS FORAGE SHRUBS AND TREES FOR SEMI ARID REGIONS

R.B. Das

Introduction

Leguminous plants have been grown by man for its use for over at least 6000 years. During Bronze Age, in Switzerland, lake dwellers cultivated few leguminous plants (5000-6000 B.C.) Legumes featured in cropping systems of early Egyptian dynasties and later in Roman era several writers stressed their value for food and soil improvement. Symbiotic root nodule bacteria make them analogous to a nitrogen factory on the crop-land, pasture land or on silvipastoral land. Such a factory tends to remain active during the growth of the host plant. After growth has ceased, the nitrogen already fixed may still retain a substantial value. The legume may be ploughed under, eaten by grazing animals, or harvested; nitrogen gained from the atmosphere finds its way partly into animal and human protein and, in a large measure, into the soil as an agent of enrichment, provided the excreta of animals feeding on legumes or legume-grass mixtures in a silvi-pastoral system are voided on or transported to the soil. As a rule, half to two-thirds of the nitrogen fixed by herbage legumes is gained by the soil when these legumes are grazed *in situ*.

In tropical arid and semi-arid countries,uncertain supplies and increasing cost of feed, fertilizer,and food coupled with projected population increase, are giving leguminous shrubs and trees whose foliage is browsed by animals a status they never previously enjoyed.

In large measure, the present day under-production of animal protein in the developing world is caused by lack of forage. Trees and shrubs play a dual role in the forage supply, serving both as shade for grasses and as forage themselves. In dry semi-arid and arid regions leguminous shrubs and trees are very precious; without them, stock raising would probably be impossible, for pasture grasses die when upper soil layer looses its moisture, but trees and shrubs with their deep roots exploit moisture from lower levels of soil strata and they continue to flourish. During dry and lean periods shrubs and trees provide green fodder-leaves, flowers and fruit-often rich in protein, vitamins and minerals. Indeed, in semi-arid regions livestock, domesticated or wild, would barely survive a drought season were it not for leguminous browse shrubs and fodder trees. It has been observed that in shrub-grass pasture cattle obtain as much as 60 per cent of their forage from leguminous shrubs and trees.

Extending this principle of associated growth of forage pasture species with fodder shrubs constitute silvi-pastoral system. Silvi-pastoral system is in fact a land management technique, wherein the interspaces between two or more rows of trees are utilized for cultivation of grasses and grass-legume mixtures. This management technique is used either for the establishment of vegetation where there was previously little or none or substitute less useful vegetation by more useful one, having values as fuel-cum-fodder or timber or food and fuel tree.

In the arid and semi-arid regions such development activity has immense possibilities. It is an admitted fact that the entire socio-economic fabric of this region rests on proper management of degraded and wastelands and many species of grasses and trees are capable of growing inspite of the inhospitable ecological conditions and many of the tree species are economically important for food, fodder, fuel and small timber.

With their extensive root system, trees and shrubs adapt to steeply sloping lands and can often be grown on sites unsuited for food production from conventional crops. In doing so, they may stabilize sandy and eroding soils and can protect them from torrential downpour and tropical wind storms.

Promising Leguminous Shrubs and Trees

The leguminous shrubs and trees which can contribute in providing food, fodder, fuel and timber are detailed below keeping in mind their role in silvi-pastoral system.

Cassia sturtii : This plant can be grown in 200-250 mm of rainfall, but thrives even in higher rainfall regions. Australians have not considered it important as forage species, but in Israel it is providing nutritious forage under the conditions of Negev Desert, where it has demonstrated better year-round palatability than any bush yet tested. It also has good grazing resistance and the leaves have a protein contents of 12 per cent. The dry matter yield per hectare as leafy fodder is over 1500 kg in two cuttings.

Desmanthus virgatus : It is a small shrub, 2-3 meter tall native to tropics and semi-tropics roughly resembling *Leucaena* in appearance. As a browse shrub it has proved to be very palatable, aggressive, persistent and tolerant to heavy grazing because its re-growth is very rapid.

Eco-climatic conditions required by the plants are similar to those of *Leucaena.* It's foliage has a lower protein contents(leaves 22 per cent, foliage with stems 10-15 per cent) than that of *Leucaena.* Also, its yields are lower (70 t of green foliage per hectare per annum or say 7.6 t D.M./ha/year). Nevertheless, it deserves a better consideration and wide spread introduction because, unlike *Leucaena,* it is not toxic to livestock. Also, its pithing stems are more easily harvested and utilized then *Leucaena's* woody ones.

Desmodium gyroides : Indigenous to south and south-west Asia, this bushy shrub reaches a height of about 4 m. It is very leafy and cattle graze it readily. This legume deserves wider introductions in silvipastoral system for it establishes readily from seed, grows vigorously even in poor soils (both acidic and alkaline) and thrives well at altitudes ranging from sea-level to 1000 m. Also it remains fairly leafy through drought period.

Apparently *Desmodium gyroides* has no problem in nodulating at various sites. It produces abundant nodules with cowpea inoculant and also it can nodulate easily with native rhizobium strains. Like *Leucaena* it may well have importance as green manure because of its abundant leaf-fall.

Acacia tortilis : It is commonly called Israeli babool (India) and umbrella thorn (Africa); one of the most distinctive and wide spread of African acacias, supplies fodder, fuel, shade and shelter in most of semi-arid Africa and middle east, also widely introduced in India. It is very resistant, often being the first tree to colonize arid regions and last survivor in the face of encroaching desert. Even in the absence of all other feed, the pods of this plant are said to be sufficient to fatten sheep and other livestock. Throughout much of Africa, during dry season in wild or cultivated form it provides (during dry season when the pods fall) the main forage for cattle, sheep, goats and wild-life.

It can survive well on most refractory sites. *Acacia tortilis* is a promising leguminous species for establishing in silvi-pastoral system on dry, rocky and sandy areas. It has proved to be the best multipurpose tree for growing in arid and semi-arid regions of Rajasthan (India) becoming a boon to the people of this desert who suffer from shortage of fuel, fodder and timber.

This plant is usually a middle-size tree (4-20 m tall), sometimes with several trunks that spread upward and outwards and that support a flat-topped umbrella of foliage.

It does well, too, in hot climates with maximum temperatures close to 50 ^{o}C, and it grows where minimum temperatures are close to 0 ^{o}C. The tree favours alkaline soils, but grows well in sand dunes, sandy loam, rocky soils and other soils that drain well. Also, it thrives well where annual precipitation is 1000 mm as well as in regions which have as low as 100 mm annual rainfall and a long erratic dry seasons.

***Acacia albida* :** A most valuable plant which is native to Africa's dry regions. Contrary to usual tree behaviour *Acacia albida* retains its leaves through dry season and shed them just as the rainy season begins. This has a number of economic benefits.

(a) Forage is available throughout the dry season when other trees are leafless,

(b) At the end of dry season, when feed is often desperately scarce, the protein-rich pods are maturing and drip off in huge quantities,

(c) During hot months, its dense foliage provide-cool shade for the livestock,

(d) The tree's leafy crown protects the soil when most grasses have succumbed to drought, leaving the ground to wind-erosion,

(e) The leaf drop and continuous presence of livestock near the trees greatly enrich the soil, making it more suitable for growing crops among the inter-row spaces in silvi-pastoral system,

(f) The tree's foliage falls off just when food or fodder crops are planted with soil working perfectly timed for providing soil nutrients when they are most needed (the heat and humidity at the rainy season's onset fostering quick decay of the leaflets and rapid release of their nutrients),

(g) The tree's lack of leaves during rainy season, enable sunlight to reach the crops planted between the rows.

It is one of the fastest growing legume found in semi-arid scrub lands. It reaches 6.5 m after 4 years and 10.5 m after 7.5 years. Under favourable conditions it can reach the height of 30 m.

***Acacia pendula* (weeping Myall) :** The weeping myall, a strikingly attractive tree with drooping branches resembling those of weeping willow, is one of the most graceful of all *Acacias*. Its silvery-white foliage is readily eaten by sheep and cattle and is thought to be more palatable and nutritious than other Acacias.

The tree reaches height of 6-12 m and makes a fine shade tree. It is also excellent for windbreaks, ornamental planting, fencing besides being extremely useful in silvi-pastoral system as a component tree. It can grow in regions receiving 400-650 mm precipitation with excess to ground water. But is is exceptionally robust, and in its native habitat summers are often extremely hot with annual precipitation only 300 to 650 mm.

***Prosopis* species :** There are 44 species of *Prosopis* which have been recognised. At least three are aggressive weeds that cause great devastation to sub-tropical grass or pasture lands The most important of which is *Prosopis juliflora, Prosopis glandulosa, Prosopis ruscfolia* and should not be introduced in new locations as they compete with associated species for water and reduce carrying capacity. However, these species are useful in salty soils where other crops are difficult to grow.

Other *Prosopis* species lack the exceptional aggressiveness of weedy types but retain many of the desirable features. Their value lies in redeeming arid and semi-arid regions that would otherwise remain economically worthless. These trees are very drought resistance and well adopted to locations having hot or cool climates and poor soils of the desert. Species like *Prosopis cineraria* in Indian desert and *Prosopis tamarugo* of Atacama desert of Chile (South America) are the main stay of life of natives providing food, fodder, fuel, wood, weapons, tools, shade and shelter. Hence, these species are valuable and could be considered important in silvi-pastoral system in arid and semi-arid regions.

These species generally need annual rainfall of 250 mm, but in Indian desert we find them growing in regions receiving as low as 75 mm of rainfall or less or none for 2-3 years. They easily withstand protracted drought and yet produce pods and leaves which can be lopped and fed to the animals. Also, species can readily grow from seed and regenerate by suckers or coppice shoots. Their tap roots penetrate 15-20 m of soil depth or more.

Another, fact about *Prosopis tamarugo* is that it attains a height of 18 m and is native of driest desert of the world, the northern desert plateau of Chile where it is the only tree in association with hardy grasses which survives on arid salt flats. Each tree of *Prosopis tamarugo* yields 160 kg of pods, leaves and twigs, which layer the soil beneath and provide year round feed to the livestock. It is the region which does not receive rain for years and when it comes the flat turn into salty marshes that later evaporate, leaving a crust of salt crystals. Under large scale planting programme sheep and angora goat industry is being developed in Atacama desert of Chile with UNDP technical assistance.

Thus, leguminous species contribute significantly in converting driest desert of the world into a productive region.

***Sesbania grandiflora* :** This species grows amazingly fast and provides forage, fuelwood, pulp and paper, food, green manure and landscape decoration; also it has much potential for re-foresting eroded and grasses wasteland or enhancing productivity of silvi-pastoral system throughout tropical semi-arid regions.

This legume species is native of India, Malaysia, Indonesia and other south-east Asian countries. The plant's outstanding feature is its extremely fast growth rate specially during the first 3 to 4 years after planting. When introduced in Australia in the very first year it attained the height of 4.3 to 5.5 m. In India when planted under field conditions as an associated crop it reached to the height of nearly 8 m in as short a time as 3 years.

The species is very easy to propagate by cuttings or seedlings. On large scale, seeding plantation in rows could also be carried out for successful establishment. It requires little maintenance, grows fast, can be utilized for cutting or grazing even in the first year.

Prolific nodulation and extremely large nodules are special feature of *Sesbania grandiflora*. This species has multipurpose utility as illustrated by following examples.

(a) *Forage*: All animals relish its leaves and long pods (upto 60 cm). For breeding cattle it is of special importance where animal can be fed with any dry straw diet along with leaves and pods of *Sesbania grandiflora* indicated animal gains comparable with those obtained by feeding formulated diets.

(b) *Green manure*: Foliage makes excellent green manure. Yield of 5 t green material per ha have been obtained in 6-7 months. Its extraordinary nodulation coupled with its rapid growth, suggests that its soil-improvement qualities are exceptional.

(c) *Wood, pulp and paper*: A fully grown plant attains a height of 10 m with diameter of about 30 cm. The wood is satisfactorily pulped by sulphate process and paper-making properties of the pulp seed adequate for limited range of paper products. It bleaches readily to high brightness with standard bleach sequence and should be accepted for off-set printing papers.

(d) *Reafforestation*: In south Asian countries it has proven useful for reafforesting eroded hills by growing it along contours and as hedges in pastoral lands. It can establish well by self-sown seed also.

(e) *Food*: The young leaves, tender pods and giant flowers of *Sesbania grandiflora* are favourite Asian vegetables, used in curries and soup or fried, lightly steams or boiled. The leaves, which contain 36 per cent crude protein and high contents of mineral and vitamins, make a remarkably nutritious spinach like vegetable. Flowers are largest of leguminous plant (10 cm long), produced year round, contain sugar, and if boiled for 1 minute taste like mushroom. Pods eaten as vegetable much like beans.

(f) *Other uses*: *Sesbania grandiflora* gives light shade, it is useful as shelter-belt and also as living fence. The leaves drop continuously making a thick mulch that adds nutrient to soil. Also bark exudes gum which is as good as gum-arabic in food and adhesives. Thus, in semi-arid tropics this tree is of excellent importance.

***Leucaena leucocephala* :** Amongst tropical legumes suitable for arid or semi-arid regions *Leucaena leucocephala* is versatile, whose full potentials so far are untapped. It is a plant of importance to marginal lands and low-income farmers. Through its many varieties, *Leucaena* can produce nutritious forage, fire-wood, timber and rich organic fertilizer. Its diverse uses include revegetating tropical hill slopes and providing wind breaks, fire-breaks, shade and ornamentation. *Leucaena* tree have yielded extraordinary amount of wood, indeed among the highest annual totals ever recorded, and although the plant is responsible for some of the highest weight gains measured in cattle feeding on forage yet it has remained a neglected crop.

The varieties with exceptional size, vigour and other desirable qualities have been discovered or developed only during last 3 decades. *Leucaena's* development has been retarded because its foliage contains an uncommon amino acid, mimosine, that is toxic to non-ruminants at levels of about 10 percent in diet. *Leucaena* is not fatal to ruminants such as cattle, since stomach micro-organism convert mimosine to dihydroxypyrdine (DHP), which causes problems only if *Leucaena* is consumed for months on end.

Varietal Variations in Leucaena: Varieties differ enormously in size and form which can be classified broadly into these three types .

(a) *Hawaiian type:* Short bushy variety is not photoperiodic and flowers throughout the year. Reaches nearly 5 m in height. It is comparatively low yielder. It is a prolific seeder and hence could become an aggressive weed. Its value lies in its ability to revegetate barren hill slopes to provide wood and charcoal and shade. Its use in silvi-pastoral system is possible if kept near a meter height by frequent cutting or grazing.

(b) *Salvador types:* Tall tree like plants 20 m in height, having large leaves, pods, seeds and thick branches. These varieties often produce more than twice the biomass of Hawaiian type. They are also known as Hawaiian Giants or by the designation K8, K28, K67, etc.

(c) *Peru type:* Tall plants upto 15 m, like Salvador type but with extensive branching even low down on the trunk. This type produce little trunk, but extremely high quantities of forage grow on their branches.

Brewbaker *et al.*, (1972) conducted studies on varietal trials in *Leucaena* yield, the result are detailed in Table 1.

Table 1. Varietal yield (fresh weights) of *Leucaena leucocephala* at two locations

		Yield (t/ha/yr)		
Varieties	Source	Oahu	Kaval	Av.
K8	Mexico Guerrero(Hawaiian type)	102.5	85.9	95.2
K67	El Salvador	99.5	75.6	87.7
K28	El Salvador	81.4	78.7	80.0
K62	Ivory coast	77.3	66.1	71.7
K5	Peru	70.4	63.9	67.3
K3	Guatemala	56.5	44.6	50.7
K1	El Salvador	55.6	44.8	50.2
K4	Guatemala	43.7	37.0	40.4
K63	Hawaii	46.9	28.7	37.9

Establishment and Management of Leucaena: The seed coat of Leucaena is hard hence, for better establishment seed is scarified mechanically by scratching or acid treatment. Simplest treatment is to soak in hot water (80 ^{0}C) for 4 minutes. Rates of seeding between 50 and 200 thousand plants per hectare in formation show fairly small differences in ultimate forage yield. This is shown in Table 2.

We recommended a rate of 80,000 plants per hectare for optimum yield under silvi-pastoral planting, where hedge-row with pasture species is a rule. Hedgerow management is especially adapted to animal grazing with the legume tree interspaces planted pasture grasses like *Cenchrus*

Table 2. Effect of population on yield of *Leucaena leucocephala* cut regularly when 1 m high cutting at 10 cm height

Population	Spacing (cm)	Dry matter yield (t/ha)	Percentage forage
1,33,000	75 x 15	19.6	66
66,000	75 x 30	17.9	69
45,000	75 x 45	17.1	70

ciliaris, *Panicum maximum* or *Chloris gyana* etc. In the studies of hedgerow harvesting Takahashi and Ripperton (1949) found that yields generally decreased and quality increased as height of closely spaced hedges increased as illustrated in Table 3.

Thus, when hedges 1m apart were cut to a height of 1m total yields were down by 20% from those clipped to 10 cm, but leaf fraction increased by 25%.

Table 3. Yield of *Leucaena leucocephala* from hedgerow harvest of rows spaced 1 m apart

Cutting height(cm)	Fresh yield (t/ha/yr)	Yield per man hour	Percentage leaves
10	50.6	184	36
50	43.3	131	41
100	40.1	93	46

In another study of hedgerow management when conducted with widely spaced rows (3 m apart) and seedlings 5 cm apart, cutting 4 times per year to simulate pasture grazing (Mendoza *et al.*, 1975), forage yields (coarse wood removed) increased greatly with increasing height in these studies (Table 4).

Table 4. *Leucaena leucocephala* dry matter (D.M.) yields from hedgerow spaced 3 m apart

Cutting height. (cm)	D.M. (t/ha/yr)	Protein (t/ha/yr)	Labour (Man/ha/yr)
10	93	1.91	56
150	14.3	2.82	345
300	22.8	4.52	629

From above table it would also appear that yield per man hour or was minimum at the lowest cutting height. Besides this, all heights of cutting led to highly economical returns. In the related studies Mendoza *et al.* (1975) concluded that yields were maximum when simulated grazing was managed so as to leave at least 25% of the leaves on the plant (Table 5).

Hedgerow data illustrate wide range of variation that is encountered as management practices of silvi-pastoral system changes. Therefore, it is suggested that studies should be undertaken under local conditions for generating more meaningful and dependable information. Containment and pan-feeding of browsing animals make hedgerow harvest more effective.

Frequency of harvest is probably the most significant variable other than variety in determining yields and quality of *Leucaena*. Forage yields from *Leucaena* harvested at varying

Table 5. Yield of *Leucaena leucocephala* related to percentage defoliation

Per cent leaf removed	Yield in t/ha/yr D.M.
100	17.8
75	20.5
50	15.6
25	12.8

intervals (Takahashi and Ripperton 1949) spacing 95 x 5 cm indicated that, although, dry matter yields dropped somewhat with 6 cuttings per year, the quality of forage increased, maximizing the protein yield at this rate.

Frequency of harvesting is best judged by the height of forage re-growth and the extent of flowering. Salvador type of *Leucaena* flower only after about 2 m regrowth, and yields greatly exceed those of Hawaiian type when cut at this height, averaging over 20 tons dry matter per hectare per year.

Environmental Effects on Leucaena: Several environmental constraints to *Leucaena* production occur in tropics. They influence especially the decisions on time of harvest or controlled grazing. Water use by *Leucaena* has been estimated to be 54 mm pėr ton of dry matter. Prolonged water deficiency results in leaf fall, stem dieback only when drought is severe.

Leucaena survives frosts, but is not an aggressive legume under cool temperatures in tropical highlands. Growth rate and yield of *Leucaena* in cooler, low light winter months drop significantly.

Normally a silvi-pastoral system aimed at being utilized by browsing is characterized by a distinct ecosystem. This consists of two recognizable vegetal strata.

(a) A herbaceous stratum, very largely dominated by mixture of grasses, legumes of annual or perennial nature with a height reaching from 0.5 to 1.25 meter at maturity; producing 1.5 to 3.89 tons of dry matter per hectare, and having an active growth period between late June to early October each year.

(b). A ligneous stratum dominated by shrubs, trees or bushes etc. These trees or shrubs may be planted in hedgerow or scattered in a properly pre-conceived pattern in a tamed or a natural pasture land. The active growth of the vegetation is generally concentrated during rainy season but, they tend to remain green almost throughout the year.

In arid and semi-arid regions the observations on pattern of utilization by animals as influenced by its behaviour reveal that, grazing is according to species, animals utilize one or other stratum of vegetation more or less preferentially, so goats and camels make use of ligneous stratum earlier than do sheep and cattle but these preferences may also vary according to season.

At the beginning of the rains the livestock find residual straw from the previous year (often in a poor state of preservation) mixed with young shoots of new plants (specially annuals) and new sprouts on the leguminous shrubs or trees grown in hedgerow manner or scattered. Then, the utilization of grasses which has grown rapidly and have reached the stage of active stem growth, flowering and seed formation, at the same time their amount of dry matter increases, whereas their protein value decreases. On the contrary, the leguminous shrubby stratum providing browse has a more regular production and the qualitative value varies very little affording a pattern of utilization much different from pure pasture stands of grasses or legumes or mixture of both as indicated by Das (1984).

Nutrition Needs of Bovine Browse From The System

For our purpose in tropics we would consider a reference to an adult animal unit termed as "Tropical Livestock Unit" (T.L.U.) as explained by Boudet and Riviers (1968). It is an adult bovine of live-weight nearly 250 kg. Its needs have been evaluated as 2.3 forage units (F.U.) and 125 gm of Digestible Protein (D.P.) per day for its maintenance. This quantity of forage unit (F.U.) and Digestible Protein (D.P.) must be contained in the ration of 6.5 kg of Dry Matter (D.M.) which an adult animal unit (T.L.U.) would require in order to have a satisfactory space filling coefficient for digestion, therefore the animal must ingest 2.5 kg of D.M. per 100 kg of its live-weight.

Any F.U. or D.P. in the ration (feed) exceeding these values will be used for movement, or production of meat and milk. The utilization and grazing management is directly linked to satisfy the needs of the livestock from the available feed source through silvi-pastoral stand where legumes have to play a very significant role. If there is any lack of resources in the grazing unit, the management would change and pattern of utilization would be greatly influenced.

The ratio of R.E. is the ration equivalent= total need/6.5 It allows us to compare directly the nutritive value of feed (Theoretical value given by analysis expressed per kilo D.M. with requirements of animal concerned). Thus, ration equivalent (R.E. would be:

- For maintenance of T.L.U., 0.37 F.U. and 20 gm of D.P./kg D.M.
- For 7 KM of movement per day 0.64 F.U. and 4.6 gm of D.P./kg D.M.
- For 100 gm of weight gain 0.53 F.U. and 4 gm of D.P./kg D.M.
- 1 litre of milk 0.6 F.U. and 0.6 gm of D.P./kg D.M (D.P. expressed in gm/kg D.M.)

The Importance as Browse : Leguminous trees and shrub browse, because of its nitrogen accumulating economy, is even more valuable in animal nutrition than other types. Chemical analysis reveal that browse has high nutrient potential except for high fibre, and, by selective grazing, animals will choose a diet of higher nutritive value than normal sampling and chemical analysis reveal (Wier *et al.*,1959 and Hardison *et al.*,1954).

Quantitative Dietary In-sufficiency in Natural Stand : Throughout the years, the vegetative stage of the edible shrubs or tree species comparing the natural grassland with browse stand in monsoonal zone is relatively varied, so that it may be considered that livestock by its grazing behaviour are always able to find some green and fresh leaves but the quantity of feed they can make use of is itself most valuable. Cattle never have the opportunity of obtaining 6.25 kg D.M. from browse species that could form the adequate ration.

Hence, it is important to note that animal should find a fair amount of perennial grasses along with shrubs although, such a situation in nature is rare and could only be achieved by raising stand with plantation in proportionate manner evolving a balanced system under silvi-pasture pattern in arid and semi-arid region.

Hence, it appears that from quantitative point view, these feed sources (except for fallen leaves which are akin to straw are fed rich enough to allow for maintenance at all times and usually a certain amount of production also.

Productivity of Silvi-pastoral Vegetation Influenced by Grazing : Yield of pasture varies a great deal depending on intensity and manner in which different types and kinds of animals have grazed in relation to physical environment and dynamic stage in the trend of pasture vegetation.

The average yield of good pastoral area and with little deterioration over number of years is of the order to 1 F.U. or the 3 kg of edible DM/ha per millimetre of actual rainfall.

On a deteriorated pasture unit and on skeletal soil the production is generally 0.2 to 0.5 F.U. or 1.5 kg/ha of dry matter per millimetre of rainfall, that is one half or one fifth of production on non-degraded pasture units on good soil.

Certain pastoral units characterized by continuous and over-grazing the grazing capacity falls from 2 animals per hectare to 1 animal per 4 hectare, on an average.

Thus, all the efforts should be directed to optimize feed and fodder production by maintaining a suitable harmony in various ecological factors involving soil-plant-animal relationship where legumes will play an important role.

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SILVIPASTURE APPROACHES FOR ARID LAND MANAGEMENT

A.L. Choudhary

Growth of the human and livestock population in India has placed tremendous pressure on its land and water resources. Out of the total geographical area of India (328.6 m ha), about 175 m ha is affected by soil erosion and land degradation and about 260 m ha faces varying degree of drought. Excessive exploitation of the nature's gift and indiscriminate felling of forest trees are the major destructive forces operating over the years.

It is estimated that annual average loss of nutrients from the land is 8.4 million tonnes. Average annual loss of production for not developing ravines is worth 3 million tonnes. It is further estimated that India requires 60 m ha for fuel wood and 10 m ha for fodder production. The problem is indeed huge and calls for concerted efforts to meet these challenges. The total area available for grazing in India is over 121.2 m ha and this includes forests, pastures, miscellaneous tree groves, cultivable wastelands and fallow lands. Thus, more than 40% of the geographical area of India is available for grazing. States of Himachal Pradesh, Jammu and Kashmir, Meghalaya, Nagaland and Arunachal Pradesh have more than 70% of their land for grazing. In the extreme desert area viz., Jaisalmer district of Rajasthan state over 95% area is used for grazing domestic herds. These grazing areas provide the main support to livestock in India, whereas forage support in the form of stall feeding is not sufficient enough to feed even the dairy cattle. supply and demand of forages is now widening, mainly due to upward trend in the livestock population and also to some extent, due to poor attention given to grass land improvement and intensive fodder cultivation programme in the States.

Silvipasture production practices have potential not only to conserve the production base of land but also tend to check soil erosion, one of the important and direct cause of land degradation, effectively by use of such technologies affecting both erosive agent (rainfall) and medium (soil). The system has, therefore, low erosion rates against other systems.

Ruminants like cattle, goat and sheep are an extremely important resource in the semi-arid and arid regions. However, their productivity level by and large is extremely low, because of low quality and seasonal nature of forage supply. The problem becomes more acute during dry seasons. In such a situation, forage based agrisilvicultural systems and silvipastoral systems could be of promise. In arid and semi-arid regions careful selection of shrub and tree fodder is important as feeds because these can withstand harsh environmental conditions. Also, in this region, there are large areas of marginal lands that can not support good crop and or pasture growth. Thus agrisilvipasture system could be developed as a feed base also for such regions.

Silvipaspasture system, being a site specific technology, needs to be developed according to the location and people's requirements. Various forms of agroforestry viz., agrisilviculture, improved fallow, multistorey tree garden, plantation crop combinations, alley cropping and silvipastoral systems may be practised with twin objectives of the sustained diverse yields and soil fertility maintenance. Some such options for degraded lands in dry areas are as under:

- Silvipastoral in place of natural savanna on degraded forest lands
- Horti-silvipastoral systems on marginal agricultural lands
- Agri-silvicultural use of rainfed farming areas
- Multi-tree-stylo combinations to derive nursing effect from legume and short rotation tree species
- Farm boundary planting with crop-lands to get improved micro-environment.
- MPTS mixtures around homesteads for shade, fruit and feed
- Suitable species: *Acacia albida, A. farnesiana, A. tortilis, Albizzia amara, Azadirachta indica, Borassus flabellifer, Dalbergia sissoo, Hardwickia binata, Leucaena leucocephala, Melia azedarach, Pongamia pinnata, Prosopis cineraria, Prosopis juliflora.*

Silvipastoral Approach

The grasslands improved through the assisted ecological methods viz., fertiliser application and legume introduction, have a higher herbage production level. Some of it can be conserved for feeding during the long lean period faced in the tropical monsoon belt of India. The erratic monsoon, however, may reduce, some-times substantially, the level of herbage production in the improved pastures, causing large scale livestock migration due to forage scarcity. To meet this situation and also to provide green browse material during the lean period, there is a need of a contingency planning, dovetailed in the overall grassland improvement programme. Silvipastoral approach would be the right kind of thing and a silvipasture would serve as an insurance against unforeseen situations. What is needed is to introduce in the grassland the forage shrubs and trees in a proportion that this does not overshadow the herbage production. For example, in an arid rangeland in the 350 mm annual average rainfall zone, it has been found that 14% of the rangeland area covered by shrubs plus tree canopy was optimum for high forage, as well as browse production.

Under poor soil, water and nutrient situation, where cropping is not possible, the programme of silvipastoral management serves the twin purpose of forage and wood production with system conservation. The multi purpose species planted at 4 x 5 m or 5 x 5 m spacing and the inter-row space sown with grasses and legumes, optimise the overall gains during the early growth period of trees with cut and carry system of forage and in situ grazing afterwards. It has been found that under a 1000 mm annual rainfall situation with 9 dry months, the annual production was 3.65 t/ha by incorporating cutting and manuring schemes under a normal rainfall year. The identification of a versatile range legume *Stylosanthes hamata* added to the nutritive value of the grass and provided excellent ground cover to eliminate weeds and improve the soil fertility.

Socio-economic and Technological Issues

Improvement of such resources through silvipastoral technology and its sustainability depends on who benefits. In case it has to be operated by Government agency we may have little participation but more negative interactions. If managed by the community groups then interest of the weaker sections and landless or in a situation where every one was to get benefited, the proper strategies for its adoption need to be worked out. Protection of such lands can be better achieved by inviting peoples participation through cooperatives and building of faith in them. It is seen that any amount of policing may not help this situation. It shall only come when full confidence has been built up in the participatory groups.

The system of silvipasture can really be sustainable if some of the issues discussed above are kept in mind. We may have to further analyse the issues to identify constraints and identify the basic inputs to the system that is needed. Some of these could be listed as under:

- People's willing support is very important for any wasteland development programme. Women's participation in such programmes is even more important.
- Most of the wastelands are exposed to stray grazing, the social cost of which is too high. Controlling grazing is a difficult problem. Public support in keeping the livestock away would be meaningful if alternate arrangements to meet fodder requirements can be suggested.
- Vast arid areas are under the control of revenue authorities who do not have adequate staff to look after these areas. Practice of giving such areas on long term lease to institutions and individuals needs be encouraged.
- Extension related to tree farming and protection of wastelands is inadequate.
- Land tenure giving security to Land owners and sound base of Land record would encourage Long term investment by farmers. Legal rights to trees and ill conceived 'tree patta systems' i.e., "right on trees but no right on Land" contained several clauses making it unpopular among farmers.
- In any wastelands development programme, a farming system approach is important. In such systems, research diagnostics require an integrated understanding and social science enquires rather than performing biological experiments. This requires a deep understanding of the needs of the clients.
- Availability of adequate and timely funds for afforestation is very important as the items of work are largely bound by time and season.
- Protection of plantation is the single most important problem. Feasibility of various methods of fencing for different areas needs to be looked into. Planting of selected live hedges on the boundary can help to a large extent check stray animals.
- Technology for soil and moisture conservation on different types of wastelands need to be assessed and developed.

Research and Development Priorities

Some of the research and development priorities of exploit the potential of arid lands in India are indicated below:

- Genetic upgrading of suitable tree species for faster biomass productivity.
- Suitable nursery and planting techniques to ensure proper establishment and cost reduction.
- Introduction of top feed species to make fodder availability during lean periods.
- Screening and selection of salt tolerant strains of tree species and fruit crops.

- Availability of technical information and advice for selection of species, establishment, and maintenance and plantations to the growers.
- Arrangements for marketing the produce well in advance.
- Availability of inputs and adequate funds in time to carry out the operations regularly.
- Cooperatives should be encouraged to take up wasteland development programmes.
- Creating greater awareness of the advantages of national land use policies at all levels through better extension and education system.

Conclusions and Recommendations

To practice silvipasture system for enhancing the supply of demanded goods like fodder, minor products, and fuelwood is the solution and not the imposing stringent laws like compulsory castration of bulls, banning people from entering forest, and curtailing their rights to trees and other products from private degraded lands.

There is not much scope to expand the forest area managed by the Government. Therefore, degraded and marginal lands should be planted with suitable tree species. For the development of these lands the following suggestions are made:

- Firm political commitment towards policies and implementation.
- Proper strategies and working methods should be developed.
- Target groups should be involved in all rural forestry works through the Zila Parishads and be technically supported and supervised by national and regional forestry officials.
- To attract local people, benefit sharing mechanisms should be applied.
- Co-operation of extension oriented NGO's and independent organisations should be stimulated.
- Training at all levels including project personnel and target groups should be provided and seminars organised.
- Extension methods, also for transferring research results, should be improved.
- Adequate and timely flow of funds should be ensured.
- For taking up afforestation and silvipasture programmes in wastelands on a large scale, the following steps have to be taken urgently.
- Identification and survey of different degraded soils .and their classification for reafforestation purpose.
- Identification of different tree species which can tolerate stresses of moisture, nutrients, salinity/alkalinity, acidity, etc.
- Selection of multipurpose tree species suited to specific site conditions.
- Genetic improvement in fuelwood and fodder species for raising nurseries, plantations, and use of bio-fertilisers, etc.

ASSESSMENT OF SOME PLANT AND SOIL PARAMETERS RELATED TO THE PERFORMANCE OF SILVI PASTORAL SYSTEMS

Uday Burman and B.K. Dutta

The intricacies of above ground and below ground interaction in a silvipastoral system can be better understood through proper periodical assessment of a) above ground biomass, b) below ground biomass, c) soil moisture, d) plant water relation parameters and e) plant and soil nutrient analysis.

Estimation of above Ground Biomass

Destructive sampling for total biomass accumulation is possible only at nursery of seedling stage however for bigger trees use of regression equations for biomass is very useful even though it has certain limitations e.g. 1) it is inappropriate to apply equation outside the range of sizes used to develop it, and 2) caution must be exercised in applying an equation outside the geographic region for which it was developed.

Wood Biomass

1) Randomly select trees in appropriate size class, 2) Measure DBH and height, 3) Fell tree, 4) Remove all branches, 5) Saw stem into sections, 6) Record fresh weight for branches and stem by spring balance, 7) Select subsamples of three branches-remove all leaves from branches and record total fresh weight of leaves and stripped branches and 8) Transport leaves, branches and stem sections to laboratory for recording fresh weight and dry weight after oven drying at 70 °C for at least 48 hours. Develop regression equations. Foliage biomass may be predicted using area of sapwood as independent variable (Gower *et al.*, 1987).

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Estimation of Below Ground Biomass and Related Parameters

i)Horizontal Extent and Morphology

(a) root excavation, b) radioactive tracer method

Method 1- inject highly active radio-isotope
- trace activity with Geiger counter or by analyzing soil cores

Method 2- inject radio-isotope to soil
- monitor stems of surrounding trees for radioactivity

ii) Vertical Distribution and Extent

- Profile wall technique - dig the trench - prepare profile wall - expose roots - map and count

Limitations a) technique is destructive, b) may not work in stony soils and c) difficult to apply statistics to the results obtained

iii) Root Biomass

- Complete extraction - regression technique wherein weight of various root classes are regressed against the DBH to obtain a prediction equation.

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Soil Moisture Determination

i) Gravimetry with Oven/Microwave Oven Drying

Place sample (about 100g) of soil in metacans with tight fitting lids. Weigh immediately. Place samples with lid off and dry to constant weight. Remove sample from oven, replace lid and place it in a dessicator until cool. Weight it again. Tare the container weight. Compute the water content.

Limitations-definition of dry state - variation in oven temperature - variation in balance - drying time may vary with kind of colloidal materials present

ii) Electrical Conductivity and Capacitance

Calibrate blocks of either nylon cloth/fibre glass/gypsum - install blocks in field. Pack it properly to ensure good contact with soil - measure resistance and convert to water content value with a calibration curve

Limitation - a) Not direct method as it utilizes the concept that equilibrium between block and soil is a matric potential equilibrium and not water content equilibrium, b) in net range, resistance change with changing water content is small and precision is low, and c) gypsum block gradually deteriorates particularly in sodic soils.

iii) Neutron Thermalization

- Install access tubing and make several standard counts before probe is lowered.
- Make one or more counts at each depth convert count ratios to volumetric water.
- Content through calibration curve.

Limitation a) If used improperly hazardous being radioactive, b) manufacturer's calibration curve inadequate when soil is unusual or if access tubes are different in size or material.

iv) Gamma Ray or Neutron Attenuation

- Change in attenuation of monoenergetic gamma ray due to changes in water content recorded.

v) Lysimetry

- Involves the volumetric measurement of all incoming and outgoing water of a container which encloses an isolated soil mass with bare or vegetated surface four types a) weighing - directly gives soil water depletion, b) non-weighing - indirectly gives moisture depletion by installing resistance blocks or tensiometer, c) zero-tension lysimeter, and d) suction lysimeter (useful for leachate collection).

vi) Time Domain Reflectometry

- Measures dielectric constant of soil which is dependent on its water content.

vii) Tensiometer (Indirect Method)

- Measures soil water potential which in turn varies with soil moisture.

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Water Relation Parameters and other Related Parameters

i) Plant Water Potential (Instrument - Pressure Chamber)

Operation :

- Cut a twig from the plant to be tested. A clean slanting surface is best. Use a sharp blade and avoid breaking of the twig. Remove the bark for about one inch away from the cut surface.

- Insert a twig into a hole in the cover seal and press the seal into the recess in the cover with the twig poking through the hole in the cover.Place the cover on the chamber press down firmly and rotate clockwise to stop (insertion toll may be used if necessary).
- Open the valve of the chamber and observe the cut surface of the twig. A hand lens may be helpful for small twigs.
- When a film of water appears on the cut surface of the twig. Close the valve and read the water potential on the gauge.
- Open the exhaust valve, remove the cover and discard the twig. Repeat for another measurement.
- After completion of the measurement close valve of the tank, bleed pressure from the hose by opening chamber value while cover is removed and lubricate 'O' ring before storing.

ii) Canopy Temperature (Instrument: Infra-red Thermometer)

Operation - Point the instrument at the object to be measured and display will immediately indicate the temperature press trigger on the front of the hand grip for determine the temperature difference between the target and the ambient temperature while recording temperature of organic targets set the emissivity switch between 0.95 to 0.99

Application - Helps in irrigation scheduling as a) leaves of well watered crop canopy is much cooler than the surrounding air, and b) temperature rises as the soil moisture is depleted.

Advantages - a) Measures radiant thermal energy therefore physical contact not necessary, b) Response time is less, and c) Portable with rechargeable Ni – Cd battery

iii) Radiation (Instrument : Integrated Radiometer)

Sensors-

(A) Quantum - measure PAR (400-700nm) Units=E S^{-1} m^{-2}

(B) Pyranometer - measures solar radiation received from whole hemisphere (global sun + sky radiation) between 400 - 1100 nm, Units = Wm^{-2}

(C) Photometer-measures illumination as human eyes see (400-700 nm), Units = lux

Operation a) Zero adjustment disconnect any input to the instrument - set integration time to see and range to x1 - set function switch to the position it will be used - insert small screw driver into the zero screw and adjust till the display reads '000', b) Set the sensors in position and hook them with multisensor console, c) Record the reading with sensor in air/water depending on the situation i.e. in arid or under water respectively and d) when in battery mode if the display reads below 300 change all three 9-volts transistor batteries.

iv) Transpiration (Instrument: Autoporometer)

Operation - Acclimate the instrument to ambient condition with null adjust valve closed and sensor head leaf clamp in open position, adjust null valve for the dry air flow to maintain steady state humidity in cuvette, clamp in sample to the sensor head and immediately press "HUMSET" switch for 1-5 seconds to set null point humidity almost equal to ambient (If humidity is less or more adjust through null switch). At null point humidity the indicator painter should be within the scale ends.

Nitrogen Determination for Soil and Plant Tissue

A general approximation of total soil N_2 content can be made from organic matter 0.M x 0.03 = N otherwise modified kjeldahl method is followed

Procedure

Digestion: A soil sample of 5 gm or 0.5 g dried plant tissue finely grounded and sieved. 1 gm Na_2SO_4, catalyst digestion mixture and 35 ml of con H_2SO_4 were added and swirled. It is then digested for one hour. At the end of digestion the heating is stopped and 300 ml water is added to the cooled mixture.

Distillation: 25 ml of 4% Boric acid is pipetted into 500 ml conical flask and drops of bromo-cresol-methyl red. Indicator solution was added and placed below the receiver tube. Cooling water is started and digested material is poured into slanted distillation unit. 100-125 ml of 40% NaOH is added slowly. Heating is started and temperature is raised slowly again when approximately 100-150 ml distillate is collected, it is put off.

Percent 0% N in soil/plant = $(T-B) x N x 1.4 x S^{-1}$

where T= sample titration mt standard acid; B= blank titration standard acid; N= normality of standard acid; S= sample weight gm

Reference : M.L. Jackson, 1973, 191-195.

Phosphorus

Chlorostannous Reduced Molybdophosphoric Blue Colour Method

This method has high sensitivity per unit of P present providing ranges from .002 to 0.6 ppm of P.

Development of molybdophosphoric blue colour: The test solution is placed in 50 ml volumetric flask then 2 ml of sulpho-molybdic acid solution is added with the pipette. Volume is made up and 3 drops 0.15 of chloro stannous acid reluctant is added and mixed. Colour developed within 3-4 minutes. It is read photocalorimetrically at 660 nm monochromatic light

Reference : Dickman & Bray (1940) A.E. Analytic Extract 12.665.

Potassium

Flame Photometer Method

Procedure: Using Potassium chloride (0.02 N) and Lithium chloride (0.02 N) prepare a series of standard potassium chloride solution, each containing the same concentration of lithium chloride. Prepare a similar series of standard potassium solution using potassium chloride in 1N ammonium acetate and lithium chloride (0.02N). The concentration of potassium chloride are 0, 0.1, 0.2, 0.3, 0.4, 0.5, 1, 1.5 and 2 meq/l. The optimum concentration in lithium chloride varies with individual flame photometer but is usually 5 to 10 meq/l. Calibrate the flame photometer for operation over the concentration range 0 to 0.5 meq/l. of potassium, using the standard solutions of the appropriate series. The instruments should be recalibrated for operation over the concentration range 0 to 2 meq/l of potassium with another set of standard solution of appropriate series. Pipette an aliquot of the solution to be analysed containing less than 0.1 meq of potassium into a 50 ml volumetric flask. Add an amount of reagent D which, when diluted to a volume of 50 ml, will give a concentration of lithium chloride exactly equal to that in the standard potassium chloride solution. Dilute to volume with water 1N ammonium acetate, if ammonium acetate extracts are being analyzed, mix and determine the potassium concentration by use of the flame photometer and the appropriate calibration curve.

Calculations

Milliequilents per litre of K in water or extract = (meg/of K as found by interpolation of calibration curve x 50)/ml in aliquot).

Reference : Williams (1941)

Calcium and Magnesium

Versenate Method

Procedure: Pretreatment of soil extracts: Ammonium acetate and dispersed organic matter, when present in appreciable amounts, must be almost entirely removed from soil extracts prior to titration with versenate. Evaporation of an aliquot of the soil extract to dryness followed by treatment with aqua regia (3 parts conc. hydrochloric acid +1 part conc. nitric acid) followed by second evaporation to dryness usually suffices for the removal of ammonium acetate and organic matter. Very dark coloured soil extracts may require additional treatment with aqua regia. The residue is dissolved in a quantity of water equal to the original volume of the aliquot take for treatment.

Calcium: Add 5 to 25 ml aliquot containing not more than 0.1 meq of calcium into a 3 or 4 inch diameter porcelain casserole. Dilute to a volume of approximately 25 ml. Add 0.25 ml (5 drops) of approximate 4N NaOH and approximately 50 mg of indicator Titrate with Versenate solution using a 10 ml. microburet. The colour changes from orange red to lavender or purple. When close to the end point, Versenate solution should be added at the rate of about a drop every 5 to 10 second as the colour change is not instantaneous. A blank containing NaOH (4N), black T indicator and a drop or two of F aids in distinguishing the end point. If the sample is over titrated with versenate solution. it may be back titrated with 0.01N Calcium chloride.

Calcium plus magnesium: Pipette 5 to 25 ml aliquot containing not more than 0.1 meq of calcium plus magnesium into a 125 ml Erlenmeyer flask. Dilute to approximately 25 ml add 0.5 ml (10 drops) of buffer solution and 3 or 4 drops of black T indicator. Titrate with versenate, using a 10 ml microburet. The colour change is from wine red to blue or green. No tinge of the wine-red colour should remain at the end point.

Calculation: Milliequivalents per litre of Ca or Ca+ Mg = (ml of versenate solution used x normality of versenate solution as determined by appropriate indicator x 1000) / (ml in aliquot).

Reference : Cheng and Bray (1951). Diehl and Coworkers (1950).

PHYSIOLOGICAL BASIS OF YIELD IN DIFFERENT SILVIPASTORAL SYSTEMS WITH EMPHASIS ON MOISTURE AND FERTILITY MANAGEMENT

Uday Burman and B.K. Dutta

Introduction

Excessive deforestation has resulted in wide gap between supply and demand of fuel, wood, fodder and food crops. Therefore, cultivation of woody perennials in association with crops/grasses has immense potential to ensure stability and sustainability in production and to provide ecological and economic security as compared to conventional monocropping systems.

Indian arid tract, characterised by hostile environmental conditions such as low and erratic rainfall, intense solar radiation and high wind velocity, has low and uncertain productivity. Therefore, in arid tropics the prime consideration in the planning and management of silvipastoral system should be appropriate and efficient use of available water with particular emphasis being placed on optimising its partitioning between tree and grass component.

In arid regions farm soils are highly erodible and it is well established that agroforestry/silvipasture has most apparent potential in such marginal areas. Therefore, it would be ideal to select such a combination of crop/grass and tree species which will have no adverse effect on growth and productivity of each other.

Agroforestry is *NOT* agriculture + forestry but collective name of land use involving compatible species in optimum spatial and temporal arrangements applying appropriate method of management.

Interaction Between Components

Long term sustenance of any agroforestry practice requires basic knowledge of tree crop/grass interaction.

Whenever we seek to improve aerial environment within specific system we should always be aware of the possible implications and consequences of below ground interactions.

In intercropping - root establishment of both the components is at the same time.

In silvipasture/agroforestry - root system of perennial is established when crop is sown

Above ground interactions involves effect on light interception, temperature and wind speed while below ground interactions with moisture and nutrient availability to both the components. Tree acts as :

- Protective zone.
- Protects under ground water sources.
- Recycle nutrients through their litterfall and fine root turnover.
- Answers direct financial returns.

Amendments of Microclimate

Changes in soil temperature, relative humidity and incident radiations as well as wind speed around tree on agriculture/pasture lands is well known. Normally protection zone of a tree is 3H where H stands for height when planted in rows (Chaturvedi, 1988). In some cases water input beneath the canopy due to rainfall interception is reduced by 20% (Trilica *et al.* 1988). 13 years old *Acacia tortilis* in arid tracts allowed only 14 to 30% of total incident radiation of that received in open area (Ramakrishna, 1984).

In tree-grass mixed system, dry matter distribution in the understorey as a response to shading is in the direction of increased leaf and stem growth at the expense of root growth (Cannell, 1983, Ericsson, 1995) - This is a preferred response in fodder grasses.

Shelterbelts of different trees across the wind also resulted in variable check on total soil and nutrient loss (Table 1).

Table 1. Soil and nutrient loss under different trees

Species	Total soil loss (kg/ha)	Nutrient loss (g/ha)		
		N	P	K
Prosopis juliflora	351.2	123.0	65.0	667.4
Cassia siamea	184.3	64.5	34.1	350.2
Acacia tortilis	300.0	105.0	58.5	570.0
Bare	546.8	191.4	101.2	1039.0

(Gupta, 1983)

C.siamea was more effective because of thicker branching and heavy foliage. This reduces wind velocity

Changes in Soil Physical and Chemical Properties

.Soil physico-chemical properties have been reported to vary under different trees as depicted in Table 2

In sodic soils at Karnai plantation of *Eucalyptus teriticornis, A. nilotica, A. lebbeck, P. juliflora* and *Terminalia arjuna* had ameliorative effects. pH and electrical conductivity was

Table 2. Effect of tree species on soil properties

Particular	Open canopy	*A. nilotica*	*A. lebbeck*
pH	7.8	7.4	7.2
EC	0.41	0.30	0.27
OC(%)	0.39	0.57	0.61
Av. N (kg/he)	95.2	137.5	143.2
P	9.8	13.2	14.0
K	167.5	206.2	213.0
Infiltration rate (cm hr -1)	4.2	3.2	3.0
Compaction (kg/cm)	8.2	6.2	5.8

Source : (Hazara, 1988)

reduced, while content of organic carbon and available phosphorus and potassium increased (Singh and Gill, 1992). In arid soils, under the canopy of most tree species the percentage of sand decreased and that of clay and silt increased upto 120 cm depth. However, at greater depths reverse trend was observed. Furthermore, soil beneath tree cover had higher OC than open field (Aggarwal *et al* 1976).

Roots of trees are known to bind soil differentially (Table 3.). This soil reinforcement characteristics checks soil erosion to varying levels depending on dry weight of fibrous roots (W) and its average radius (r).

Table 3. Soil reinforcement (binding) characteristics of 28 months old tree species from Doon Valley, India

Tree species	Soil binding factor (W/r^2)
Bauhinia purpurea	72.3
Grewia optiva	131.0
Eucalyptus tereticornis	55.9
Leucaena leucocephala	152.0
Ougeinia oojeinensis	228.0

Source: Dhyani *et al.*, (1990)

Introduction of *Panicum maximum* as an understorey species under the trees species as in Table 1 leads to further reduction in soil pH, EC, infiltration rate and compaction but increase in organic carbon, nitrogen, phosphorus and potassium content after three years. Grass alone too showed similar response (Hazara, 1988). Grasses are also known to differentially accumulate nutrients from identical sites (Dutta and Dhir, 1980). *Cenchrus ciliaris* and *C. setigerus* revealed identical behaviour. *Lasiurus sindicus* however had high Ca and Mn but low Na.

Dynamics of Moisture Depletion Pattern

In soil during the drying process from water potential near zero to a point where wilting occurs, leaf and root water potential of a typical transpiring plant follows a diurnal rhythm. There is all likelihood of plants reaching permanent wilting percentage earlier in arid soils because of its sandy nature.

Therefore, quantification of water use by plant components in a given soil environment complex is of great practical significance for its close relationship with plant production in general and for its involvement in hydrological cycle. Such assessment becomes more meaningful in the arid areas. Transpiration from plants and evaporation from soil surface are the two main sources of water loss. Nikolaeviteh an UNESCO expert while working on water balance at CAZRI reported that only 18 per cent of water loss occurred due to evaporation from soil while transpirational loss amounted for as much as 64 percent; the remaining 18 percent was lost by percolation to the kankar layer (Mann and Lahiri, 1979). In general, most arid plants transpire at very high rate thereby restricting their active growth (Table 4).

Table 4. Average transpirational water loss by trees in different seasons

Species	Transpiration (g/g tr. wt/hr)	
	Summer	winter
P. cineraria	1.76-2.49	0.27-0.33
T. undulata	0.66-1.30	0.38-0.61
A. bivenosa	0.51-0.59	0.17-0.29
H. binata	0.72-1.12	0.36-0.49
A. senegal	1.01-1.76	0.34-0.54
D. nutans•	0.60-1.00	0.23-0.35

Source Burman, (unpublished)

Under field conditions moisture distribution in the 0-30 cm profile under *P. juliflora* indicated lower depletion than *T. undulata, A. senegal* and *Albizzia lebbek* (Gupta and Saxena, 1978). This trend got reversed at deeper layers. Plants extracting water from water table or just above it (phreatophytes e.g. *P. cineraria*) not only avoid competition in the upper strata but also transfer nutrients from depths to surface (Cronnor, 1983).

Roots : Major Nutrient Source

Though leaf fall is considered as major conduit of organic matter addition and therefore of nutrients to soil (Brinson *et al.* 1980) fine roots have been calculated to contribute 2-4 times .more N, 6-10 times more P&K and 2-3 times more Ca to soil than aboveground litterfall (Bowen, 1984). This is more clearly illustrated in Table 5.

Table 5. Nutrient return from the above and below ground vegetation components in a yellow popular (*Liriodendron tulipifera*) forest in Tennessee

Process	Return (kg / ha / hr)		
	Biomass	N	K
Above ground processes			
Litterfall	3310	42.2	10.0
Leaching	-	2.3	29.4
Total	3310	44.5	39.4
Below ground processes			
Root death	6750	76	128
Root consumption	750	9	14
Root exudation and leaching	-	-	128
Total	7500	85.0	270
Ratio of below : above ground	2.3	1.9	6.9

(Source : Cox *et al.*, 1978)

Grass roots are also known to play pivotal role in fertilized rangelands or pastures. In a silvipastoral system after presence of roots is established in vertical and/or horizontal zone of the associated components the effectiveness of these roots will depend on SRL and LV. Species with high SRL (specific root length) and LV (length/soil volume) extract more water and nutrients.

Criteria for Species Selection

Khosla and Sehgal (1988) have identified following characteristic favoured for the tree component of silvipastoral system in arid and semi arid tropics :

> N_2 fixing, tolerant to heavy lopping , wide and light crown , good coppicer, no toxin in leaves, palatable, no allelopathic effect on pasture, litter easily degradable, drought tolerant, fast growing, multipurpose, high biomass yielding , highly nutritive, wide adaptability, fodder availability during lean period ,amenable to wide spacing.

It is difficult for one species to possess all the above characteristics, so species selection programmes have invariably restricted themselves to few species identified for that region e.g. out of *Ailanthus excelsa, A. indica, D. nutans* and *P. cineraria* identified for area around Avikanagar, Rajasthan forage fodder yield was maximum (43.10 kg/tree) from the last species (Hasan *et al.* 1988).

Further, though preference is invariably for fast growing species, on sustainable basis they are not fast as they lead to deterioration of environment by faster depletion of water and nutrient resources (Purohit, 1994). Considering environmental constraints and biomass demand, component species should have :

- Low Water Consumption Per Unit Dry Wt.
- High Par Absorption Potential
- Leafy (evergreen) during unfavourable period
- High photosynthetic rate
- Low transpiration rate

Based on water consumption per unit biomass produced *Wrightia tomentosa* followed by *A. lebbeck, P. juliflora* and *Acacia nilotica* are promising tree species for large scale plantation in dry region (Srivastava and Misra, 1989).

Comparative performance of different grass species have also been studied under Indian arid zone conditions. *Cenchrus ciliaris* has been rated better than *C. setigerus* due to its high germination percentage, salt resistance and fodder production (Gupta *et al.* 1970). Further, boot leaf stage was best time for its utilization when crude protein is maximum.

Nutrient Cycling

Forest and grasslands have been reported to enrich soil with different nutrients (Jha *et al.* 1995) .Organic carbon, nitrogen, potassium and Ca are invariably more in forest floor while phosphorus is more in grasslands. This often leads to drastic depletion of specific nutrients in sole component system and therefore in order to maintain proper nutrient balance silvipastoral system is often advocated.

Distance from trees also plays pivotal role in influencing nitrogen dynamics (Browaldh, 1995). In a field study done at Sweden, soil sampling done from 0-10 cm layer at A (0.5-1.5 m), B (2.5-3.5 m) and C (4.0-5.0 m) distances from trees revealed significantly larger amounts of organic matter, total carbon and nitrogen at A than at B or C. This indicated increased inputs of trees through litter, decaying roots and root exudates. N-mineralization, potential nitrification and respiration were significantly higher at A than at B and C. Trees also resulted in better utilization of N and moisture in soil thereby reducing potential for NO_3 leaching and accumulation of N close to trees.

Perusal of available literature reveals that decomposition of leaf-fall accounts for substantial share of nutrient build-up under the trees. Further, trees are likely to reflect variable response owing to the variation in their N and other metabolite content. Tarafdar and Rao (1992) reported following sequence of decomposition: *Prosopis juliflora>Albizia lebbeck>Tecomella undulata> Eucalyptus camaldulensis and Acacia nilotica>control* (bare soil). *P. juliflora* leaves probably decomposed easily due to higher cellulose content. *A. nilotica*, on the contrary, had high liquid hemicellulose contents (Bohra and Abichandani, 1987). Some authors have attributed significant role to N-content while others (Prescott, 1995) clearly demonstrated that N-availability alone, exogenous or endogenous does not control rates of litter decomposition. Lignin to nitrogen content, on the contrary, is more important. Its higher ratio reduces rate of decomposition. Our work (Burman, unpublished) also revealed that *A. eriopoda, Simmondsia chinesis, A. aneura* and *A. ampliceps* had high L/N ratio while *Ziziphus, P. juliflora, P. cineraria* and *H. binata* had low L/N. The latter group also had high N, P and K content. This will have clear reflections on the suitability of the species in arid climate.

Impact of Nutrient Input

Nutrient availability have been reported to affect growth and shoot ratio of seedlings (Ericsson, 1995). When N, P and S were major constraints root growth was promoted while opposite pattern was observed when K, Mg and Mn was low. Ca, Fe and Zn, however, had no effect on root: shoot ratio.

With the concept of exogenous fertilizer application in forest and grasslands gaining grounds in order to sustain productivity the concept of fertilizer prescription for pre-set yield levels becomes important (Velayutham, 1979). The nutrient uptake for producing desired forage yield at a particular period can be calculated as-

$$F\ (\text{nutrients}) = \left[(YT \times A) - \left(\frac{STV \times B}{100}\right)\right] \frac{100}{C}$$

Where,

F	=	Fertilizer requirement (kg/ha)
YT	=	Green forage yield target (q/ha)
A	=	Total nutrient uptake to produce one quintal of green forage
STV	=	Soil Test Value
B	=	Uptake STV
C	=	Expected nutrient contribution (from STV)

Further, nitrogen requirement (10-15 kg-N/ha) in arid regions for sustained productivity can also be met by *Azospirillum* (Lahiri, *et al.*, 1988) .Nitrogen gains from different ecosystem is elaborated in Table 6.

Table 6. Nitrogen gains from biological N_2 fixation

Ecosystem	Range in reported values kg N/ha/year
Arable land	7 - 28
Pasture (non-legume)	7 - 114
Pasture (grass-legume)	73 - 865
Forest	58 - 594
Paddy	13 - 99
Alfalfa	125 - 335
Red clover	85 - 190
pea	80 - 150
Soyabean	65 - 115
Cowpea	65 - 130

Reconstructed after Mengel and Kirkby 1982, Alexander, 1977

Further, in order to meet N-requirement of the system leguminous components have been advocated since long. N_2 fixing trees are reported to increase agronomic yield of associated crop. Their litter too has been reported to decompose faster than those from non-N_2 fixing (Sharma *et al.*, 1994, 1995) trees. In this regard distribution of nitrogen in different compartments of Alnus - Cardamom system in comparison to mixed spp. cardamom is illustrated below (Fig. 1).

Management for Sustainable Yield

Management of trees for sustainable yield involves two major aspects viz.,

- Alleviation of allelopathic effects through root trenching or barriers with 400 gauge clear polythene sheet. However, the barrier may not be very effective in long duration crops like castor because reproductive phase occurred in dry season when water is being drawn from below 0.5 metres.
- Lopping for reducing competition for light.

On similar lines management of grasses is important as forage is required for livestock while fibrous roots helps in controlling soil erosion. Thus pasture management practices should take care of both root and rhizome for regrowth. Longer cutting interval favoured root and rhizome growth in *C. ciliaris, C. setigerus* and *Lasiurus sindicus* (Shankarnarayan *et al* 1979; Kathju *et al.* 1985). However, height of cutting did not influence underground biomass in *C. setigerus*, decreased in *L. sindicus* but increased in *C. ciliaris*. In the latter species this is likely to increase soil binding index and consequently promote soil conservation. Further, application of N (40 kg ha^{-1}) increased root number and this helped in regaining root vigour in the grasses. Thus proper interval between grazing, its intensity and nutrient inputs results in accumulation of reserves in root and rhizome for regrowth.

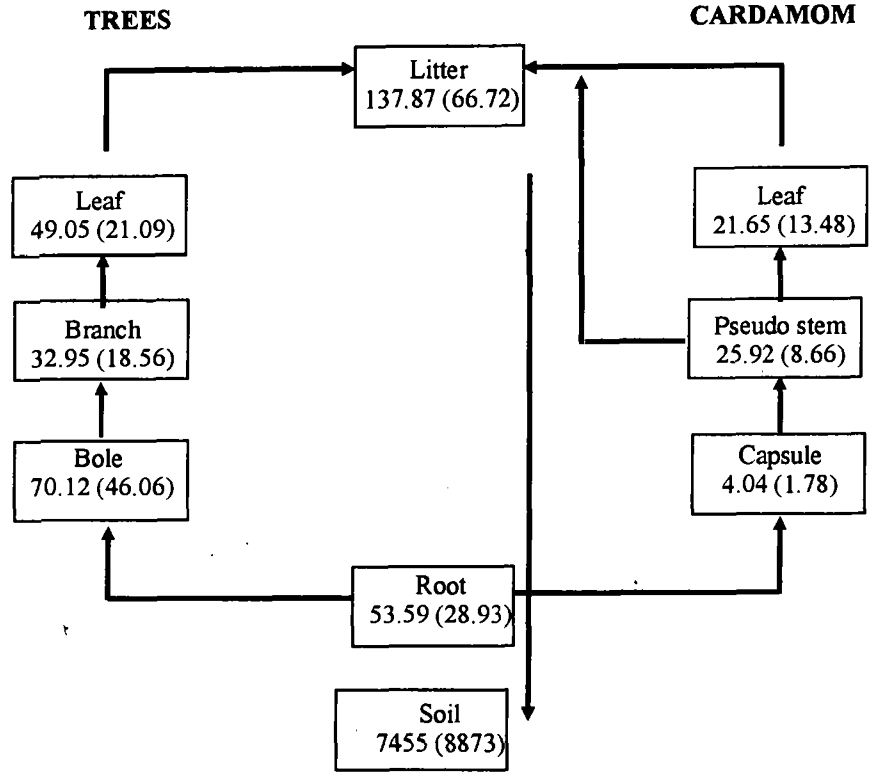

Fig. 1 Values within parenthesis are of mixed spp-Cardamom system.
Units for compartments is kg/ha.

Conclusion

Since cultivation of crops is very risky and uneconomical in arid lands, most desert farmer raise livestock as a subsidiary occupation to cover risk and uncertainty of crop production. While planning for silvipastoral system consideration should be given to above and below ground interactions in order to achieve optimum productivity on sustainable basis.

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LIVESTOCK PRODUCTIVITY UNDER SILVIPASTORAL SYSTEM

S.K. Kaushish and A.K. Patel

Introduction

A major portion of the arid region and parts of semi-arid region of the country have been classified under class IV to VII lands as per the FAO land use classification. Such lands, specially under low rainfall areas, i.e., less than 500 mm, are only suitable for silvipastoral development. Livestock production, therefore, plays an important role in the management and utilisation of arid and semi-arid lands. The population density of livestock, on an average, ranged from 0.7 - 1.4 animal unit per hectare with total population of 17.2 million cattle and buffaloes, 22.5 million small ruminants and 0.8 million camels.

As a result of hostile environmental conditions and high pressure of human population, livestock raising is one of the principal sources of livelihood of local population. About two-thirds of bread earners in the households surveyed in Anupgarh-Pugal tract of western Rajasthan, follow animal husbandry as their main occupation (Anonymous, 1965). Livestock in Rajasthan is mostly maintained on extensive grazing on rangelands. Owing to harsh climatic conditions, the nature of the pastures and the grazing pressure, ground vegetation is usually available for about six months. During the rest of the year, feeding of large ruminants, shifts to crop residues, supplemented with concentrate feed where there is a market for milk. Small ruminants and camels continue to be extensively grazed and in the absence of grass, they depend on browsing leaves and twigs of woody species. These shrubs and trees are a major component of the silvipastoral system. It is, therefore, necessary to assess the productivity of land in terms of livestock production, economic returns and the long range benefit to the land. This paper attempts to discuss livestock productivity under rangelands of the arid zone of Rajasthan.

Forage

The drier tract of Rajasthan could broadly be divided in two zones (i) zone 'A' with mean annual rainfall below 300 mm (arid zone) (ii) zone 'B' with annual rainfall above 300 mm (semi arid). In normal rainfall years, forage needs are just met within zone 'B' to the extent of 16.4%, giving an overall deficit of 8.4% for the arid zone of Rajasthan. Fodder shortage assumes an alarming state during low rainfall years, which are quite frequent in arid region. It is, therefore, necessary to have about 25 to 30 fodder trees per hectare in any good grassland, which can provide feed during drought period. Introduction of suitable leguminous trees will not only provide nutritionally better quality fodder during the lean period, but will also be useful in nitrogen build up in the soil and will provide shade to the grazing animals. In addition, fodder trees and shrubs will ameliorate the microclimatic conditions and thereby improve conditions for better regeneration of grasses. The nutritive value and palatability of various important grasses and top feeds in arid zone are given in Table 1.

Table 1. Palatability ratings and chemical analysis of feed species

Botanical name	Common name	Palatability rating	Crude Protein	Crude Fibre	Nitrogen Free Extract	Ash	P	Ca	Mg
Acacia nilotica	Babul	Good	13.9	9.2	69.8	7.1	0.1	2.6	0.4
Acacia senegal	Kumat	Moderate	10.3	9.5	65.7	16.4	0.1	6.9	0.6
Acacia tortilis	Israeli babul	Good					0.14	2.2	0.4
Acacia leucophloea	Orinja	Moderate	15.0	29.0	45.0	9.0			
Azadirachta indica	Neem	Fair	12.4	11.4	66.6	9.4	0.1	3.4	0.6
Prosopis cineraria	Khejri	Good	13.9	20.3	59.2	6.5	0.2	1.9	0.5
Tecomella undulata	Rohida	Fair	12.2	15.8	63.0	8.9	0.2	3.4	0.9
Ailanthus excelsa	Ardu	Good	19.0	23.0	47.7	11.0	0.1	3.26	0.8
Pithecellobium dulce	Jungli jalebi	Good	23.0						
Ziziphus nummularia	Bordi	Good	11.7	16.0	65.0	7.2	0.2	1.6	0.3
Ziziphus mauritiana	Ber	Good	15.0	15.0	56.0	14.0	0.14	2.0	-
Cenchrus ciliaris	Anjan	Good	11.4	27.2	41.1	18.1	-	-	-
Lasiurus sindicus	Sewan	Fair	5.98	30.1	44.7	-	-	-	-

NB: Palatability ratings of 'Good', 'Moderate', 'Fair' and 'Poor' were arrived at by conducting trials with sheep following the cafeteria technique.

Source: Ganguli, Kaul and Nambiar (1964)

Livestock

Livestock of the arid zone of Rajasthan is reputed for their inherent high production potential and drought hardiness. Cows of Tharparkar, Rathi, Gir and Kankrej breeds possess high milk production capacity (1500 to 2500 Lt./lactation) and bullocks of Nagauri, Hariana and Kankrej breeds are excellent draught animals. Carpet wool of sheep from desert areas helps in earning substantial foreign exchange. Goats are drought hardy, prolific breeders and are reputed for mutton/milk production. Camels are important source of transport in the sandy tract of the arid zone. However, the production from the domestic animals has received a set back due to subnormal level of nutrition, resulting from extremely high pressure of livestock.

The overall livestock population in the Rajasthan increased from 25.5 millions in 1951 to 40.9 millions in 1988. The livestock density per sq. km in 1951 was 49 animal units which increased to 67 animal units by 1988. Total number of Adult Cattle Units (ACU) in zone 'A', 'B' and their total is 2.043, 4.690 and 6.733 million, respectively. Availability of land per ACU under grazing in Zone 'A', 'B' and their average is 2.83, 0.59 and 1.27 hectare and cultivated land is 1.76, 1.22 and 1.38 hectare, respectively.

Livestock Production: Different systems of grazing were tried in order to optimise production from different species of livestock . In general, growth of animals was influenced by rainfall and its distribution pattern and type of soils which finally affect the vegetation.

Gain in body weight of yearling heifers under different intensities of grazing stress on rangelands, viz. (a) light intensity (i.e. based on carrying capacity), T1; (b) heavy intensity (four times stress as compared to light intensity), T2; (c) moderate intensity (double stress as compared to light intensity), T3; (d) heavy intensity, T2 plus concentrate feeding from middle of December to June, T4 and (e) moderate intensity + concentrate feeding from December to June, T5, were studied. The growth on year long basis in case of Tharparkar heifers on *Lasiurus - Aristida* cover (annual rainfall 200 mm) was 70.3, 30.7, 46.7, 95.6 and 122.9 kg/animal under the respective treatments (Ahuja *et al.*, 1971) and of Kankrej heifers under *Cenchrus - Aristida* grass cover (light soils - annual rainfall 433 mm) was 74.0, 63.4, 70.4, 117.7 and 127.3 kg/animal under the above treatments, respectively (Ahuja *et al*;1974). Hence for optimum growth and production of animal, it is essential to provide concentrate ration to productive animals during lean period (i.e. December-June) which practically doubles the livestock production and hastens maturity.

The growth of yearling heifers/month (average of 12 months) under monthly rotational grazing system, based on carrying capacity, was 4.9 to 8.7 kg/animal under *Cenchrus setigerus - Aristida* cover (at Borunda), 3.9 to 8.0 kg/animal under *Sporobolus* cover (at Jadan) and 5.7 to 8.5 kg/animal under *Cenchrus ciliaris - Aristida* cover (at Palsana). From July to October (Monsoon season) on rangelands varied from 6.4 to 17.5 kg/months (Table 2).

Table 2. Average gains in body weight of yearling heifers over different periods of the years when grazed on different rangelands under rotational grazing system

Grass cover type	Rainfall (mm)	Forage yield kg/ha	Carrying Capacity ha/ACU	Breed of cattle kg	Initial body wt.	Average gain (kg/animal month)						
						July Aug.	Sept. Oct.	Nov. Dec.	Jan. Feb	Mar Apr.	May June	Entie Year
Cenchrus	506	519	4.0	Hariana	89.5	13.1	7.3	14.7	6.2	4.4	0.1	7.9
Aristida	1107	1169	4.0		84.0	14.3	13.8	10.9	2.2	3.2	2.3	8.5
Cenchrus	295	1042	4.0	Hariana	103.6	12.7	14.7	7.8	3.7	3.3	-	8.4
Aristida	933	2393	4.0		87.1	17.5	16.3	13.3	6.5	3.6	0.4	8.7
Sporbolus	242	281	4.0	Kankrej	84.6	3.0	14.4	7.7	2.5	0.5	-	6.6
Cyperus	795	2375	4.0		95.6	14.9	12.7	12.0	4.7	4.7	2.3	8.0

The productive performance of Tharparkar cattle under two different management systems,conventional and scientific management was studied under arid conditions. Under conventional system concentrate was fed to only lactating cows however, during first 15 post parturient days, the cows were provided 5 kg of Til (*Sesamum indicum*) oil, 15 kg of Methi (*Trigonella foenum-graecum*) grains, 15 kg of Jaggery and 60 kg cooked sorghum grains. In case of scientifically managed group, concentrate feed was provided to all category of animals as per physiological stage of the animal round the year and the feeding of mineral mixture for most part of the year was carried out. Ecbolic (Replanta powder 1 kg) with jaggery (10 kg) was fed to every early post parturient animal in divided doses. The grazing of animals on *C. ciliaris*, *C. setigerus* and *L. sindicus* rangeland grasses for 6-7 hrs a day was common practice for both the groups. The overall productive performance of cows of conventional and scientific groups is presented in Table 3 The milk fat percent in former (4.57 0.10) group was significantly lower

Table 3. Productivity of Tharparkar cattle under two different management systems

Economic trait	Management System	
	Conventional	Scientific
Lactation milk Yield (kg)	1263.8 ± 159.6	1438.4 ± 140.40
Fat percentage	5.0 ± 0.13	4.6 ± 0.10
Lactation length (days)	369.8 ± 22.5	357.2 ± 27.20
Dry period (days)	149.7 ± 38.6	106.3 ± 43.50

than the latter (5.02 0.13) group (Patel *et al.*, 1994). It is obvious from the study that for higher productive performance of cattle under rangelands in arid zone, scientific incorporation of concentrate in diet is highly essential.

Studies on growth of yearling ram lambs of different rangelands under different systems of 2 to 4 months rotational grazing versus continuous controlled grazing did not reveal any difference in the growth of lambs. However, it varied between breeds and rangelands. Higher growth was recorded during 1966- 67. Gains in live weight of yearling. Jaisalmeri rams was 27.80 kg/animal on *Eleusine - Lasiurus* rangelands, 27.4 kg/animal for Marwari breed on *Cenchrus - Aristida* rangelands and 19.3 kg/animal for Chokla breed on *Cenchrus - Aristida* rangeland (Ahuja, 1967). Growth rate was highest from July to October (approximately 3.2 kg/lamb/month) and thereafter, it slowed down and least gains were observed during March and April (Table 4).

Annual wool yield was found directly proportional to body weight of sheep. Wool yield from rams was higher than that of ewes. Wool yield from adult wethers was 2.1 kg/animal while that of breeding ewes on 'Fair' and 'Good' rangelands was 1.43 and 0.92 kg/animal, respectively. Average yield for yearling lambs on 'Fair' and 'Poor' rangelands was 1.16 and 1.676 kg/animal, respectively (Anonymous, 1965). Yearling ram lambs of Chokla, Marwari and Jaisalmeri breed yielded annually 1.83, 1.86 and 1.54 kg wool/animal/year, respectively during 1966-67.

While studying the performance of native (Malpura) and cross bred sheep at Central Sheep and Wool Research Institute, Avikanagar , where sheep were fed partially on *Acacia arabica* pods during summer but were kept mainly on grazing, the average body weights over the years at birth, 2, 4, 6 and 9 months of age ranged from 2.76 to 2.95; 8.66 to 9.63; 12.33 to 14.11; 15.27 to 18.04 and 17.02 to 21.99 kg, respectively with an overall average of 2.84 ± 0.016, 9.19 ± 0.146, 13.11 ± 0.101, 16.12 ± 0.131 and 19.73 ± 0.162 kg, respectively (Kaushish *et al.*, 1990). The native lambs were significantly ($P < 0.001$)lighter only at birth (4, 6 and 9 months of age). At two and four months of age the differences between native and crossbreed were

Table 4. Growth of different breeds of yearling ram lambs on different types of rangelands

Types of range lands	Forage yield (kg/ha)	Breed of sheep	Increase in body weight (kg/animal)							
			(kg/ animal)	July Aug.	Sept. Oct.	Nov. Dec.	Jan. Feb.	Mar Apr.	May June	Entire year
Sporobolus Cyperus	983	Chokla	16.5	5.65	3.18	3.13	2.66	1.42	2.23	18.3
Aristida Cenchrus	1133	Chokla	13.7	7.84	5.39	0.00	3.13	0.85	3.82	19.3
Sporobolus Cyperus Echninochloa	988	Marwari	12.0	8.35	4.80	4.17	1.02	3.47	4.70	26.51
Cenchrus Aristida	2070	Marwari	12.5	8.47	6.02	2.50	3.40	2.87	4.12	27.40
Sporobolus Cyperus	915	Marwari	12.5	7.82	4.12	1.98	2.67	1.70	5.30	23.59
Aristida	451	Jaisalmeri	14.7	7.55	7.29	4.83	1.85	0.62	4.10	26.15
Eleusine Aristida	431	Jaisalmeri	16.6	9.13	4.87	3.68	2.13	0.38	8.37	27.80

non-significant. The body weights at four, six and nine months of age were influenced greatly by average rainfall during a particular year. The rainfall influenced directly through higher milk production for suckling lambs and indirectly through higher fodder production for grazing lambs.

Studies were carried out from 1987-91 to explore the possibilities of maximising biomass production through single, two and multi-tier systems of fodder production and compare the same with natural pastures under semi-arid conditions of Avikanagar. Results of 5 year studies revealed that multi-tier system *Ailanthus excelsa* (ardu) + *Dichrostachys nutans* + *Cenchrus* provided maximum average dry fodder (23.75 q/ha) + 9.52 q green leaves with highest net returns (Rs. 2056.25/ha) followed by two-tier silvipastoral system (20.93 q/ha dry fodder + 6.21 q green tree leaves), *Cenchrus* pasture (19.13 q/ha) and natural pasture (16.58 q/ha), respectively.

Milk yield of ewes kept on these silvipastoral systems was higher (365.0 to 467.22 ml/day) as compared to *Cenchrus* alone (310.55 ml/day) and natural pastures (285.55 ml/day). Higher milk yield of ewes maintained on silvipastoral systems could be due to green *Ailanthus excelsa* (Ardu) leaves supplementation.

Among comparative species under multi-tier system at the age of two years establishment *Ardu* + *Mulberry* attained the maximum height and basal diameter and at the same time provided more biomass (1196.84 g), dry leaf (253.17 g) and fuel wood (221.42 g) per plant as compared to *A. excelsa* (Ardu)+ *Dichrostachys* (536.1, 90.8 and 149.25 g) and Ardu + *Bauhinia recemosa* (301.53, 71.25 and 39.78 g), respectively.

Nutritive Evaluation and Grazing Studies

Pasture evaluation studies, in terms of nutritive value during different seasons and different months, as well as in terms of animal performance were taken up at Central Sheep and Wool Research Institute, Avikanagar. The main pasture species was *Cenchrus ciliaris* and the grass legume mixed pasture was that of *Cenchrus* and *Dolichos*. The crude protein percentage in the native pasture varied from 4.3 to 10.3 and remained below 7 per cent during September and March. The TDN full expansion intake by rams on available pasture were lowered by 20 to 50 per cent than NRC full expansion allowances. Digestible Crude Protein (DCP) intakes was also not adequate for the most part of the year. Dry Matter (DM) digestibility of *Cenchrus* pasture and *Cenchrus-Dolichos* pasture was 44 and 50 per cent, respectively.

A stocking rate of 5 ewes/ha on *Cenchrus* pasture gave satisfactory performance. Vitamin A level in ewes declined gradually from September to December. Mutton synthetic ewes grazing 8 h/day on *Cenchrus* pasture performed well with annual lambing percentage of 83.5 and adult mortality 5.5 per cent. The body weight of lambs at birth, 3 and 9 months was 3.0, 11.5 and 20.9 kg and annual wool production per sheep was 2.1 kg.

The natural forest rangeland could sustain 3 sheep or goats/ha. Ewes lost weight from January to July followed by an increase in body weight upto December, whereas goats lost weight from February to July. The body weights of lambs and kids at birth, 3 and 6 months of age were 2.7, 8.6, 12.5 and 2.9, 9.3 and 13.6 kg, respectively.

Grazing of 8 to 10 month old kids on rangelands with *Blepharis - Fagania - Cymbopogon - Lasiurus* cover at Jaisalmer resulted in increase in body weight by 9.8 kg/female and 13.5 kg/male kid during grazing period of ten and a half months in 1971-72.

On rangeland with *Cenchrus - Ziziphus* cover at Pali, yearling male goats increased their body weight by 13.2 kg/animal/year during 1977-78. Yearling castrated male goats increased their body weight on 'Good' pasture by 7.2 kg/animal, which amounted to 1800 kg/year on a unit area of 100 ha (Bhimaya *et al* 1969).

In feed lot experiment at C.R. Farm, Jodhpur, the 6 months old kids of Marwari, Jamunapari and their crosses were offered 800 g dry top feed of *P. cineraria* (loong) and *Z. nummularia* (pala) in 1:1 ratio and 200 gm concentrate feed with *ad-libum* water for 47 days. The gain in body weight per month per animal was be 3.79, 2.94 and 3.07 kg for these three breeds, respectively. The highest gain was observed in Marwari and lowest in Jamunapari which may be due to unsuitability of climate to the Jamunapari breeds in the arid regions. It was also observed in this experiment that pala (*Z. nummularia)* was more preferred by kids than loong (*P. cineraria*).

Reproductive performance of different breeds of goats Kuchhi, Marwari and Beetal allowed 8-hr. browsing on *Prosopis cineraria and Acacia arabica* pods and *Azadirachta indica* and *Ziziphus nummularia* leaves besides *Cenchrus ciliaris, C. biflorus, C. setigerus* and *Cynodon dactylon* grasses was studied (Kaushish *et al.*,1994). The average age at puberty, first conception and first kidding was highest in Kuchhi (561.0 ± 6.52, 605.9 ± 4.59 and 760.3±

Beetal (320.1± 4.93, 405.9 ± 4.50 and 520.4 ± 7.32) and Marwari (311.2 ± .75 and 509.4 ± 3.45 days) respectively. The average service period and kidding were least, (157.00 ± 1.30 and 305.0 ± 4.56 days, respectively) in Kuchi and longest in case of Beetal.

Utilisation of Tree Leaves and Pods: Goats could maintain body weight on *Prosopis cineraria* (Khejri leaves dried and fresh lopping), whereas sheep lost weight. Dried *P. cineraria* leaves mixed with concentrate in 60:40 ratio, produced a weight gain of 90 g/day in weaner lambs. The expansion and TDN value of dry *P. cineraria* leaves were 4.6 and 31.6 for goats and 1.5 and 24.9 for sheep, respectively. *Ziziphus nummularia* (Pala) had 5.6 per cent DCP and 49.7 per cent TDN with a nutritive ratio of 1:79.

Rations containing 30 to 50 per cent *Z. nummularia* (Pala) leaves with maize/barley, groundnut cake, mineral mixture and salt in complete feeds have produced weight gains from 100 to 150 g/day in feed lot lambs. *P. cineraria or Z. nummularia* leaves should be fed in combination with other feed ingredients but never as sole feed.

Treatment of *Z. nummularia* leaves with PEG (Polyethylene glycol - 4000) significantly increased DM intake and DM digestibility. The body weight gain was higher in PEG treated group as compared to untreated group. *Ailanthus excelsa* (Ardu) leaves have been found to be best among all tree leaves. *A. excelsa* leaves and wheat bhoosa in 50:50 ratio could form maintenance ration for sheep.

Supplementary Feeding: Fine wool crossbred lambs of about 2 months age, grazing on *Cenchrus* pasture were supplemented with concentrate *ad-lib.* and 75, 50 and 25 per cent of the concentrate intake for 194 days. The lambs in above four groups on an average consumed, 656, 490, 327 and 163g concentrate/lamb/day and gained 123,110,104 and 87 g/day, respectively. First clip average wool production was 1249,1218,876 and 863 g per animal in the respective groups. Hence grazing alone on *Cenchrus* pasture was limiting wool production.

Avivastra ewes and Marwari doves at a stocking rate of 4 animals (2 ewes + 2 goats) grazing on *Cenchrus ciliaris* pasture consumed 37.2 and 28.5 g DM/kg body weight with DM digestibility of 60.8 and 51.0 per cent during lush season and 28.5 and 27.3 g DM/kg body weight with 45.3 and 40.3 per cent digestibility during lean season, respectively. After one year of grazing goats and sheep gained 8.15 kg and 6.2 kg respectively Six monthly greasy fleece yield of the ewes ranged between 1.29 - 1.46 kg and in doves the average daily milk yield was between 514 - 700 ml.

Male hoggets grazing on three, two, single tier silvipasture plots and routine sector management (the biomass availability in these pasture ranged from 21.72 to 28.91 q/ha) re vealed that the weight gain was higher in silvipastoral plots (7.3 kg) compared to sector management (3.4 kg).

Pregnant mutton synthetic ewes maintained on three, two, single tier silvipasture and natural rangelands for 4 months (2 months pregnancy and 2 month post lambing) at stocking density of 12 animals/ha herbage availability at pre and post grazing (g DM/ha) and expansion (q/kg body weight) in grazing ewes were 8.78, 6.69, 32.0; 11.84, 6.41, 38.0; 15.19, 9.33, 43.0 and 26.45, 17.11, 44.0, respectively, in these pasture plots. These pastures could sustain the pregnant and lactating ewes for a short period with a high stocking rate.

The birth and one month weight (kg) of the lambs born to the experimental ewes in three, two, single tier silvipasture, natural rangeland and sector management were 3.10, 5.90; 3.26, 5.94; 2.70, 4.11; 2.80, 3.95 and 3.20, 7.15, respectively. Higher body weight (one month) of lambs in sector management was due to *ad-lib* concentrate supplementation to lambs and 250 g concentrate/head/day to lactating ewes, whereas the experimental animals were maintained on grazing alone. Average milk yield (ml/day) of ewes in three, two, single tier and natural rangelands were 467, 365, 310 and 285 ml, respectively.

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FODDER CONSERVATION TECHNIQUES

P.K. Malaviya and R. Pancholy

Introduction

The ideal and simple method of fodder conservation is to drive off the moisture in the fresh grass with artificial heat and store the product as dried fodder for use when required. To combine cheapness and simplicity yet ensure at the same time a product of high feeding value and virtually independent of weather condition, natural fermentation may be used. It is quite obvious that there is no single conservation system that will meet the requirements of all farm situations, but there are certain principles that apply universally. The composition of the herbage and the stage of growth at which it is cut determine the quality and digestibility of the conserved material. Hence an efficient conservation system can be geared to critical cutting dates and will incorporate waste proof storage facilities. While the process of hay making and ensiling are traditional and simple, special techniques and modifications are required for fodder conservation in arid and semi arid regions taking into consideration the extreme environmental conditions and available forage quality (Pancholy and Mali, 1992).

Hay Making

Basically hay refers to grasses or legumes that are harvested, dried and stored at 85- 90% dry matter. High quality hay is green in colour, leafy and pliable and free from mustiness. When harvested in the proper physiological stage of growth and well cured to 20 per cent or less moisture at the time of storing, hay can be utilised as an excellent feed for dairy cattle. Unfortunately hay in developing countries and arid regions is seldom of the actual hay quality and consists of dry grass on which the seed has ripened and leaves has usually been shed, therefore, in feeding value, it mostly corresponds to the straw or other fibrous residues (Church,1991). Hay can be successfully made, only if, principle of hay making is properly understood and the steps are followed in proper sequence at right stage of crop production.

Principle: The principle involved in hay making is to reduce the water content of the herbage so that it can safely be stored in mass without undergoing fermentation or becoming mouldy. This should be done in such a manner that the hay is not leached by rain and the loss of leaves is kept at minimum.

Kinds of Hay for Arid and Semi-arid Regions

- Legumes Hay
- Non-legume Hay
- Mixed Hay

Procedure for Hay Making

Harvesting of crop: a)The crop should be harvested during the day time after the dew has dried off so that plants when spread over the ground may dry evenly, b)The field should not be wet, otherwise the uniform drying would not be possible, c)The crop should not ripe too much, at the time of cutting as the crop cut early is high in protein, low in crude fibre, contains more of vitamins, is more palatable and will shatter less. The best time for cutting a crop for hay making is when it is half or one third in blossom, (pre-bloom or bud stage).

Curing and storage of hay: In curing it is necessary that the herbage should be saved from bleaching by the sun, and in arid and semi-arid regions, since the sun intensity and duration is pronounced, the material should not be exposed to direct sun for a longer period of the day. The leafy portion should be prevented from shattering during curing considering the less humid conditions of the arids. To prevent this in grasses, chopping to smaller lengths should be avoided. To avoid serious losses of leafy portion and carotenes of the herbage in arid region the hay should be handled early in the morning before it becomes too dry, Hay when ready for storing should not contain more than 20% moisture. Turning, stirring should be done during curing. More than five times as much carotene is preserved through artificial drying than sun drying, with a negligible carotene loss during artificial drying.

During seasons when it is likely to rain, good hay is made by drying on tripod stand or drying on small fences. Tripods or tetrapods, these are constructed from 5 cm-thick larch poles or metal rods 2 to 3 m long. Tripods will hold about 250 to 300 kg of herbage, which becomes 125 to 150 kg of finished hay. In tetrapods 300 to 400 kg of herbage can be held up. An average crop of 100-200 quintal per hectare will need about 30 to 60 tripods per hectare. The hay should be clear off the ground to promote quick drying. Herbages for hay can also be dried on specially designed poles. Fence-type racks made of temporary wire fence with struts on which grass can be loaded. Winding drums are used to keep wire tight. A fully loaded 30-40 m fence will carry 2-3 tonnes of wet grass. As in tripods or tetrapod racks, they must be carefully sited to take full advantage of prevailing wind. Herbage should be kept off the ground.

Storage of hay does not require any special enclosure. Any storage normally used for straws etc. can be used for chopped hay. Unchopped hay can be stacked in a shady place where there is no danger of fire. Stacks in Western Rajasthan are stored in 'karai' - an enclosed structure built of stone slabs at a higher ground level.

Decision for Hay Making

The decision for conserving forage by hay making can be taken considering the following points :

If the weather is uncertain and rains are frequent, hay making should be avoided. Similarly, if the crop/grasses are of poor nutritive value, ensiling should be preferred since when the cutting is late, nutritive value of hay will correspond to that of straws and therefore will be of no use. The warm periods of the day are prolonged,in arid regions, and therefore losses of nutrient due to shattering of leaves will be considerable.

Silage and Microbial Fermentations

Silage is the material produced by the controlled fermentation of a crop of high moisture content. Ensilage is the term given to the process and the container, if used is called the silo.

For arid and semi-arid regions the basic ensiling technology is modified to overcome the shortcomings of the weather extremities. While the basic principle of ensiling remains the same, modified ensiling technology for arid and semi-arid conditions basically require cheap additives for nutritive improvement to go alongwith conservation process (Pancholy and Mali,1994).

Principle of Silage Fermentation

The first essential objective in preserving crop by natural fermentation is the achievement of the anaerobic conditions. The efficiency of anaerobiosis will depend upon the degree of consolidation and the effectiveness of the final sealing. The main aim of the sealing is to prevent re-entry and circulation of air during storage. Where oxygen is in contact with herbage for any period of time, aerobic microbial activity occurs and the material decays to a useless, inedible, and frequently toxic product. The second main objective is to discourage the activity of Clostridia. These bacteria are usually present on harvested forage in the form of spores and can multiply as soon as the conditions in the silo are anaerobic. The growth of these organisms are undesirable.

Suitability of Silage Making under Silvipastoral System in Arid Regions

Grasses under the practical conditions can be best conserved as silage as the modified technology for arid regions permits fluctuations of the season as well as cutting stage. Once infrastructure for silage making is complete, storage conditions and period hardly affects the fodder. If the silage is properly prepared, environmental extremities will not effect the nutritive value during the conservation. Poor quality fodder can be improved by using additives during fermentation.

Fodder Preservation Structure or Silo

The silo in which silage is made is of greatest importance and will determine to large extent the nature and quality of the final product. The size of silo will generally depend upon the number and kind of animals to be fed from it and the length of feeding period. The silo can be above ground or underground. These are discussed in brief.

Tower silo: Tower silos are built of brick, concrete or metal and are durable and wind resistant. But loading of this type of silo is difficult. Either a mechanical loader or a large capacity blower is essential for elevating the cut fodder into tower silo. Walls of the silo should be smooth, circular and perfect in plumb to provide structural strength and to permit free settling and packing of silage without air pockets. The wall should be strong enough to avoid cracking due to lateral pressure. To avoid such failures, heavy reinforcement has to be carried out. Unless water table is very close to the ground level, the upright tower silo offer no special advantage over the other types. The cost of constructing this silo is comparatively much higher.

Bunker and Trench cum Bunker Silo: Bunkers are rectangular structures above the ground. The same structure when located partly below ground (1/3rd to 2/3rd) and partly above the ground is called trench cum bunker silo. Large quantities of forage material can be conserved at a time reducing handling cost. Compression of forages could be done most efficiently with tractors.

Modified Ensiling Process for Arid Regions

The common difficulties in ensiling under arid conditions viz. forage of low carbohydrate content, lack of natural epiphytic flora of lactic acid bacteria and deficit protein levels, can be overcome by using modified ensiling process standardized at CAZRI.

Harvest: The grasses or fodder for silage making is generally harvested at the flowering stage when it has the maximum amount of nutrients. The ideal dry matter for ensiling is 25-30%.

Chopping: The length of the cut sections affects the packing and hence the quality of silage. Grass silage require to be more finely chopped than maize or sorghum. Wilted and dry forages and forage with hollow stems should be chopped more finely than forage of high moisture content thus permitting more thorough packing and eliminating most air packets

Control of Moisture Content: Grasses containing more than 70-75 per cent moisture are heavier and more costly and difficult to handle, apt to produce putrid, slimy silage, have excessive seepage of juices resulting into loss of nutrients and will exert high pressure on silo walls. The high moisture content can be brought down by - wilting, adding dry hay or straw, combining high and low moisture crops and adding dry preservatives.

The second procedure is of immense use in arid and semi-arid regions as it also facilitate improvement of fibrous crop residues by value addition. If the crop is over ripe or matured, the moisture can be adjusted by overnight soaking in required quantity of water to active 60-70% moisture.

Additives for Ensiling of Arid/Semi Arid Region Fodder: a) Molasses: Adding molasses definitely improves the quality of silage of fodders low in sugar content. Molasses also improves palatability and nutritive value of silage. Molasses can be added at the rate of 8 to 10% on dry matter basis depending upon fodder quality. Animal grade jaggery can be substituted where molasses are not available.

b) Lactic Acid Bacteria (LAB): An inoculum of lactic acid bacteria helps in establishment of acidic as well as anaerobic conditions and rapid fermentation. The cheapest source of this can be butter milk, curd or similar fermented milk by products. This is added on the basis of c.f.u. (colony forming units) in the source at the rate of 1.8 x 106 c.f.u.

c) Urea: This can be added at the rate of 1-2% (D.M. basis) as NPN source for protein. It is cheap and easily available and increases crude protein value of the silage.

Rapid filling and sealing: Once silo filling is started, it should be rapid, and for creating the desired type of anaerobic conditions, the forage should be compressed during filling. It should not be filled when it is raining. The top should be covered by insulator like, mud, plastic or loose earth. Sufficient load should also be applied on the top for compactness.

Opening and Feeding: Within 45-60 days silage is normally prepared. The silage may be taken out of the silo from the top in case of tower or trench silo and front side from bunker silo. After opening 2-4 inch layer of silage must be removed daily for feeding.

Quality Parameters for Determination of Hay-silage Quality

Since the main objective in the conservation of any crop is to preserve it at the optimum stage of growth, the maximum retention of nutrients, for use during seasons when the crop is unavailable, it is necessary to evaluate the quality of conserved fodder on the basis of microbiological and biochemical parameters.(AOAC; 1975; Pancholy and Mali,1994)

Dry matter (D.M): It is generally defined as the constant weight a sample attains when heated at 100° C. The simple procedure for forages is to weigh accurately 5 grams (25 g. in case of large size cuts) of material in an empty dish, heating at 105° C±2° C for 2 hours or 60° C ± 2° C for 6-8 hrs, cool in a dessicator and weighed twice. Silage samples can be analysed by toluene distillation method.

pH Can be measured on any standard pH meter and a set of buffers for standardisation. pH of silage should always be 4.2 or lesser.

Lactic acid & volatile fatty acids - Lactic acid is an important indicator for an efficient lactate fermentation of silage. It is determined by Barker and Summerson method by development of blue colour red at 560 lambda. The lactic acid content of the silage should be between 3-12% (DM basis). Butyric and acetic acid determination aids in calculation of Fleigs Index for silage quality.

Crude Protein - To be estimated by microkjeldahl method by transformation of nitrogenous compounds to ammonium sulphate through digestion with boiling sulphuric acid. The cooled acid digest, diluted with water and made basic with sodium hydroxide and the released ammonia is distilled into a boric acid solution which is then titrated with standard sulphuric or hydrochloric acid. Crude protein is calculated as 6.25 x N value. The total nitrogen should not exceed 10% of total feed.

Water soluble carbohydrates (WSC) - These are calculated by Anthrone method using anthrone reagent. The residual water soluble carbohydrate in final silage should be reduced at least by 10% as compared to initial premix value.

Microbiological examinations - Microbiological examination of silage helps in indicating silage quality, presence and quantity of pathogens if any and initial LAB count. Here the silage extract is prepared with autoclaved physiological saline instead of distilled water and sample is collected under aseptic conditions. The extract is diluted and plated on Phenol-rose bengal agar, EMB agar, sodium citrate iron sulphate agar and Rogosa medium for yeasts and moulds, coliforms, Clostridia and Lactobacillus group of organisms.

Physical observations - The hay and silage both should be periodically examined for colour, texture, odour and silage temperature should be recorded at different heights in silo.

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PALATABILITY, CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF DESERT TOP FEEDS

H.C. Bohra and R.K. Abichandani

Introduction

In the true sense, the desert region of western Rajasthan is the area of abudances and scarcities. In this area, with the on set of monsoon all the dormant seeds lying in the soil bank sprout and cover whole ground but when the monsoon withdraws, the plant species either would have consumed or deteriorated nutritionally. Thus from post monsoon till the next monsoon appears, this became zone of scarcities. But there are few species of shrubs and trees (Table 1) which thrive well in this region throughout the scarcity period and provide considerable quantities of nutrients through its moisture laden leaves and nutritious pods which proved to be boon for sustaining livestock of this region. These plants besides providing shade, shelter also supply the much needed nutrients like calcium and B-carotene which are always in short. The leaves of important desert top feed and plants like *Prosopis cineraria* and *Ziziphus nummularia*

Table 1. Important top feed species of Indian desert

Botanical Name	Local Name
Trees	
Acacia nilotica	Desi babul
A. lecoophloea	Reonj
A. nilotica ssp. *cupressiformis*	Khajoor bawali
A. senegal	Kumut
A. tortilis	Israeli babul
Ailanthus excelsa	Ardu
Albizia lebbek	Siris
Anogeissus pendula	Dhok
A. rotundifolia	Indrok
Azadirachta indica	Neem
Ficus bengalensis	Bargad
F. religiosa	Pipal
Leucaena leucocephala	Subabul
Prosopis cineraria	Khejri
P. juliflora	Vilayati babul
Tecomella undulata	Rohida
Salvadora oleoides	Pilujal
S. persica	Kharajal
Ziziphus rotundifolia	Bordi
Shrubs	
Acacia jacquemontii	Bhubavli
Calligonum polygonoides	Phog
Capparis decidua	Kair
Cassia auriculata	Tanwad
Calotropis procera	Aak
Grewia tenax	Gangaran
Maytenus emarginata	Kankera
Ziziphus nummularia	Jharberi

are also rich source of moisture, containing about 75% of its fresh weight during summer. Thus, animals foraging upon fresh leaves of these leaves on ranges can get considerable quantities preformed water embodied in these leaves.

Important Top Feed Species

Besides *P. cineraria* and *Z. nummularia*, following are some of the top feed species of this region: *Ardu (Ailanthus excelsa)*, Bargad (*Ficus bengalensis*), Ber (*Z. mauritiana*); Neem (*Azadirachta indica*), Pipal (*Ficus religiosa*) and Siris (*Albizia lebbeck*) (Table 1).

Palatability

Ganguli *et al.* (1964) observed that leaves of *P. cineraria* have the highest palatability, followed by the leaves of *Z. nummularia, A. indica* and *A. lebbek*. In general, sheep and goats tend to consume more of top feeds (3.3 kg/100 kg) than the perennial grasses (2 to 2.5 kg/100 kg) (Singh, 1981). Singh and Patnayak (1977) had recorded consumption of 3.8 kg *A. excelsa* leaves per 100 kg body weight in sheep (Table 2). By and large, the consumption of *Z. nummularia* leaves is more than that of *P. cineraria* leaves, in both sheep and goats, although consumption of both these feeds by the goats is considerably higher than that by the sheep (Ghosh and Bohra, 1984). This is, of course, related to two animals distinctive grazing behaviours of these two species, the sheep being mainly a grazer and the goat, a browser like the camel. Adult camel may consume, daily approximately 7.0 kg of *Z nummularia* or of *P. cineraria* leaves , which comes to about 1.4 kg per 100 kg body weight of these animals. *A. indica* is generally not relished by the animals (Jayal, 1963), although goats frequently consume these leaves in the Rajasthan desert. It has been reported that the palatability of *A. indica* leaves can be enhanced by their treatment with molasses.

Table 2. Palatability of the leaves of some desert trees

Botanical name	Local name	Palatability rating (kg/100 kg live weight)	Test animal
Ailanthus excelsa	Ardu	3.8	Sheep
Azadirachta indica	Neem	4.0 / 6.0	Buffalo*
		0.33	Sheep*
Ficus religiosa	Pipal	1.9	Bullock
		4.7	Goat
Prosopis cineraria	Khejri	2.8	Goat
		1.9	Sheep
		1.4	Camel
Ziziphus nummularia	Jharberi	3.3	Goat
		2.8	Sheep
		1.4	Camel

* Values are in kg/ animal.

Chemical Composition

Of the dry land top feeds, *A. excelsa* leaves would seem to contain highest crude protein percentage (19.6% on dry matter basis), while the two most palatable ones, namely *S. persica* and *P. cineraria* leaves have 14% crude proteins (Table 3), *Ficus bengalensis* , which is not so important as a top feed species contain only 9.6 % crude proteins. *Z. nummularia* leaves contain the highest (73%) total carbohydrates, while *A. indica* and *A. excelsa* have a very low crude fibre content (11.4%) and (13.5%), respectively. *S. persica* and *P. cineraria* appear to be similar in this respect (16.0%,20.3%). *A. lebbeck* (31.5%), *F. religiosa* (26.9%) and *F.* *bengalensis* (26.8%) would appear to be too rich in crude fibre to serve as good feeds, except during severe drought conditions. The nitrogen free extracts of the important top feeds are more or less similar (about 50%) except for *A. lebbek* which has a low (36%) value of this nutrient A part of *Salvadora* spp. The total ash content of the *A. senegal* (16.4%) is highest followed by *A. excelsa* leaves is highest (15.5%) followed by *A. lebbek* (11.5%), *A. indica* (2.3%) and *F. bengalenis* (9.3%) leaves (Table 3). For the sake of comparison, average values of different

Table 3. Proximate components (% DM basis) of some desert top feeds

Scientific name	Local name	Crude protein	Ether extract	Crude fibre	Nitrogen free extract	Ash	Phosphorus	Calcium	Magnesium
Acacia nilotica[1]	Babul	13.9	-	9.2	69.8	7.1	0.10	2.6	0.4
Acacia senegal[1]	Kumut	10.3	-	9.5	65.7	16.4	0.05	6.9	0.6
Ailanthus excelsa[1]	Ardu	19.6	3.7	13.5	47.7	15.5	0.20	2.3	-
Albizia lebbeck[2]	Siris	16.8	4.0	31.5	36.2	11.5	0.15	2.57	-
Azadirachta indica[1]	Neem	12.4	3.5	11.4	66.6	9.4	0.10	3.4	0.6
Dalbergia sissoo[2]	Shisham	16.2	4.2	24.6	46.2	9.2	0.21	2.3	-
Ficus bengalensis[2]	Bargad	9.6	2.6	26.8	51.6	9.3	-	-	-
Ficus religiosa[2]	Pipal	9.70	2.7	26.9	45.8	-	-	-	-
Prosopis cineraria[1]	Khejri	13.9	1.9	20.3	59.2	6.5	0.20	1.9	0.5
Prosopis juliflora[1]	Vilayati babul	21.4	-	20.8	50.0	7.7	0.20	1.5	0.5
Salvadora oleoides[1]	Pieujal	9.6	-	9.3	40.2	40.8	0.10	11.9	0.7
Salvadora persica[1]	Kharajal	14.2	-	9.4	44.9	31.4	0.20	8.8	0.7
Tecomella undulata[1]	Rohida	12.2	-	15.8	63.0	8.9	0.20	3.4	0.9
Ziziphus nummularia[1]	Bordi	11.7	3.0	16.0	65.0	7.2	0.20	1.6	0.3

Sources: Ganguli *et al.*, (1964)[1]; Acharya and Patnayak (1977)[2] nutrients of an important perennial grass of this region, viz., *Cenchrus ciliaris* (Dhaman) is : Crude protein, 4.5%; Crude fibre, 37.0%; Nitrogen free extract, 44.7%; Ether extract, 0.7% and total ash, 13.1%.

Seasonal variations in the proximate components of the top feeds have been recorded. Lahiri (1978) had observed that in *P. cineraria* leaves, crude protein was maximum in winter, ether extract and nitrogen free extract were maximum in summer and crude fibre was maximum during monsoon (Table 4). In *Z. nummularia* leaves, the nitrogen free extract showed increases from monsoon to summer, while crude fibre showed a reverse trend in these seasons.

Table 4. Seasonal variation in the nutrient level (on DM basis) in *Prosopis cineraria* leaves

Nutrient	Monsoon	Winter	Summer
Crude protein	14.30	17.50	15.40
Ether extract	4.30	4.20	4.50
Nitrogen free extract	52.60	54.00	56.80
Crude fibre	18.60	14.40	13.00
Phosphorus	0.18	0.16	0.18
Calcium	1.94	2.00	1.92

Source: Lahiri (1978).

As mentioned earlier, the arid land top feeds are often rich in moisture, containing 60- 70% preformed water, which substantially meets the water requirement of the animals and thrive upon these freshly lopped desert tree leaves.

Nutritive Value

Leaves of *A. excelsa, Z. nummularia* and *P. cineraria,* the three most important top feeds, are also high in the TDN (total digestible nutrients) scale (64%, 50% and 41.0%, respectively), while the DCP (digestible crude protein) value of *A. excelsa* leaves is quite high (16%) (Table

Table 5. Percent digestible crude protein (DCP) and total digestible nutrients of the some desert tree leaves

Botanical name	Local name	Digestible crud protein (DCP)	Total digestible nutrients (TDN)	Test animal
Ailanthus excelsa	Ardu	16.2	63.8	Sheep
Albizia lebbek	Siris	11.6	49.3	-
Azadirachta indica	Neem	9.3	42.8	Sheep & goat
Ficus bengalensis	Bargad	2.0	44.5	-
Ficus religiosa	Pipal	5.5	39.2	-
Prosopis cineraria	Khejri	4.5	41.0	Sheep
		8.9	48.7	Camel
Ziziphus nummularia	Bordi	5.6	49.7	Sheep
		6.0	52.0	Camel

5.), whereas, that of the more palatable *Z. nummularia* or *P. cineraria* leaves, are considerably low (5.6%and 4.5%).

The presence of a trypsin inhibitor in these leaves has also been reported (Nath *et al.*, 1969). The DCP of the relatively less palatable *A. indica* and *A. lebbek* are relatively high (9.3 and 11.6%, respectively). From the point of view of nutritive value, *A. excelsa* leaves can be considered the best feed among all desert tree leaves. However, this tree does not grow as extensively as either *P. cineraria* or *Z. nummularia* in this region. On the basis of per unit of feed material in general, top feeds provide more energy than the grasses, as the digestibility of

Table 6. Effect of level of Tannins and Lignin (% on DM basis) on apparent digestibility of crude protein and hemicelluloses in sheep

Plant species	Lignin	Hemicellulose digestibility	Tannins	Crude protein digestibility
Prosopis cineraria	7.8	74.2	11.6	22.0
Ziziphus nummularia	11.0	60.3	8.5	32.4

cellulose from desert grasses like *C. ciliaris* is higher than that of the tree leaves (Bohra and Ghosh, 1977) presumably because of the high lignin content of the top feeds (Table 6).

The nutritive value of different feeds differ with the animal species. For example, *Z. nummularia* has high nutritive value for camel followed by the sheep and goats, while *P. cineraria* has the highest value for goats, followed by the camel and the sheep (Table 5).

Improvement of Nutritive Value

An important component of the top feeds is the tannin, which often determines their palatability. Generally, tannin content of the leaves was higher in winter than in summer (Bohra, 1980). The lignin content of the cell wall of top feeds is also an important determinant of the nutritive value of the feeds. *P. cineraria* suffers from the handicap of having a higher percentage of tannins (15%) (Gupta, 1967; Bohra, 1980), which not only reduces the palatability, but also hinders utilization of dietary proteins by the animals. The tannins combine with the feed proteins or the microbial proteins and make the conjugates non-degradable in the hind gut of the animals. The lignins, on the other hand, decrease the digestibility of cell wall constituents as recorded in *Z. nummularia* leaves (Table 6).

Attempts have been made to improve the nutritive value of *Z. nummularia* leaves by treatment with dilute formaldehyde (Ghosh *et al.*, 1971) and *P. cineraria* leaves by treatment with ferric chloride (Gupta, 1967). Formaldehyde protects the feed proteins from microbial degradation in the rumen. Thus, most of the proteins become available to the animals for production purposes. Treatment of *P. cineraria* leaves with ferric chloride inactivates the tannins, but it does not improve, the DCP value of the feed. A successful attempt has been made to improve the nutritive value of *P. cineraria* leaves by removing their tannin contents. For this purpose, several chemicals have been tried, but overnight soaking the leaves with 0.5 N aqueous sodium carbonate solution, followed by washing with water, proved to be the best method for *detanning* of *P. cineraria* leaves as this treatment has resulted in removal of as high as 94% tannins of these leaves (Bohra and Goyal, 1986).

The desert trees, besides providing nutritious, moisture laden leaves, also provide highly palatable and nutritious pods, too. The range foraging domestic as well as wild ungulates consume considerable quantity of the pods of *A. nilotica, A. senegal, A. tortilis, P. cineraria* and *P. juliflora* trees (Goyal *et al.*, 1988), which fall on the ground on maturation. On an average, fully grown *A. tortilis* yield more pods than the leaves. Other desert plants also yield appreciable quantity of palatable pods. The leaves of *P. juliflora* plants are not relished by the animals, but its pods are highly palatable and relished by almost all the species of the livestock. The chemical composition and the nutritive value of the pods of important desert plants given in Table 7. The range foraging animals can get limited quantity of nutrients from these pods as the seed coat of these plants is hard and remain intact throughout the gut, so the appreciable quantity of protein present in the seeds is not available to these animals. Feeding of pods after suitably processing, like crushing and grinding of these pods is suggested. *A. tortilis* pods

Table 7. Chemical composition and nutritive value (%) and micronutrient (ppm) of *A. tortilis* and *P. juliflora* pods

Trait	*A. tortilis*	*P. juliflora*
Crude protein	12.3	16.50
Ether extract	1.8	4.20
Crude fibre	22.4	16.80
Nitrogen free extract	57.9	57.00
Ash	5.6	5.40
Calcium	-	0.33
Phosphorus	-	0.44
DCP	5.7	7.00
TDN	62.0	75.00
Micronutrients	-	ppm*
Iron	-	208-639 (30-50)*
Copper	-	13-16 (5)
Manganese	-	22 (20-40)
Zinc	-	13-16 (35-40)

* Critical levels of micro nutrients in feed

contain 5.7% DCP and 62% TDN and the *P. juliflora* pods, 7% DCP and 75% TDN (Mathur and Bohra, 1993). These pods also contain appreciable quantity of microminerals, too (Table 7).

The desert trees can thus, provide the considerable quantity of nutrients through its leaves and the pods. Feeding leaves and pods of the trees, after suitably processing, will certainly augment the availability of nutrients from the feeding stuffs derived from top feed species of Indian arid zone.

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PRIMARY AND SECONDARY PRODUCTIVITY IN TOP-FEED DOMINATED SANDY GRAZING LANDS

R.S. Mertia

Introduction

Jaisalmer, the largest district of Rajasthan covers 38401 sq. km area and lies on the Indian part of the Thar desert. The physiography of the Jaisalmer is heterogeneous, viz., barren rocky area, shifting sand dunes, sandy plains, saline flats, alluvial flats, dead streams and hills. The blown sand forms shifting sand-dunes mostly in the north and the west. As a result of the hostile agroclimatic conditions agriculture is practised in 5% of the total land area of Jaisalmer (Ahuja, 1977). Grazing based animal husbandry is the predominant occupation and the main stay of inhabitants of this region and therefore 95 per cent of the total district area is used as grazing lands (Shankar and Kumar, 1987 ; Mertia, 1992).

In fact in western Rajasthan both semi-arid and arid grazing lands bear the brunt of past misuse and present neglect (Mertia, 1992). The grazing pressure on the rangeland vegetation is estimated at 3.2 ACU/ha. In this region, the accessible tracts are overgrazed and so, are generally of "poor" range conditions. As against carrying capacity of 0.2 to 0.5 ACU/ha (Raheja, 1962) the grazing pressure ranges from 1 to 4 ACU/ha. The vegetation in this region is commonly shaped by nomadic and sedentary forms of pastoral use. The livestock in this region are hardy and highly productive which mainly comprises of cows, sheep, goat and camels.

The entire Jaisalmer district falls within acute drought and famine belt, which makes highly vulnerable. In the years of normal rainfall, the available forage from farming, cultivable wastes and fallow and pasture land is about 63.3 per cent of the total need of the existing livestock. However the conditions become serious during the years of sub-normal rainfall. Due to ever increasing trends in human population there is a continuous encroachment on marginal and sub-marginal land for cultivation and human settlement, thereby reducing the area under grazing lands.

The present paper attempts to discuss and summarize the results of grazing land management studies with particular emphasis on the potential of top-feed species in the context of primary and secondary productivity on arid grazing lands.

Climate

The climate is arid, where precipitation over a greater part of the year is less than the potential evapotranspiration and meets less than one third of the annual water need. A significant feature of the distribution of rainfall in the desert regions is that a major part of the rainfall is received during the south west monsoon (June to September). The contribution of this seasonal rainfall to annual rainfall is quite high (91 to 96%) over whole of Gujarat and south and central parts of western Rajasthan (Ramakrishna *et al.*, 1992). Another interesting feature of the rainfall is the higher co-efficient of variability in the annual rainfall which often exceeds 50 per cent in NW Indian arid zone and is higher than 70 per cent in the extreme regions of western

Rajasthan where the annual rainfall is as low as 180 mm. Dust storms are frequent during hot weather season, especially in the month of May and June. The average wind speed during June is more than 25 kmph in the western part of desert regions.

The mean diurnal variations of temperature is 14°C to 16°C. The maximum temperature during the season varies from 40°C to 42°C but in some years mercury touched 50° C- 52° C. During the cold season minimum temperature varies from 3°C to 10°C. Frost occurs at all stations when temperatures touches -2°C to 4°C but its incidence varies from 5 to 20 days and is associated with the western disturbances

Grazing Resources

Grassland of this extreme arid region have been grouped into four major types (Table 1). *Lasiurus sindicus* is the dominant type occurring in dunes-interdunes and plains and cover nearly 80% of the total geographical area. It has two associations viz., *L. sindicus-Panicum turgidum* and *L. sindicus-Eleusine compressa* which occurs.on different habitats.

The other three types *D. sindicum-E. compressa, Aristida-Oropetium thomaeum* and

Table 1. Extent of four major grassland types and their respective habitats in desert district, Jaisalmer

Grassland types	Habitat	Av. dry forage yield (Kg/ha)	Av. carrying capacity (ACU/ha/year)
Lasiurus or Sewan			
Lasiurus sindicus	Dunes-interdune plains	450	0.3
Panicum turgidum			
Lasiurus sindicus	Sandy undulating plains	925	0.6
Dactyloctenium sindicus *Eleusine compressa*	Buried pediments and alluvium	275	0.2
Aristida spp. *Oropetium thomaeum*	Rocky-gravelly plains and hillocks	180	0.1
Sporobolus marginatus	Saline-depressions	650	0.4

Source: Shankar and Kumar (1987).

Sporobolus marginata occupy 8.64, 6.06 and 0.35% of the geographical area, respectively, in Jaisalmer district. Highest average dry forage yield. kg/ha have been recorded in *L. sindicus-Eleusine compressa* type (925) and lowest in *Aristida* type (180). The range of average carrying capacity on year long basis varied from 0.1 to 0.6 ACU/ha/year in these grassland types.

Forage yield trend of three major grass species *L. sindicus, P. turgidum* and *E. compressa* on different habitats revealed maximum yield of *L. sindicus* on all the habitats except on saline depressions and similarly, *E. compressa* has forage contribution in all the habitats but *P. turgidum* has relatively less forage as compared to other two species (Table 2).

Table 2. Herbage yield (kg/ha) oven dry weight) from natural grazing lands on different habitats in Jaisalmer district

Habitats	Major species			Other species	Total	No.of sites sampled
	Lasiurus sindicus	*Panicum turgidum*	*Eleusine compressa*			
Buried pediments	119	7	110	34	271	23
Interdunal plains	678	-	231	13	922	18
Dune windward	55	43	199	112	409	11
Interdunes	217	36	204	69	525	9
Sandy undulating	220	174	53	-	447	4
hummocky plains Hills and piedmonts	92	4	78	5	180	3
Ranns (saline depressions)	-	-	216	424	640	6
Khadins (watersheds)	114	-	245	-	359	3

Rangeland Utilisation

Best way to utilize arid rangelands is through controlled grazing based on carrying capacity. Therefore, a balance between the productivity of rangelands and the number of grazing animals, need to be maintained by continuous and careful observations on peak forage production, morphological and physiological characters of the range vegetation. In this region due to highly erratic rainfall, the forage production of rangelands varies year to year and so a relatively low stocking rate is needed to avoid over, grazing. The stocking rate can vary within the region and different seasons depending upon the habitat and the vegetation type of the rangeland, but the objectives always should be to achieve efficient utilization of the available forage while aiming at improvement of the range condition (Mertia, 1992).

Rangeland dominated by *L. sindicus* having productivity of 20, 15, 10, 7.5 and 5.0 q/ha have been classified as Excellent, Good, Fair, Poor and Very Poor which can sustain on year long basis 25-30, 20, 17, 13 and 1.6 adult cattle units per 100 ha, respectively (Bhimaya and Ahuja, 1969).

Primary Productivity

Primary productivity studies cover a series of plant ecological observations on the grassland types, seasonal changes in composition, phenology, vigour, productive structures, herbage dynamics, compartment transfers and system transfer functions of the grazing land ecosystems. In this paper the effect of different conventional grazing systems on vegetation composition, plant cover and forage production is discussed.

In the arid rangelands *Lasiurus sindicus* is the dominant grass and its RIV range from 9.26 to 100 during the study and is closely followed by *Eleusine compressa*. Very little yearly fluctuations in the over all dominance of *L. sindicus* was noticed, where as yearly fluctuations in the RIV of *E. compressa* were influenced by both rainfall and grazing.

With adequate protection, grazing the rangeland on carrying capacity basis, aiming at 70 percent utilization for the period of two years, forage yield increased by 148.3, 91.9 and 116.3 percent in poor, fair and good condition class of rangelands, respectively. The impact of continuous grazing by sheep on year long basis adversely affected the basal cover, indicating a decline where as it increased in all the rotational grazing treatments. Continuous grazing also affected all the major grass species viz., *Eleusine compressa, D. sindicum, Aristida funniculata, Cenchrus biflorus* and *Indigofera cordifolia.* Rotational grazing on these rangelands provides rest period to the grass species to recover. (Gupta and Saxena, 1971 and Mertia, 1984). Chakravarty *et al.* (1970) reported that though *L. sindicus* and *E. compressa* are very hardy and survive under the impact of grazing pressure, but their normal vigour and cover were affected adversely. Once these grasslands are allowed a rest period, they regenerate by self seeding and assume normal vigour and cover.

Another study has revealed that grazing habit and accessibility to grazing also had a clear impact on primary productivity of these grazing lands. *L. sindicus* being a tall and tussocky perennial grass, cattle have an easy access to it. The overgrazing exhibited sharp decline in the productivity of *L. sindicus* where as the short grasses *E. compressa, D. sindicum* and *I. cordifolia* declined when grazed by sheep alone (Mertia, 1987) did not exhibited the adverse effect to that of the level of *L. sindicus.* Preponderance of annuals such as *Tragus biflorus, Brachiaria ramosa, Eragrostis unioloides, Glossonema variance* and *Dipcadi erythraeum* was observed only in the years of good rainfall and change in their composition did not seem to be an indicator of selective grazing.

In an another study it was discernible that over all percentage (0.72) was higher in the treatments where partial cutting of grass was introduced than the cent (0.25) per cent continuous grazing (Table 3). Among species *L. sindicus* contributed most significantly (83.53%) to the forage yield compared to all the species. Harvesting of grass from the half of the pasture every year at pre-flowering stage coupled with continuous controlled grazing was distinctly superior (2.108 t/ha) over the continuous controlled grazing (1.306 t/ha) in terms of forage production (Table 4). This was largely because of better sprouting of the earlier harvested pasture.

Table 3. Percent basal cover of key species under two grazing management system

Species	I1						I2					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean
Lasiurus sindicus	2.00	1.82	0.96	1.31	1.01	1.42	3.53	4.15	4.74	3.93	4.44	4.19
Eleusine compressa	0.01	0.01	0.00	0.00	0.06	0.01	0.05	0.03	0.02	0.05	0.21	0.07
Dactyloctenium sindicum	0.02	0.06	0.00	0.00	0.00	0.01	0.04	0.08	0.00	0.00	6.00	0.02
Cenchrus biflorus	0.01	0.01	0.04	0.07	0.04	0.03	0.02	0.01	0.02	0.05	0.05	0.03
Aristida funniculata	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Indigofera cordifolia	0.13	0.01	0.08	0.07	0.03	0.06	0.12	0.05	0.05	0.06	0.03	0.06
Mean	0.36	0.31	0.18	0.24	0.19	0.25	0.62	0.72	0.80	0.68	0.79	0.72
SEm	Treatment		Species		Years							
C.D. at 5%	+ 0.0411 - 0.1139		+ 0.0712 - 0.1975		+ 0.0650 - ns							

ns= Non-significant at 5 per cent level of significance.

Table 4. Effect of grazing treatment on dry forage production (t/ha) of major species

Species	T1	T2	Mean
Lasiurus sindicus	1.020	1.830	1.42
Eleusine compressa	0.057	0.013	0.04
Dactyloctenium sindicum	0.029	0.020	0.02
Cenchrus biflorus	0.081	0.083	0.08
Aristida funniculata	0.082	0.135	0.11
Indigofera cordifolia	0.027	0.027	0.03
Total dry matter	1.306	2.1080	1.70

The productivity of pastures from "poor" condition to good condition would be achieved over a period of 10-12 years (Table 5 and 6). Thereafter, forage production stabilized with little fluctuations over years.

Secondary Productivity

Grazing based on carrying capacity appeared to be most advantageous for sustained secondary productivity on rangelands as compared to the medium or the high intensity of

Table 5. Average dry forage yield (kg/ha) on rangelands of Jaisalmer region during 1961 to 1971

Range centres	Habitats	Grass cover	Dry Av. forage yield (kg/ha)
Jaisalmer	Rocky	*Lasiurus sindicus Cymbopogon jwarancusa Aristida* spp	473
Chandan	Sandy	*L. sindicus, Aristida* spp	424
Khetolai	Gravelly	*Aristida* spp, *C. biflorus*	334
Lawan	Gravelly	*Aristida* spp, *C. biflorus*	339

grazing. Higher body weight gains have been observed under light intensity (2.4 ha/heifer); i.e. 6.8, 5.4 and 4.4 kg/animal/month under control, moderate and heavy intensities of grazing, respectively.

It is also revealed that stocking rate of 4 ha/heifer was capable of giving 200-279.7 g/day/heifer body weight gain in early stage of range development. The increased stocking rate of 2.5 ha/heifer has given body weight gain of 178-243.8 g/day/heifer which is fairly high on *Lasiurus-Eleusine* dominated rangelands in this region (Mertia, 1992).

Maximum body weight gain of 406 g/day/heifer were achieved during the rainy period from August to October and lowest in April-June (Table 7). Similarly in ram lambs 39 g/day/ram lamb have been recorded in rainy season and very low in dry lean period. In a recent study it has been observed that heifers are capable of producing 50 to 300 per cent more body weight gain on managed rangelands as compared to local grazing practices. It has been also observed that heifers take 2.5 to 3.5 years for first calving as against 4 to 5 years by the flocked local

Table 6. Average dry forage yield (kg/ha) on rangelands of Jaisalmer region during 1972 to 1981

Range centres	Habitats	Grass cover	Dry A forage yield (kg/ha)
Jaisalmer	Rocky	*Lasiurus sindicus* *Eleusine compressa*	927
Chandan	Sandy	*L. sindicus*	1754
Khetolai	Gravelly -Sandy	*L. sindicus* *E. compressa* *C. biflorus*	1500
Lawan	Gravelly -Sandy	- do -	1163

villagers. Secondary productivity under seasonal grazing has revealed highly significant gain during August-October and lower gains from April-June which is a clear reflection of decline in quantity and quality of forage in the arid rangelands mainly because of low rainy days in a year which are confined from August-September. Partial cutting of range paddock to store grass at pre-flowering stage and feeding it during lean period has led to higher body weight gains.

Table 7. Body weight gain (kg) per heifer under four treatment during different years

Years	Grazing treatment						
	T1	T2	T3	T4	Mean	SEm	C.D. at 5%
1	31.13	24.00	13.00	12.63	20.19	0.19	2.52
2	44.30	13.00	27.87	13.27	24.58		
3	27.53	2.70	10.30	-1.00	9.88		
Mean	34.29	13.27	17.06	8.50			
SEm +		1.05					
C.D. at 5%		2.91					

Potential of Top-feed Species

A series of studies on grazing systems by Ahuja (1977), Bhimaya and Ahuja (1969), Chakravarty *et al.* (1970), Paroda *et al.* (1980) and Mertia (1984, 1987, 1989 and 1992) have given account of effect of different conventional grazing systems on primary and secondary productivity on arid rangelands. All these studies infer adverse impact on rate of body weight gain or decline in secondary productivity of range animals due to decline in quantity and quality of fodder on these arid rangelands.

The deliberate introduction of fodder trees and shrubs has a high potential for increasing the sustained productivity of rangelands. Adoption of this system offers, without impairing the growth of trees, an extra yield of grass during the wet season and browse materials in the long dry seasons.

Table 8. Effect of years and grazing management on animal body weight gain (kg/ha).

Years	Treatments					
	T1	T2	T3	T4	T5	Mean
1	33.02	24.88	30.17	25.80	33.22	28.81
2	44.48	11.55	11.14	12.48	12.17	12.36
3	28.48	27.73	28.45	28.11	28.30	28.21
4	22.08	15.46	15.77	18.93	20.60	18.56
Mean	24.51	19.90	21.38	21.33	22.82	

The natural occurrence of top-feed species in this region in different habitats indicates the potential of leaf fodder from dominant species *Prosopis cineraria, Ziziphus nummularia* and *Haloxylon salicornicum*. Higher leaf fodder is contributed by *P. cineraria*. Maximum browse (11.4 q/ha) is available in Alluvial plains and minimum (1.1 q/ha) in Ranns (saline depressions) (Table 9). Effect of canopy of naturally growing top feed species indicates higher forage production under *P. cineraria* and lowest under *Tecomella undulata* (Table 10). Similar finding were also achieved by (Ahuja, 1980). This brings into sharp focus the need for optimization of the tree density of desired species on rangelands in silvi-pastoral systems (Shankar, 1980) has given a comprehensive review of silvi- pasture to view this land use system in wider spectrum for arid grazing lands.

Table 9. Density of top feeds and leaf fodder yield in different land forms-Jaisalmer district

Habitat	Prosopis Density	Cineraria leaf fodder yield (kg/ha)	Ziziphus Density (p/ha)	nummularia leaf fodder yield (kg/ha)	Haloxylon Density (p/ha)	Salicornicum Leaf fodder yield (kg/ha)	Total Browse yield (q/ha)
Piedmonts and intermontane colluvial plains	45	675	66	3.30	160	40.0	7.2
Runnels and streams	20	300	68	5.44	54	13.50	3.2
Buried pediments	10	150	81	6.48	250	62.50	2.2
Alluvial plains	75	1125	96	9.6	20	5.0	11.4
Ranns	7	105	40	3.2	0	0.00	1.1
Dunes and interdunes	10	150	10	0.80	66	16.50	1.7
Interdunal plains	36	540	39	3.90	390	97.50	6.4
Sandy undulating hummocky plains	10	150	28	2.80	354	88.50	2.4

Source : Shankar and Kumar (1987).

Table 10. Effect of canopy of top-feed species on plant population and forage production of dominant grass species on arid region.

Under story species	Number of plant /ha								Dry wt./ha							
	Acacia senegal		*Prosopis cineraria*		*Tecomella undulata*		*Acacia tortilis*		*Acacia senegal*		*Prosopis cineraria*		*Tecomella undulata*		*Acacia tortilis*	
	2M	4M	2M	4M	2M	4M	2M	4M	2M	4M	2M	4M	2M	4M	2M	4M
Lasiurus	2000	800	2400		2800	1600	1200		0.220		0.464		0.052		0.240	
sindicus			2400				800		0.068		0.660		0.080		0.128	
Cenchrus	1200	3200	2000		5600	2400	2400		0.012	-	0.044		0.028	-	0.024	
biflorus			2800				3200		0.036	-	0.036		0.020	-	0.056	
Eleusine	2000	-	1200		1200	800	-	1200	0.016	-	0.016		0.020	-	-	
compressa			2000								0.016		0.024		0.008	
Indigofera	2400		5600		-	-	-	-	0.012		0.036		-	-	-	-
cordifolia	8000		2000						0.056		0.008					
Blepharis	4000		3600		-	-	-		0.032		0.028		-		0.020	
sindica	400		4000				1200		0.004		0.036		-			
Dactylocten	-	-	-	-	2000		3200	-	-		-	-	0.020		0.040	
ium					4000				-				0.008		-	
sindica																
Tribulus	-	-	-		800		-	-	-		-	-	0.036		-	
alatus			-		-								-		-	

Recent attempt of introduction of top feed species *Colophospermum mopane, Dichrostachys nutans, Prosopis cineraria* and *Ziziphus mauritiana* (Table 11) has indicated encouraging establishment and potential leaf fodder yields (Mertia, 1994).

As remarked by Ghose (1980) about 13 per cent land area (43 million hectare) is under potentially productive wastelands and a substantial part of which can be reclaimed through silvi-pasture system. It has been realized that the entire socio-economic fabric of this region rests on proper management of degraded pasture lands. The arid regions even comprises of

Table 11. Growth performance of top-feed species under two spacings in Reseeded Grassland dominated by *Lasiurus sindicus*

Species	Spacing 5 x 15 M			5 x 10 M			Mean			
	Height (cm)	crown Dia (cm)	Collar Dia (cm)	Height (cm)	crown dia (cm)	Collar dia (cm)	Height (cm)	crown Dia (cm)	Collar dia (cm)	Dry leaves kg/ plant
Prosopis cineraria	79.55	67.09	2.00	61.75	51.00	1.53	70.65	59.04	1.76	0.35
Ziziphus mauritiana	162.44	105.56	2.81	216.71	117.11	3.66	189.75	111.33	3.23	0.80
Colophospermum mopane	136.44	131.62	3.61	142.44	141.62	3.83	139.44	136.62	3.73	3.10
Dichrostachys nutans	91.33	114.71	1.79	109.81	125.84	2.53	100.57	120.27	2.16	0.75

variety of plant biomorphs-trees, shrubs under shrubs, perennial and annual grasses. This heterogeneity ensures better utilization of environmental resources as the biomorphs are of different height and their root extends to different depths. (Nachayeva, 1974) emphasized the optimization of varied biomorphs of our ecosystem through their preservation by proper timing of stocking in grazing and felling for firewood and introduction of lacking biomorphs. Appraisal, therefore should primarily be directed towards finding out as to whether and how much the plant cover is incomplete and requires more diversified plant communities for sustained primary and secondary productivity from arid grazing lands.

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BIOCHEMICAL MODEL FOR SUSTAINED ANIMAL PRODUCTION IN ARID ECOSYSTEM

M.S. Khan

Introduction

When the introduction of design of different animals for arid ecosystem is contemplated, it is necessary to consider the genetic and evolutionary setting of rate functions of the animals. The nearer the rate of use of water, energy and proteins to the supplies of these materials in the desert, more likely the animal is to survive. On the other hand, if large turnover of animal products are required, then high turnover rate animals can be contemplated but then survival of such animals is likely to be short at any time of deprivation of either food or water. Such high turnover animals can only find comfortable place in areas where the supplies of feed and water are normal.

The two major constraints faced by all living organisms in the desert environments are intense heat and lack of water. This is, of course, more true for the free living animals than for domestic livestock which enjoy the care and attention of their human masters. However, it is possible to convert the inhospitable desert environment to one where an animal may express its full genetic potentiality for production. In any case all livestock, except high yielding cattle, need to graze or browse for an average of 8-10 hours per day. It is during this period when the animals are exposed to very high environmental temperatures, their claim to desert habitation is tested.

In the desert region of western Rajasthan the air temperature during the peak summer may go up to 45-48^{o}C and the minimum relative humidity of the air may vary from 12 -18%. Rain fall and aridity indices of different regions within Rajasthan region have been shown in Table 1. The region has also high wind velocity during summer and monsoon, ranging from 13-14 km per hour. Scanty and erratic precipitation and a high rate of evapo-transpiration result in insufficient recharging of the ground water. Since soil salinity is high at several places within this region, the incidence of brackish water with total soluble salt contents of around 3000 ppm is common here. All these factors result in poor productivity of the land and whatever is produced under these circumstances is soon eaten by the herds of livestock which roam around the terrain.

Table 1. Rainfall and aridity index of western Rajasthan desert districts.

Groups	Mean annual rain fall	Mean aridity index
A		
Jaisalmer,Bikaner, Barmer	12"	84
B		
Jodhpur, Nagaur, Churu, Jalore	12" to 16"	75
C		
Jhunjhnu, Pali, Sikar, Sirohi	16" +	58

It might seem paradoxical that the desert region which puts so many hurdles for life should harbour such vast numbers of livestock as the Great Indian Desert does. Obviously animals indigenous to this tract have been fairly successful in adapting to their habitat and thereby these animals not only survive but also produce profusely in this environment. Let us examine the secret of these most adapted and productive animals

(A) Physiological Basis of Adaptation of Livestock Species

Water Requirement: Large variations are seen among individual animals in their water requirements. Such differences are influenced by nature of the feed consumed, environmental temperature, humidity and physiological conditions. Adding proteins, minerals and salts to diet may increase water requirements as the body must expel the metabolites and excess salts through the kidneys by way of urine.

Under tropical environment, the animals generally drink water at the rate of 7-8%, 12- 13%, 15-16% and 12-13% of their body weight during winter, autumn, summer and post- monsoon periods.

Body Water Turn Over Rates : Of all the indices linked with desert adaptation, body water turn over rate (BWTR) would appear to be the most important one. Among mammals inhabiting the desert regions, the eco-physiological hierarchy of water use function, as established by various workers is : Cattle> Man > Donkey > Eland > Sheep > Goat > Rodents > Ibex > Oryx > Camel > Gazelle > Kangaroos > Euro. BWTR values provide an understanding of a variety of slow evolutionary processes of adaptation by which quite distantly related mammals survive in arid environments, such as the camel and the goat (black coloured) with great success and economy, while others such as cattle and man perform with difficulty and huge expenditure of water and energy.

Among Indian desert livestock species, a significant ($p > 0.05$) rank order was observed in respect of water turn over rates in hydrated and rehydrated sheep, goat and donkey (Table. 2). It was lowest in Marwari goats and highest in donkeys; Marwari sheep occupied a middle position. Positive correlation between BWTR and heat load has also been observed in sheep, goat and donkey of the Indian desert (Khan and Ghosh, 1983) and Oryx and Eland antelopes of the African arid zone (King *et. al.*, 1975). Body water turn over over (BWTR) estimates suggests that the Marwari sheep turned over nearly 17% more water per day than the Marwari goat (Khan and Ghosh, 1983). The Parbatsar goat also of the Rajasthan desert, however, behaved similar to the Marwari sheep in this respect. Published reports generally assigned lower body water turn over rates in the desert adapted goat than in the sheep from the same habitats (Khan and Ghosh, 1983; Macfarlane and Howard, 1972 and Shkolnik, *et. al.*, 1979). The rate ofbody water turn over in the Marwari goat would appear to be lower than that reported for goat breeds from other dry regions (Macfarlane and Howard, 1972 and Shkolnik, *et. al.*, 1979).

Table 2. Body water and its turn over rate in normally hydrated,dehydrated and rehydrated animals

Species	Characters	Normal	Dehydration	Rehydration
Marwari goats	Body water (% b. wt.)	53.6 ± 1.8	51.5 ± 1.3	51.1 ±1.7
(4)*	Body water turnover rate (ml/kg0.82/day)	116.4 ± 2.0	11.6 ± 0.7	124.2 ± 2.7
Marwari sheeps	Body water (% b. wt.)	59.7 ± 2.0	53.7 ± 0.01	59.3 ± 0.9
(4)	Body water turnover rate (ml/kg0.82/day)	120.2 ± 2.1	12.5 ± 0.7	146.7 ± 5.7
Donkeys	Body water (%b. wt.)	53.1 ± 4.4	42.8 ± 0.6	48.5 ± 1.5
(2)	Body water turnover rate (ml/kg0.82/day)	170.3 ± 11.7	21.3 ± 0.4	170.3 ± 11.7

*Figures in parentheses indicate the number of animals used.

Values are Mean ± S.E.

Location and environmental conditions : Beriganga area, Jodhpur, (26 23'N; 73 05'E), Max. Temperature : 25C, Moisture content :10% , Rainfall : Nil.

Vegetation cover : *C. ciliaris, C. setigerus, A. funiculata, Z. nummularia.*

Body Water Distribution Pattern

The distribution of water in various body compartments in normally watered desert animals has been reported by several workers. The Marwari sheep and Marwari goat have almost similar plasma volume (PV) and total body water (TBW). However, extracelllular fluid volume (SCN Space) - a very important water compartment for combating water stress is significantly higher in the Marwari goat than in the Marwari sheep and the donkey. In the Beduin goat (Shkolnik, *et. al.*, 1972), PV and TBW are significantly higher than in Marwari sheep, Marwari goat and the donkey, but the SCN -space is lower in the Beduin goat than in the Marwari goat. The Indian desert camel, however, has higher levels of PV, Cell and Gut water and TBW than in the Marwari sheep, Marwari goat and the donkey. Such species or breed differences with regard to various body fluid compartments may be attributed to the inter -species differences in the mechanism of body water regulation during water deficiency conditions.

Body Water Distribution and Its Turn over Rate During Water deficiency Conditions : For any desert animal, the maintenance of circulatory volume is of great importance because of two obvious reasons : (i) to avoid circulatory failure which may occur if the blood gets thick and, (ii) to dissipate the internal body heat through the circulatory medium. During water restriction, water lost from the body of an animal is drawn from various body water compartments and the degree to which these compartments are depleted during dehydration differs from species to species. For example, in Marwari breed of goat, 4-days of water deprivation during summer lowered the plasma volume (PV) by 13% of normal (Table 3).In Marwari sheep, on the other hand, PV was reduced by 43% under similar environmental conditions. The Australian Merino sheep also lost about 45% of PV after 5 days of absolute water deprivation (Macfarlane, *et. al.*,1963). The mechanism involved in the retention of plasma water in the goat and in the camel appears to be associated with the retention of plasma

Table 3. Body fluid component in normally watered and water deprived Marwari goat

Character	A	B	C	D	E
Body weight kg	40.1 ± 0.80	35.3 ± 1.1	-11.97	---	---
Total body water (1)	24.5 ± 1.50	18.2 ± 1.1	-25.6	6.2 ± 2.1	--
Plasma volume (1)	2.03 ± 0.03	1.28 ± 0.1	-12.9	0.19 ± 0.07	3.40
Blood volume (1)	2.03 + 0.07	1.93 ± 0.06	-4.92	0.14 ± 0.05	2.24
Extracellular fluid volume(1) (Thiocyanate space)	11.49± 0.20	10.6 ± 0.32	-7.57	0.90 ±0.28	14.42
Cell & gut water (1)**	12.92 ± 1.5	7.6 ± 1.03	-41.43	5.58 ± 1.80	89.42
Interestitial fluid volume (1)	10.02 ±0.19	9.33 ± 0.31	-6.88	0.71 ± 0.27	11.37

A : Before water restriction
B : Day 4 of water restriction
C : Change of complete water restriction from the *ad. libitum* value (%)
D : Average amount of water lost
E : Per cent of the total body water lost

Values are Mean + S.E.

*Significantly different from control animals ($p > 0.05$)

**Cell and gut water = total body water - thiocyanate space

proteins, particularly, albumin, in the vascular bed. Unlike Macfarlane's Merino and the Marwari sheep which had severe reduction in the SCN space at the end of dehydration regimes, the Marwari goat tends to conserve its SCN space some what more efficiently --- there being a reduction of SCN space by only about 8% (Khan, *et. al.*,1979b). In the Marwari goat the reduction in the cell and gut water is of the order of 41% at the end of 4-day dehydration regime, while in sheep it may be to the extent of 30% only. Cell and gut water is of special significance during periods of water stress in the Marwari goat because it is this water which is mainly relied up on by the animal for maintaining its normal circulatory volume (Khan, *et. al.*,1979a). The cell and gut water may, thus, be considered as "emergency water reservoir" which is used to avert the circulatory failure in the goat. The inability of sheep to use this water fully at times of water crisis and its primary dependence on circulatory water for evaporative cooling, makes the sheep decisively less desert worthy than the goat.

When deprived of drinking water for as long as 13 days during late winter, the black Marwari goat showed an extraordinary ability to maintain its body weight, whereas Marwari sheep almost reached its limit of physiological tolerance by the end of this peiiod. The desert donkey could, however, resist the dehydration due to water restriction only up to 9 days. The rate of body water loss in the goat, sheep and the donkey was 46, 87 and 99 ml/kg/day, respectively during the dehydration regime. The Somali donkey dehydrated for 5 days for 12 h at 40 C alternating with 12 h at 22 C, lost water at the rate of 137 ml/kg/day (Maloiy and Boarer, 1971). During dehydration regime, a rank order in respect of maintenance of SCN space in these species has been noted as : Marwari goat > Marwari sheep > Desert donkey. Of the total amount of body water lost, the cell and gut of the donkey contributed to the SCN space to the extent of 24% only in contrast to 80% in the goat (Khan, *et. al.*, 1979a) and the camel (Macfarlane, *et. al.*, 1963). Interestingly, it is the interstitial water (IFW) which contributes about 70% to the depleting extracelllular fluid compartment in the donkey. Camels reportedly survive for more than 15 days under approximately similar environmental conditions while sustaining, unlike sheep and donkeys, about 30% loss in body weight.

Conservation Mechanism Under Water Stress

i) Conservation of Water Through Insensible Means : In order to maintain homoeostasis animals lose water through surface evaporation (insensible means), faeces and urine. In hot environments, evaporative heat loss may provide the only channel through which an animal can dissipate its heat; the supply of water and the mode of evaporative cooling then assume greater importance.

(a)*Sweating*: The evaporation of sweat normally takes place from the skin surface where its cooling power is most effective, although, under hot humid conditions there may be some evaporation from the hairs. It has been observed that the sweat collects in drops on the hairs which are water repellent, and spreads rapidly on the skin surface. This combination of repulsion and attraction tends to prevent the transfer of sweat from the skin to the hairs thereby making evaporative heat transfer from the body more effective.

(b)*Respiratory mechanism*: The rapid movement of air to and fro over the turbinate region in the nasopharynx during panting leads to evaporative cooling of the blood flowing through the surface tissues. The turbinate system is well developed, for example, in the sheep's nasopharynx, with the result, in the desert during summer the sheep which has a facial skin temperature of 42 C has a surface temperature of 34 C over the turbinate as a consequence of the movement of the dry air over the wet mucosa.

The respiratory rate gives an indication of an animal's thermal state. At 80 per minute, the animal is very warm, at 20 per minute, the animal is cool or near below the critical temperature. Panting in cattle is not effective as sweating in providing evaporative cooling. The respiratory ventilation may increase 10 folds in cattle, 12 folds in sheep, 15 folds in the rabbit, and in the dog, where panting is highly effective, as much as 23 folds.

ii) Faecal Water Loss : The amount of water lost in faeces depends on the organism's state of hydration, hence on the amount of water in food, the availability of drinking water and the rate of water loss to the environment. Water lost by mammal in the faecal pellets may account for as much as 49% of their total body water loss. In certain adapted mammals like the camel and the Kangaroo rat, faecal water loss may be as low as 0.5% of the total loss, but in the majority of desert mammals studied so far, water loss accounted for 10-12% of the total water loss. The water content falls only to 60% in cattle after 3 days without water, whereas in sheep it is 45% after 6 days and in camels about 40% after 5 days.

iii) Urinary Water Loss : The contribution of excretory organs to survival in the desert lies in their ability to help the organism to conserve its body water. This may be achieved by eliminating the end products of nitrogenous metabolism, as well as an excess of electrolyte ingested with the food and drinking water in a minimum volume of fluid. Under conditions of normal hydration, excess water and metabolic waste products are excreted by the kidneys.

Table-4. Theoretical calculation of survival time of animals kept without water*

Species	B.WT (kg)	Total body water (1)	% Dehydration tolerance**	BWTR Hydration @ /day	BWTR Dehydration @ /day	Survival time (days)***
Marwari sheep (4)	25.0	15.0	35.0	1.7	0.7	8
Marwari goats (4)	25.0	15.0	40.0	1.4	0.6	10
Marwwari donkey (2)	71.0	36.0	40.0	6.0	2.4	6

* Calculation adapted from Yousef and Johnson, 1985.

** Dehydration tolerance as a per cent mean that the animal can actually lose that per cent of its total body water.

*** Body water turn over rate in dehydrated animals is assumed to be only 40% of the hydration value.

Dehydration, on the other hand, is accompanied by a decrease in urine volume and a concomitant rise in extra-cellular osmotic pressure. The kidneys are, thus, brought in to play first to save fluid and then to adjust the electrolyte status. The kidney is adapted in its structure to an animal's habitat.

Deficiency of water triggers off the release of hormones which act on loops of Henle in the kidneys which in turn reabsorb more and more water back in to the system to compensate for water lost to the body from evaporative cooling. Of the three desert animal species, viz., the goat, camel and the sheep, the kidneys of the former two are very strong in reabsorbing much of the filtered water and thus making very concentrated urine. During absolute water deprivation for four days in Marwari goats, the urine out put was cut down by 75%. The glomerular filtration rate (GFR) in Marwari goats receiving a quarter of their daily water requirement during summer was reduced to 1/3rd of the normal values(Khan, *et. al.*, 1979a). In other words when faced with water crisis, the goats has the ability to reabsorb almost 70% of water back from the filtrate, thereby conserving water to the maximum. Water restriction in the sheep and the camel also results in reduced GFR.

Theoretical Calculation of Survival Time of Animal Without Water

By measuring the daily body water turn over rate(BWTR) in addition to total body water and the limits for tolerance of dehydration, one can estimate survival time for animals during dehydration . An example of theoretical calculation of survival times in the sheep, goats and the donkey of the Indian desert is shown in Table 4. This type of information helps in the management of range animal production in arid regions since the ability of the animal to seek food over large areas between widely spaced water sources is a critical factor in its survival and productivity.

(B) Livestock Productivity on the Silvi-pastoral Systems

Studies have been undertaken to ascertain the comparative productivity of sheep and goats on different silvi-pastoral systems, both at Central Arid Zone Research Institute, Jodhpur and Central Sheep and Wool Research Institute, Avikanagar. The forage yield data show a considerable variation in forage yield varying from 330 kg/ha to 1630 kg/ha. This indicates an approximate carrying capacity of the land from 0.5 sheep/ha to 3 sheep/ha on the basis of a minimum requirement of 4 quintals of dry fodder/sheep/annum and about 70 per cent utilization of the pasture. When expressed in adult cattle units (ACU), it is 0.1 animal/ha to 0.6 animal/ha based on 1 ACU equivalent to 5 sheep.

Expressing the forage yield alone from the pasture has a limited utility unless the production is expressed in terms of animal performance because there is considerable variation in the forage yield estimates and the dry matter intake by the animals. The forage yield data usually do not corroborate with the theoretically calculated intake data by the animals on the basis of their performance. Studies on production performance of sheep and goats grazing on the natural range land at a stocking rate of 3 animal/ha were undertaken at CSWRI, Avikanagar (Acharya and Patnayak, 1977). The dry matter yield of the herbage from surface layer was 14.7 and 0.7 q/ha under protection and grazing, respectively. The total basal cover of the surface vegetation was 6.0 and 4.9 per cent under protection and grazing, respectively. The body weight data of lambs and kids are given in Table 5. The kids were heavier than lambs at all stages. Ground vegetation was scanty from January to July. The average body weight of adult sheep declined from March to June. Grazing behaviour studies showed that goats spent 545 minutes in the grazing field whereas sheep spent 550 minutes but goats spent more time in browsing (305 minutes) compared to sheep (278 minutes). Goats consumed 1620 g dry matter as against 1307 g dry matter by sheep/day.

Reseeded Pastures : Although protection of natural range land increases production, the establishment of palatable perennial grasses through natural succession takes time. Hence, to accelerate establishment, reseeding of natural range lands with appropriate grasses and legumes suiting the soil, rainfall and climatic conditions should be undertaken. The most common grass species used for reseeding is *Cenchrus*. Reseeding with *Cenchrus* increased the carrying capacity of the land almost two fold. Satisfactory performance of cross -bred ewes was obtained when grazed on reseeded *Cenchrus* pasture at a stocking rate of 5 ewes/ha under semi-arid conditions (Patnayak, 1994). The overall body weight ranged from 29 to 36 kg. Six monthly greasy fleece weight, weaning weight of lambs, lambing percentage, adult and lamb survival for the Avikaleen strain of sheep averaged 1.14 and 11.3 kg and 75, 95 and 100 per cent, respectively.

Although adult animals show satisfactory performance on *Cenchrus* pasture, *Cenchrus* pasture alone is not adequate to support satisfactory growth of lambs (Patnayak, 1994). Either a legume component should be introduced in the grass pasture or additional supplementation should be provided. A minimum of 10 to 12 percent crude protein in the diet is essential to promote growth of lambs. *Cenchrus* pasture alone has the crude protein percentage less than 10 per cent for the most part of the year varying from 10.0 per cent in July to 4.3 per cent in January-February (Bhatia, *et al.*, 1973). *Dolichos lablab*, a pasture legume (Carpet legume) has been introduced successfully in *Cenchrus* pasture with satisfactory results (Patnayak, 1994). Weaner lambs averaging 11 kg body weight grazed on *Cenchrus* pasture from August to May attained an average weight of 16 kg whereas lambs grazing on *Cenchrus-Dolichos* mixed pasture attained the body weight of 20.5 kg during the same period.

C) Basics of Biochemical Model for Livestock

Within any species or breed, there is always a degree of polyfunctionalism, which may allow considerable selection of the most viable and productive animals for the arid environment. That there are some animals in any species or breed of animals which give more milk, wool, hair or body growth with lower than average amounts of water and energy inputs. Such animals are not easy to detect in a flock and yet their competence in dealing with the desert environment merits attention. They could be selected and bred for low maintenance and high production levels. The same approach has been used at Beltmont cattle breeding station of CSIRO in Queensland, Australia, where crosses of Bos-indicus with Bos-taurus have produced low consumption but good production type animals.

As such in a desert ecosystem, the animals could be selected on the basis of the following criterion :

- Low body water turn over rate (BWTR),
- Low basal metabolic rate (BMR).
- Low Glomerular filtration rate (GFR), and
- Low sweating rate (SR).

Therefore, the animals which have low (BWTR-BMR-GFR-SR) and are also accompanied with optimal production should be selected, bred and reared in the desert ecosystem. Rigorous selection on the basis of above parameters at each stage of breeding programme would provide us affective animals for the arid zone.

Besides the above, the animals, particularly, the sheep and goats, could also be selected on the basis of blood biochemical polyfunctionalism (sheep and goats have extensively been studied for blood biochemical polyfunctionalism in relation to adaptation and production at CAZRI, Khan, 1990). For example, there are blood potassium (K+); erythrocyte reduced glutathione (G-SH) and haemoglobin (Hb) polyfunctionalism in sheep and goats. The K+, G-SH and Hb polyfunctionalism are genetically controlled and inherited and associated with the environment and productivity. These aspects are discussed as under:

Blood potassium: In all breeds of our sheep viz., Marwari, Magra, Sonadi, Malpura, Chokla, Jaisalmeri, Poongal and Nali and two breeds of goats, viz., Marwari and Sirohi, two blood potassium type, low blood potassium (LK) and high blood potassium (HK), animals exist. On an average, the frequency of HK type animals is 60% in all the breeds of sheep and goats examined. When the effects of body weight was not taken in to account, the correlation between whole blood potassium concentration and wool weight was zero in all the breeds, except Sonadi breed, where it was significant at 5% level. Further, within the LK type sheep, two groups of animals exist viz., Homozygous LK (KL KL) and heterozygous LK (KL Kh). The frequency of KL KL, KL Kh animals is about 7% and 35%, respectively. The KL Kh (Fl+) sheep produce comparatively more wool than KL KL (Fl-) sheep. However, the KL KL (Fl-) sheep produce comparatively good quality wool than either the KL Kh or HK type sheep. Through systematic separation of high potassium type (KL Kh) progeny born to LK-LK animals at each generation, it would be possible to establish a homozygous LK (KL KL) strain within each breed that would give good quality wool. For higher wool yield the KL Kh stock of sheep could be maintained.

Erythrocyte glutathione levels (G-SH): Erythrocyte glutathione (G-SH) polymorphism exists in all the breeds of sheep and in two breeds of goats (Marwari and Sirohi) inhabiting the Rajasthan desert. On an average, 75% of sheep are low-GSH (GSH-h) type and 25% of sheep are high-GSH (GSH-H) type. Within goat breeds, the distribution of GSH-H and GSH-h type animals are about 60% and 40%, respectively.

On an average, wool production in gm/kg b.wt. was found to be more in GSH-h type animals than in GSH-H type animals. However, the erythrocyte GSH types have no significant correlation with quality of wool. Within goats, GSH-H type animals seem to be more adapted to desert environment than the GSH-h goats.

Haemoglobin types: Different haemoglobin types viz., Hb-A, Hb-B and Hb-AB are found to exist in all the breeds of sheep of the Rajasthan desert. Animals of Hb-B type are found to predominate in all the breeds of the arid zone (Kalla and Ghosh, 1972). However, the Hb-A type sheep produce more wool of good quality than either the Hb-B or Hb-AB type animals.

Table 5. Pre-weaning and post-weaning growth of kids and lambs on a natura l range land at a stocking rate of 3 animals/ha.

Species	Sex	Birth wt.(kg.)	wt. at 3-M	wt. at 6-M	wt. at 9-M	wt .at 12-M
Goat	Male	3.3 ± 0.1 (14)	11.1±0.5 (13)	18.9±0.9 (8)	---------	------
	Female	2.6±0.1 (18)	10.1±0.4 (12)	15.0±0.6 (10)	19.5±0.4 (10)	24.3±0.4 (3)
	Pooled	2.9±0.1 (32)	10.6±0.3 (25)	16.7±0.5 (18)	----------	---------
Sheep	Male	2.5±0.4 (11)	8.4±0.9 (10)	13.0 (1)	--------	---------
	Female	2.4±0.3 (11)	6.6±0.3 (9)	9.5±0.7 (8)	12.3±0.3 (3)	------
	Pooled	2.5±0.2 (22)	7.6±0.4 (19)	-------	--------	----------

Figures in parentheses indicate the number of animals.
Values are Mean ± S.E.
Source: Patnayak, 1994.

Suggested Biochemical Model for Animals for The Arid regions

The following types of animals which will not only be adapted to desert conditions but also give optimal production may be developed for the arid zone.

Sheep : Combination of GSH-h = Hb -A = KL- KL = Low BWTR = Low BMR = Low SR = Low GFR type sheep.

Goats : Combination of GSH-H = Low BWTR = Low BMR = Low SR =Low GFR type goats.

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DISEASE MANAGEMENT IN FODDER AND TOP FEED SPECIES IN SILVI-PASTORAL SYSTEM

Satish Lodha

Introduction

Many factors are responsible for moulding the agricultural economy. The most important of these is the alarmingly increasing rate of human and livestock population. Thus one of the main problems in agriculture is to step up food and fodder production to keep pace with the increasing population. There are two ways of improving the output of production : to increase crop productivity and to avoid crop failures. Diseases and pests become a limiting factor for successful crop production and responsible for crop failures to a considerable extent.

In arid lands, diseases are sometimes of little importance while at other times these become disastrous. In addition to seasonal crops, diseases take away a major share in forestry and pastures. Management of diseases is of utmost importance in forest establishment as any forest takes decades for establishment. Infestation with soil borne pathogens in addition to killing the established agro-forestry or silvi-pastoral system also do not allow its proper re- establishment. In tropics, protection research is needed more than the production research. Certain agro-climatic factors of this region are attributed for development of few specific diseases.

- Limited availability of water to crops and trees results in loss of vigour of roots, which in turn invite soil-borne pathogens.
- In arid areas, little irrigation may provide the moisture for dew formation which in turn may favour diseases.
- Adverse climatic conditions of summer and arid areas do not allow pathogenic propagules to survive. However, fungi like *Rhizoctonia* and *Fusarium* does survive as saprophytes for a longer time by forming resting spores.
- In the warm weather, powdery mildew- a pathogenic group of fungi is also a major threat to a number of crops.

Many pathogens of grasses are known (Plumb, 1988, Williams, 1984), but there is generally little information on their distribution and the damage they cause. There are many reasons for this lack of knowledge, not least of which is the comparative lack of interest that has been shown in pathogens of grass crop. This stems from the absence of any consistently apparent effect of diseases, and the difficulty of measuring any effects either overt or covert, that they might have. Diseases affect grasses in many ways: by decreasing the total quantity of seed or dry matter produced, by changing its nutritional value and by changing its acceptability to stock. There are direct effects caused on single plants or single species pasture, but in mixed pasture additional effects are seen. Depredations by pathogens can lead to change in pasture composition, either by changing the balance of sown species or by allowing weed species to invade.

Fungal pathogens of grass crops are numerous and widespread, and probably no established grass crop is free of infection. However damage depends on the host, its growth stage, the pathogen and the extent of infection, and how the crop is managed. In pastures, diseases are rarely lethal, although by weakening their host they may bring about its elimination as a result of competition from healthier plants, or may predispose it to damage during unfavourable climatic conditions. The effect of fungal diseases are often complex: fungi directly destroy leaf tissue, but may also change host physiology or produce toxins and thereby seriously affect herbage quality and palatability .

Diseases Affecting Establishment of Silvi-pastoral System

Damping off and Seedling Blights: The diseases of germinating seeds and of seedlings, collectively known as damping-off and seedling blights affect the initial establishment. Emergence is poor even with seeds of high germinative capacity; there are patches with no seedlings at all. Seedlings that have emerged often show water - soaking, browning or shrivelling of the stem tissues at soil level and they die as a result. These two stages are known, respectively, as pre-emergence and post-emergence damping off. Among the most frequently isolated pathogens are *Fusarium, Drechslera, Pythium* and *Rhizoctonia* spp.

Pythium species most often encountered are *P. debaryanum,. P. ultimum, P. aphanidermatum, P. arrhenomanes* and *P. graminicola*. Some are associated particularly with certain host families such as Graminae (*P. arrhenomanes* and *P. graminicola*).

Phytophthora species, in addition to damping off, attacks young plants about 120-150 mm high and cause brown to black discoloration of the external stem tissues at or just above soil level, a feature to which the term foot rot is sometimes used. When affected plants are pulled up the primary root system is found to be badly decayed or rotten.

Rhizoctonia species; *R. solani* and *R. bataticola* cause damping-off diseases in many tree and grass species. Similarly various species of *Fusarium* are important for causing seedling diseases but the pathogenic activities are not always combined to seedlings. Seed infection by *F. nivale* occur on oats (Noble and Montgomerie, 1956). This fungus has long known as the causal agent of snow mould of turf and grasses. Other species causing damping-off includes *Helminthosporium, Colletotrichum, Botrytis,* etc.

Majority of these fungi are limited in their parasitism to the seedling stage only and the plants become progressively more resistant to attack. Many bio-ecological factors affect these diseases. The effects of soil moisture is one such crucial factor. Damping-off by species of *Pythium* and *Phytophthora* is most severe at high moisture levels (Graham *et al.*, 1957; Wright, 1957). *R solani*, however, behaves differently. On certain host plants damping off caused by *R. solani* increases with soil moisture but in some host soil moisture stress favour the severity of disease. *R. bataticola* is invariably a pathogen of dry and warm conditions (Dhingra and Sinclair, 1978). Seeding rate and depth of planting are factors which may also be important where they adversely affect plant growth. Seedling blight of oats by *F. nivale* and *F. culmorum* is increased by deep planting (Noble and Montgomerie, 1956), probably because the susceptible coleoptile becomes attenuated under these conditions.

The first line of approach in their control must therefore be good seeded management. Yet another but most important feature which many of the fungi concerned have in common is their ability to survive for relatively long periods in soils. Once damping-off becomes troublesome on a site, steps must be taken to reduce the inoculum level of these fungi. This is achieved by partial soil sterilization. In recent years, solar heating (soil solarization) has been found to be a novel method to control soilborne pathogens (Katan, 1981). It is especially effective in hot arid regions where intense solar irradiations and more sunshine hours are available during summer months (Lodha and Solanki, 1992; Lodha, 1995). In a detailed experiment carried out at CAZRI, an attempt was made to disinfest nursery soils from soilborne pathogens like *Macrophomina phaseolina, Fusarium solani* and *Cylindrocarpon lichenicola* (Bohra. *et al.*, 1996). Mulching with transparent polyethylene sheet during month of May increased the soil temperatures by as much as 10 and 7°C at 5 cm depth in dry and wet nursery soils, respectively. This resulted in pronounced reduction in the population of *M. phaseolina* and *F. solani* and completely eliminated *C. lichenicola* (Table 1). As a result, mortality due to root rots was also significantly decreased in seedlings raised in solarized soil (Table 2).

Table 1. Effect of solar heating on the viability of *Macrophomina phaseolina, Fusarium solani and Cylendrocarpon lichenicola*.

Treatments	Population g^{-1} soil [a]		
	M.phaseolina	*F. solani* x 10^{-3}	*C. lichenicola* x 10^{-3}
Solarized [b]			
Wet	10	0.3	0.0
Dry	13	0.7	0.0
Non- solarized			
Wet	800	3.2	0.3
Dry	1067	5.8	0.7

Bohra *et al.*, (1996)

[a] Initial population of *M. phaseolina, F. solani* and *C. lichenicola* was 1195, 7.3 x 10^{-3} g^{-1} and 2.6 x 10^{-3} g^{-1} soil, respectively.

[b]. Soil solarization test was performed from 16-30 May, 1993.

Seed treatment with fungicides is another method of controlling damping off and seedling blights, particularly when the fungus is seedborne. Compound like Tetramethyl thiuram (Thiram), carbendazim, streptomycin sulphate are few of the important fungicides/antibiotics for seed treatment.

A further possible method of controlling damping-off fungi is to make use of microorganisms which are antagonistic to them. *Bacillus subtilis, Trichoderma harzianum*, etc. are many such bio-control agents which are extensively used these days as seed protectants (Hadar *et al.*, 1979).

Table 2. Effect of solar heating on the root rot mortality (%) in Jojoba due to three soilborne pathogens

Treatments	*M.phaseolina*	*F. solani*	*C. lichenicola*
Solarized			
Wet	0	0.3	0
Dry	5.3	8.5	0
Non- solarized			
Wet	12.5	10.0	0.5
Dry	14.2	12.5	0.5

Bohra *et al.*, (1996)

[a] Aftre six months of planting

A much more promising line of approach is to add to soil organic materials which will stimulate the development of a wide range of saprophytic microorganisms, some of which are antagonistic to the pathogen. A dramatic increase in the antagonistic actionomycetes against *Macrophomina phaseolina* (Table 3) and *Fusarium oxysporum* (Table 4) have been recorded when the soil was amended with castor or mustard cake (Sharma *et al.*, 1995).

Diseases Affecting the Established Silvi-pastoral System

Root Rots: Most of the economically important diseases in this group are caused by fungi and these are more common on tree saplings than grasses. There is a progressive rotting of the root system which often involves the basal portion of the stem and, as a result, the plant can not obtain the water and nutrients its needs. This gives rise to a number of symptoms in the shoot: growth is checked and plant becomes stunted, the leaves yellow and wilt, some drop and eventually the plant collapse and dies. This group of disease are more important in the establishment of top feed species, because often it takes long time to exhibit the symptoms on above ground parts, by the time root portion is enough damaged. This affects the success of

Table 3. Effect of soil amendments on *Macrophomina phaseolina* total microbial and antagonistic actinomycete population[a] g^{-1} soil after 45 days

Amendments[b]	*M. phaseolina*	Bacteria and Actinomycetes ($x10^6$)	Fungi ($x10^4$)	Antagonistic actionomycetes ($x10^6$)
N + PMR	152	109	14	4.3
N + PMR +MC	0	145	23	23.3
N + PMR +CC	366	164	16	38.3
MC	0[c]	162	8	27.3
CC	200	143	2	24.0
Infested soil	1132	97	2	2.3
LSD (5%)	116	9	2	4.4
Initial	2753	87	1	0.9

Source: Sharma *et al.*, (1995)

[a] Average of six replications

[b] N-nitrogen (40 kg ha^{-1}) as urea, PMR - Pearl millet residue (0.9%), MC - Mustard cake (1%) and CC - Castor cake (1%)

[c] Same as 30 days

Table 4. Effect of soil amendments on the *Fusarium oxysporum* f sp. *cumini*, total microbial and antagonistic actinomycete population[a] g^{-1} soil after 60 days

Amendments[b]	F.o. f sp. cumini (x 10^3)	Bacteria and Actinomycetes (x10^6)	Fungi (x10^4)	Antagonistic actionomycetes (x10^6)
N + PMR	1.3	136	16	4.3
N + PMR +MC	8.3	209	20	10.6
N + PMR +CC	2.0	634	19	14.5
MC	0[c]	240	4	11.0
CC	1.3	486	3	6.6
Infersted soil	1.7	94	4	0.3
LSD (5%)	1.9	84	3	2.4
Initial	0.3	87	1	0.3

Source : Sharma *et al.* (1995)

[a] Average of six replications

[b] N-nitrogen (40 kg ha^{-1}) as urea, PMR - Pearl millet residue (0.9%) MC - Mustard cake (1%) and CC - Castor cake (1%)

[c] Same as 30 days

control measures. More so, many root rot diseases spread from one infected root to healthy root. Thus lateral spread of root rot is often observed in established silvipastoral or agro-forestry systems.

One of the serious root rot in arid and semi-arid region on trees is caused by *Ganoderma lucidum*. In the early stages, one or two twigs of an affected plant gradually starts drying from the top of the branch. Leaves turned yellowish brown, becoming wrinkled and brittle, then finally abscissed new vegetative growth also retards in these plants. Roots of affected plants are blackish brown. with time, one to three basidiocarps developed on decayed roots near the collar region. In arid regions, most susceptible tree species is *Acacia tortilis*. Many other tree species are also susceptible to Ganoderma (Lodha *et al.*, 1986; Lodha *et al.*, 1994). In the absence of any control, permanent trenches should be dug around infected trees to minimize chances of direct root contacts with healthy trees (Bakshi *et al.*, 1976).

Macrophomina phaseolina is also a serious pathogen for certain pasture species particularly under severe moisture stress. Proper manuring and removal of debris can minimize its incidence in an established pasture.

Wilts: Several types of pathogens are responsible for producing wilt symptoms which are mainly caused on top feed species. First indication is that the lower leaf-petioles bend downwards. This is called epinasty. Cultivation of resistant strains and use of organic amendments can reduce wilt incidence.

Rusts: Mainly *Puccinia* and *uromyces* spp. are ubiquitous on grasses of agricultural importance. prominent are *P. coronata* (crown rust), which occurs in many specialized forms and attacks a wide range of important grasses (Eshed and Dinoor, 1981). *P. graminis* and *P.*

striiformis are two other important species which causes severe damage to many grass hosts. Other rusts of grasses are described by Cummins (1971).

For the control of heteroecious rust, one possible method is the elimination of the alternate host, which checks the fungus completing its life cycle. Cultivation of resistant strain is the most successful method of controlling rust in case of cereals. But no serious effort has been made for grasses. However, for many fodder species resistant sources have been identified (Ahmed, 1985).

Spraying with systemic fungicides is another method to control rusts. Systemic fungicides are now available but the intensity of the disease in a pasture can only justify the application.

Smuts : These diseases are caused by fungi belonging to ustilaginales and are so called because of the soot-like masses of spores which many of these fungi produce on their hosts. The grass smuts occurs within three genera, *Tilletia, Ustilago* and *Urocystis*. Some individual species invade the florets and ultimately destroy the inflorescence and seed, entirely or in part. The cycle of this disease begins when smut spores are deposited on the exterior of maturing seeds. The organisms becomes established interiorly as an endophyte and, with seed germination, enters the seedlings and later invades the inflorescences prior to its emergence. At that stage the vegetative form of the fungus is replaced by large accumulations of black spores. Plants carrying this systemic infection produce little if any seed.

At present no attempts are made to control smut diseases in grasses. External disinfection of harvested seed using suitable fungicides like vitavax, thiram, etc. could be expected to eliminate spores deposited on the seed surfaces. A hot water treatment is generally used to eliminate smut infection from seeds.

Ergot : This disease occurs on several pasture grasses (Dingley 1969). Infection takes place at flowering time. Spores of the fungus are blown on to the open flowers where they germinate. The fungus enters the ovary, where a mycelium develops. The fungus at this stage exudes a honey like substances which attracts insects and at the time it produces a second type of spore which the insects carry away to infect other flowers. This is known as the honey dew stage of the disease, when there are no hard black sclerotia, merely a certain stickiness of the flowering head. The ovary gradually becomes enlarged by the presence of the fungal mycelium and ultimately the hard sclerotia appear similar in shape to the grain but much larger.

When ergotised seed heads are ingested by livestock, ergot poisoning may result due to the toxicity of products arising from the black structures (sclerotia) which constitute a phase in the life history of the causal fungus. After ingestion by an animal these sclerotia liberate a number of alkaloids including ergosterel and ergotoxine, the presence of which in the blood stream induces ergot poisoning symptoms.

The disease rarely appears in great density and control can be facilitated by destroying affected seed heads, especially those of weed grasses among the hedge-rows. Where ergot poisoning has been previously experienced, animals should not be allowed to graze on severely affected pasture until ergotised seed heads have been destroyed.

Blight, Leaf Spots and Anthracnose : In this group of diseases, death of the tissues is a common feature. On leaves and stems blight results in dark-brown lesions of varying size and shape under favourable conditions. The number of lesions increases rapidly, coalesces and often the top of the young seedling is killed. However, in many leaf diseases, the area of necrosis is limited and the main symptom is simply a spot of varying size and shape. Leaf spots can be caused by unfavourable water relationships or temperatures, by mineral deficiencies or excesses and by insects. But diseases in which leaf spots are the principal symptoms are most commonly caused by bacteria and fungi. Most common pathogens involved are *Xanthomonas* and *Pseudomonas* (bacteria), *Alternaria, Aschochyta, Botrytis, Cladosporium, Cercospora, Helminthosporium* (fungi), etc.

Most practical and commonly used control measure is the spray of some contact or systemic fungicides. Though in most cases these diseases are not so severe but if control becomes a circumstantial requirement than spraying with zineb, ziram, mancozeb, copper fungicides can minimize the infection.

Nematode Diseases: The significant role of nematode in causing losses/damages, or even benefits to the silvipastoral systems is of interest warranting attention of scientists and developmental workers. The plant parasitic nematodes, viz. *Ditylenchus sp., Helicotylenchus sp., Hoplalaimus sp., Tylenchus sp., Discolaimus sp.* are found causing problems with turf grasses, pasture legumes and shrubs/fodder trees, whereas, *Aphelenchus sp., Heterodera sp., Tylenchorhynchus* sp. were found in grasses and legumes. *Psilenchus sp.* and *Eudorylaimus* sp. with grasses and trees. *Heterodera* sp. was isolated from both grasses and trees (Azmi and Ahmed, 1980). Spiral nematode, *Helicotylenchus* sp. is very common in silvipastoral system and found associated with all the crops in various levels of infestations (Azmi, 1978).

General Principles of Plant Disease Control in Silvi-Pastoral System

Our prime objective in silvi-pastoral system is to grow grasses and trees free from diseases and obtain a profitable harvest. In the event of an outbreak of a disease, control measures that have to be adopted should be economically justifiable. But before suggesting any control measures precise information is needed on the monetary losses due to diseases. In case of silvi-pastoral systems, control measures are limited, to what can be achieved through silvicultural management practices, to create growing conditions ideal for growth of the plants but unfavourable to development of the diseases.

The principles of disease control in such a system are: 1. Sanitation, 2. Eradication, 3. Isolation trenches, and 4. Chemical control.

Certain silvicultural practices are considered better in controlling a large number of diseases,like 1. Choice and improvement of site, 2. Choice of species, and 3. Cultural practices.

In addition to these control measures, development of genotypes resistant to specific diseases is of paramount importance. Indigenous and exotic germ-plasm (Grasses and forest trees) should be screened against specific diseases under artificial epidemic conditions. Suitable agronomic characters should be incorporated in resistance breeding programme.

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INSECT PEST MANAGEMENT IN SILVIPASTORAL SYSTEMS

M. P. Singh and D. R. Parihar

Introduction

The grazing lands in the arid and semi arid areas are sources of sustenance for myriads of organisms. Diverse life forms find food, shelter and breeding grounds in the pasturelands. One of the most commonly witnessed group of animals at any time in pastures is that of the insects. Their association with grasses and legumes in the pastures initiates right from the establishment stage. As the system matures, changes in insect fauna may occur in terms of species diversity, abundance and succession. But insects are invariably to be found at any stage in the system.

Silvipastoral systems entail inclusion of woody component with forage grasses and legumes. Consequently, there arise interactions among herbaceous and woody components which have a bearing on the associated insect fauna on either component. The plants in most silvipastoral systems were not assigned as much economic value as in commercial plantations. As such little attention was hitherto paid to the insect pests affecting these systems. Also, in the undisturbed systems instances of sudden outbreaks have been rather few. Occasional pest plagues were noticed only when the agricultural or commercial crops were affected. The vegetation in silvipastoral systems hailing from wild origin has often been bestowed with inherent capacity of withstanding a certain degree of insect herbivory.

The silvipastoral systems in the arid and semi arid regions are destined to bear the brunt of additional insect populations during the periods of absence of main hosts of most agricultural pests. A chunk of the area under agriculture in the arid regions is rainfed. The short lived rainfed crops in these regions are attacked by a number of pests. After harvest, many of these pests migrate to the grass, legume and trees in the silvipastures. The same is true of the pests of non cultivated plants that flourish during the short lived rainy season only. Thus the pressure of feeding in the silvipastoral systems is likely to be greater during off season of agricultural crops in the area, as compared to when the vegetation abounds around. There are few specific pests of pastures and trees, and the majority of the injurious insects are polyphagous- capable of surviving on a variety of vegetation.

There seems to be no precise estimate of the injury inflicted to pastures due to insect attack, in arid regions, perhaps because of relatively low value and priority assigned to forage in pasturelands. Further, the insect activity in rangelands was not always viewed as injurious. A large number of insect species in limited populations act as primary decomposers- cutting plant parts to small size, paving the way for the detrivorous micro-organisms to act further. Majority of the soil dwelling insect fauna in pasturelands inflict no appreciable direct injury to plants. This, however, is not meant to give the impression that the vegetation in silvipastures is free from insect pest attack. In recent years, the pressure of overgrazing on the waning pasturelands is acting as a major biotic stress, rendering the system vulnerable to relatively milder insect herbivory, which in earlier times could comfortably be overlooked. Adding to the pest severity in silvipastoral systems is the phenomenon of erosion of floral biodiversity all around.

Destruction of trees and other vegetation for fuel, to convert forest lands to agricultural fields, for industrial purposes and for developmental work etc., has all led to extinction of an incredibly high number of plant species. This coerced the insect fauna associated with these plants to either starve or to migrate and adapt to remaining vegetation.

With the increase in importance attached to silvipastoral systems in the present times, the management of insect pests has become significant too. The modern silvipastoral systems are raised with multifarious objectives to yield a variety of products. Insect pests contribute towards loss in output or deterioration in the quality of the produce obtainable from the silvipastoral systems. In the following text the major insect pests encountered in silvipastoral systems in the arid and semi arid regions are being described. It may be borne in mind that each system in any ecogeographical region has its own spectrum of insect pests and that the same type of insects may or may not be found to occur or inflict injury under different geoclimatic conditions

Grasshoppers

The grasshoppers are the most commonly found group of insects in pasture based farming systems. Most of the acridoids have a fairly long life cycle, some of the species being active round the season, reproducing once or more in a year. There are no precise estimates about how much injury is imparted by grasshoppers to herbaceous and tree plants in silvipastoral systems in the tropical areas. Parker and Connin (1964) have stated that even when the infestation of a range is light, the grasshopper population consumes grass at about the same rate as a cow. If the grass is sparse, the amount thus destroyed may reduce the supply to the point where cattle can no longer sustain it. Cowan (1958) opined that on the rangelands of the US, grasshoppers annually consume from 6 to 12 percent of the available forage. The losses under tropical conditions could be still higher, where temperature induced suppression of insect activity is comparatively lower for the most part of the year.

In the naturally occurring grasslands, there is often an equilibrium in operation regarding the grasshopper population. Variations in the distribution of insects in a habitat result from their response to the complex microclimatic pattern within it. The response could be kinetic or akinetic. In the event of disturbance to the system through natural or man made interruption, there is corresponding reaction in the activities of the grasshopper fauna. Such an action may result in decline or upsurge in the population of any species. Shortage of food plants and their low water content may contribute to the intensity and the range of movement of hoppers and adults in the field.

Grasshoppers are believed generally to have a wide range of food plants. The number of species definitely known to feed equally on grasses and other herbs is rather small. However, the relative availability of food plants can play more important role than inherent preferences under some situations. Differential feeding may result in a great diversity between species as regards the range of plants devoured.

Ground living grasshopper species feed on leaves lying on or near the ground. When the food there is exhausted, they may climb on plants to feed on foliage. The herbivorous species normally begin feeding on the edges of leaves, advancing deeper, but often avoiding the main veins of broad leaves. At times, few species may nibble the leaves, without eating the same. Buxton (1932) had indicated that dry plant debris in desert areas absorb moisture from night dew which was used by grasshoppers as food.

A few species of grasshoppers form swarms under certain circumstances and inflict heavy injuries as locusts. Table 1 presents an account of some of the grasshopper species occurring across the Asian region. Most of the species are ambivorous, surviving on grasses as well as on other plant species. The gregarious forms of the swarming species appear sporadically. In swarms, they cover long distances away from the place of hatching. The stay of the swarms at any location could be very short, but the losses caused could be far greater. In the context of the silvipastoral systems, it would be relevant to consider the species in solitary phase or the non swarming species, which stay with these systems for the most part. Small journeys of these forms to shift food following the exhaustion of the source is different from the movement of the swarming forms.

The injury inflicted to food plants and also to non-food plants is not always proportional to the amount of food consumed. At times the grasshoppers only nibble the foliage, without actually consuming it, but spoiling it anyway. Thus the magnitude of injury is escalated. The injury level is also governed by the period of stay of the hoppers at any locale, beside population and other factors. Compared to the insects with short life cycles, the progression in acridoid population is much slower. Therefore greater opportunities exist to apply control measures, if required, because of the longer stay of the pest on host.

Control

(i) Cultural control: Destruction of egg masses of grasshoppers forms an effective method of pest population suppression. Exposure of eggs to sun and predators could be achieved through ploughing the land. The survival of grasshopper eggs depends on four factors, viz., temperature, availability of moisture, availability of oxygen and the ability to withstand adverse conditions by suspending development. Exposure of eggs interrupts in maintenance of optimal temperature and moisture levels. Eggs of most non-diapausing grasshoppers have ability to regulate water uptake according to the requirement. Exposure of eggs to sun (42 degrees and above) creates conditions of desiccation and heating simultaneously. The grasshopper eggs also do not develop in waterlogged conditions, perhaps due to loss of oxygen for long periods. In China, flooding egg sites with water has been used as a control measure. In the arid and semi arid regions elsewhere, artificial flooding may not be a suitable proposition, though water logged conditions due to natural rains may serve to reduce egg viability.

(ii) Chemical Control: With the awareness about the ill effects of pesticides, rarely is this method advocated for suppressing grasshopper populations in range and pasturelands. The advantages of insecticides are that a great choice of materials with proven efficacy is available; the application equipments and dose to be applied are available; and the result is achieved in minimum time after application. Such an approach has advantage for the individual land owners with limited holding with valued produce on farm. It could be a useful method in large holdings under grass or forest cover when an outbreak of the pests occurs and immediate check is

Table 1 Grasshopper species commonly found across a part of Asian region

Grasshopper species	Distribution	Activity Period	Other food plants
Family ACRIDIDAE			
Acorypha glaucopsis	Ir In	Jul - Mar	Wheat, Barley, Maize, Sesame, Cotton
Acrida exaltata	Ir Afg	Mar - Oct	Lucerne, Cucurbits, Vegetables, Clover
Acirda oxycephala	Ir Afg In BD SL	Mar - Nov	Millet Cotton, Rice, Teak, Sgarcane
Acrorylus insubricus	Ir In Afg SL BD	Apr - Nov	Veg Cotton Rice Lcerne Wheat
Aiolopus simulatrix	Ir In BD	Mar - Nov	Sorghum Millet Lucerne Maize Wheat
Aiolopus strepens	Ir	thr year	Rice Cotton Lucerne Wheat Vegetables
Aiolopus thalassinus	Ir In SL BD	Feb - Nov	Millet Cereals Cotton Maize rice Wheat
Anacridium aegypticum	Ir Afg	Mar - Nov	Fruits Cotton Wheat Lucerne Maize sugarcane
Apalacris varicornis	In BD	Jul - Sep	-
Aulacobothrus luteipus	In BD SL Nep	Apr - Aug	Teak
Calliptamus barbarus	Ir	Apr - Sep	Cereals Veg Lucerne Cotton Melon Potato
Calliptamus italicus	Ir Afg	Apr - Sep	"
Calliptamus turanicus	Ir Afg	Apr - Oct	Barley Wheat Cotton Cereals
Catantops pinguis	Afg In Nep BD SL	Apr - Nov	Millets Cotton Maize Rice Teak
Catantops pulchellus	In BD	Feb - Aug	Cotton Rice Wheat
Chondracris rosea	In BD	Mar - Oct	Citrus Castor Cotton Maize Groundnut
Choroedocus illustris	In BD	Apr - Dec	Sugarcane Sorghum Mulberry
Cyrtacanthacris tatarica	In BD Nep SL	Jul - Apr	Cotton Castor Casuarina Pulses Veg
Dericorys albidula	Ir Afg	Apr - Aug	Salt Bushes
Duroniella gracilis	Ir Afg	Mar - Nov	Lucerne Cotton garden Crops
Eremippus persicus	Ir Afg	Apr - Oct	Lucerne Garden Crops
Eyprepocnemis alacris	Ir Afg In SL	Mar - Oct	Cotton Lucerne Tobaceco
Eyprepocnemis rosea	In BD	Jul - Oct	Vegetables Maize Rice Teak Tobacco Castor
Gastrimargus africans	In SL Nep	thr year	Millet maize Rice Teak Tobacco Castor
Heteracris adspersa	Ir Afg	May - Feb	Cotton Cucurbits Tobacco
Hieroglyphus littoralis	Ir Afg	Apr - Dec	Cucurbits Sorghm Sugarcane veg Berseem
Hieroglyphus banian	Afg In Nep BD SL	Jul - Dec	Millet Castor Chilli Cereals cotton Pulses
Hieroglyphus coricolor	In BD	Jul - Nov	Cereals Sgarcane
Hieroglyphus nigrorepletus	In BD	Jul - Nov	Millets Sorghum Rice Sugarcane
Hieroglyphus oryzivous	In BD	Jun - Sep	Rice Sugarcane Millets Maize
Ochrilidia geniculata	Ir Afg In	Mar - Oct	Vegetables Wheat Lucerne
Ochrilidia tibilis	Ir	Mar - Sep	Vegetables Sorghum Cotton
Oedaleus sendgalensis senegalensis	Ir Afg In	Jun - Nov	Millet Cowpes Groundnt Maize Wheat
Oxya fuscovittata	Ir Afg In BD	Apr - Nov	Cotton Maize Rice Sorghum Sugarcane
Oxya hyla	IN BD SL	Jul - Nov	Rice Cotton Barley Citrus Lucerne
Oxya japonica	In SL	thr year Feb - Nov	Veg Maize Mustard Sorghum Pulses
Oxya velox	In BD	Mar - Nov	Castor Cotton Cucurbit Maize Rice

Family PAMPHAGIDAE			
Eremopeza gigas	Ir Afg	Mar - Jul	Wheat
Family PYRGOMORPHIDAE			
Atractomorpha angusta	In Nep BD	thr year	Cotton Maize Tobacco Soybean
Atractomorpha crenlata	In BD SL Nep	Jul - Dec	Tobacco Maize Castor Cotton Veg
Atractomorpha psittacina	In BD	Jun - Nov	Cotton Veg Groundnut Pulses Sorghum
Aularches miliaris	Pak In Nep BD SL	Jul - Dec	Beans Chilli Cotton Cucurbits Sesame
Chrotogonus homalodemus	Ir Pak	thr year	Beans Cereals Cotton
Chrotogonus oxypterus	In SL	May - Jul	Cotton Millet Maize Wheat
Chrotogonus trachypterus	Ir Afg In Pak BD Nep	the year	Millets Veg Cucurbits Mustard
Colemania sphenarioides	In	Sep - Dec	Millet Sorghum Pigeonpea Cotton
Poekiloceruus pictus	Afg Pak In	May - Sep	Cucurbits Veg Sorghum Citrus Cotton
Pyrgomorpha bispinosa	Pak In	Apr - Nov	Millets Sorghum

In = India, Ir = Iran, Nep = Nepal, BD = Bengladesh, SL = Sri Lanka, Af = Afghanistan, Pak=Pakistan

warranted. In silvipastoral systems where grazing is one of the central activities, chemical measures are assigned low priority. An attractant spiced with insecticide could have important application in grasshopper control.

(iii) Biological control: A good deal of biological control is exercised by the natural enemies of the grasshoppers. These include Insects, Arachnids, Reptiles, Birds, Worms, Mammals and the microorganisms (Table 2).

(iv) Microbial control: Microbes causing disorders or mortality in grasshoppers may be used as control agents. Protozoan, Fungal and Viral pathogens have been identified as causing mortality to different stages of grasshoppers. Among the Protozoans, *Malameba locustae*, some species of gregarines, *Nosema locustae, N. acridophagus* and a few species of microsporidians have been noticed causing chronic infections in grasshoppers. Entomopox viruses have been characterised for a few species. Crystalline array viruses have also been observed in body fluids of ailing acridoids.

Fungi and bacteria are considered to be the most potent microbial agents for insect control. However, there ought to be specific conditions for initiating infections. The fungi require high relative humidity and optimal temperatures for germination and growth, while the bacteria will perform better when the insect is predisposed to infection by some stress already. *Entomopthora* spp have been the most common entomogenous fungi reported on a number of grasshopper species.

Table 2. Some biological control agents for grasshoppers

Grosshopper species	vertebrate Predator	Acarine /Insect Predator	Insect parasites	Fungal Disease	Nematodal/Protozoan disease
Acrida oxycephala	-	-	*Blaesoxipha lineata* (Dip)	-	-
Ailopus simulatrix	*Milvus migrans* (Av) (A)	*Tettigonia cantans* (Aca) (A)	*Blaesoxipha anceps B.monticola B.tertia* (Dip) (A) *Leptus* sp. (Aca) (A)	-	-
A. thalassinus	*Threskiornis spinicollis Bubulcus ibis Numida melagris mitrata Milvus migrans* (A)	-	*Scelio aegyptiacus S.popovi S. hieroglyphi S.tristris* (Hym) (E) *Blaesoxipha aspinata B. monticola B. tertia* (Dip) (H) *Leptus* sp. (Aca) (H)	*Entomophthora grylli*	*Cheilospirura hamulosa* (Nem) (H)
Acrotylus insubricus	-	-	*Blaesoxipha anceps B. lineata B.laticornis B. filipjevi B.unicolor* (Dip) (H,A) *Tachysphex nigripennis* (Hym) (H,A) *Eutrombidium rostratum E. trigonum* (Aca) (H,A)	-	-
Anacridium aegyptium	-	-	*Sarcophaga ungulata Acemyia acuticornis* (Dip)	-	-
Atractomorpha crenulata	-	-	*Scelio* sp. (Hym) (E)	-	-
Aularches miliaris	Wild Pigs (Mam) (E) Hawks (A) (Av)	-	-	*Entomophthora grylli* (A)	-
Calliptamus italicus	*Pastor roseus* (Av) (H/A)	*Mylabris sp. Percosia equestris* (col) (E)	*Epicauta erythroceph- ala* (col) (E) *Anastoechus nitidulus Blaesoxipha lineata Cytherea setosa Systoechus sp. Wohl- fahrtia balassogloi* (Dip) (E)	*Entomophthora grylli* (H,A)	-
C. turanicus	*Pastor rosaeus* (Av) *Coracias garrulus* (H,A)	*Mylabris frolovi* (col) (H)	*Anastoechus nitidulus Callostoma desertor- um Cytherea setosa Anthrax oophagus*	-	-
Catantops pinguis	-	-	-	*Entomophthora grylli* (A)	-

Chondracris rosea	-	*Epicauta hirticornis* *E.waterhousei* *Mylabris cichorii* *M. phalerata* (col) (E)	*Scelio bipartitus* (Hym) (E)	*Entomophthora* sp. *E. grylli*	-
Chrotogonus homalodemus	-	-	*Leptus sudanensis* (Aca) (H,A)	-	-
C.trachypterus	-	-	*Scelio aegypticus S. hieroglyphi S. tristris* (Hym) (E)	-	-
Colemania sphenarioides	*Sitana ponticeriana* (Rip) (E) *Acridotheres tristris Bubulcus coromandus* *Corvus splendens* *Eulabes religiosa* *Milvus govinda* *Neophron ginginianus* (Av) (H,A)	*Systoechus nivalis* *S.Socius* (Dip) (E) *Mylabris Pustulata* (col) (E)	-	-	-
Cyrtacanthacris tatarica	*Bubulcus ibis,* *Milvus migrans,* *Numida meleagris* (Av) (H,A)	-	*Blaesoxipha filipjevi B.anceps* (Dip) (H) *Scelio zolotarevskyi* (Hym) (E)	*Entomophthora grylli* (A)	-
Dericorys albidula	-	-	*Blaesoxipha filipjevi B.lineata villa decipula* (Dip) (A)	-	-
Gastrimargus africanus	*Nomida meleagris mitrata* (Av) (H,A)	-	*Scelio* sp. (E)	-	-
Heteracris littoralis	-	-	*Scelio princeps* (Hym) (E)	-	-
Hieroglyphus banian	-	-	*Scelio hieroglyphi* (Hym) (E)	*Entomophthora grylli* (A)	*Gordius mermis nigrescens* (A)

H. nigrorepletus	-	-	*Scelio hieroglyphi* (Hym) (E) *Eutrombidium trigonum Trombidium* sp. (Aca)		
Oedaleus senegalensis	*Coracias abyssinica Merops albicollis* (Av) (H;A)	*Mylabris* sp. (col) (E)	*Systoechus sp. Xeramoeba oophagus* (Dip) (E)	-	-
Oxya hyla	-	-	*Scelio aegyptiacus S.serdangensis* (E)	-	-
O. japonica	-	-	*Epicauta gorhami* (col) (E) *Anastatus coimbatorensis Scelio murai S.oxyae S.pembertoni S. serdan gensis S.tsuruokensis Tumidoscapus oophagus* (Hym) (E)	-	-
Parahieroglyphus bilineatus	*Coracias benghalensis Eudynamis scolopaceus* (Av) (H,A)	-	-	-	-
Poekilocerus pictus	-	*Mantis religiosa* (Ph) (H,A)	*Blaesoxipha kraestneri* (Dp) (H)	-	-
Spathosternum prasiniferum	-	-	*Scelio tristris* (Hym) (E)	-	-
Sphingoderus carinatus	-	-	*Blaesoxipha filipjevi B. laticornis* (Dip) (A)	-	-
Stenocatantops splendens	-	-	-	*Metarrhizium* sp. (E,H)	-
Trilophidia annulata	-	-	*Scelio aegyptiacus* (Hym) (E)	*Entomophthora grylli* (A)	-

A= Adult , E= Egg , H=Hopper , Aca= Acarina , Av= Birds , Col= Coleoptera , Dip= Diptera , Hym= Hymenoptera , Ph= Phasmida , Rep= Reptile

Termites

White ants or termites are the most dreaded pests in most farming systems around the globe. These insects have the potential of spoiling the plant right from the sapling stage to the post harvest stage when the timber or fuelwood is reduced to mud if left to the termites. The infestation of termites is not noticed until a certain degree of irreversible loss is already caused. The incidence of non mound forming termites could be quite misleading or sudden in virgin lands.

Termite attack is believed to be accentuated by aridity. In most silvipastoral systems, the presence of termite colonies may not be worth an alarm until a certain level of moisture exists in soil and plants. In the water stressed conditions of semi arid and arid regions, chances of losses due to termites are expectedly greater. However, these insects are not viewed as invariably imparting negative stress to the farming systems. In the naturally occurring ranges, pastures and stable forest lands, termites also play useful role of soil enrichment. Barnes et al (1992) observed that bacteria associated with the termites appeared to be fixing nitrogen. Pandey et al (1992) estimated that *Reticulitermes* colonies were capable of fixing 125 to 445 g nitrogen/ha/year. Malik and Sheikh (1991) found soil from termite mound of *Odontotermes obesus* and subterranean nest of *O. lokanandi* to be more fertile than termite free soil.

Control

Conventional methods of termite control till recently had relied on the use of persistent organochlorine insecticides. Realising the environmental impact of these insecticides, their use has been discontinued by most environment conscious masses. Alternative methods of control are constantly being tested for effectiveness. The non chemical techniques include the use of microwaves, heat, cold, electric shock, barriers and many others. Integrated management of termites will involve one or more of the many options in a compatible manner, some of which are being described in the following text.

Cultural practices: Proneness to termite attack depends on a number of factors. One of these is provisioning of conditions in the system that favour their activities or lure them. In systems where stress conditions are created by higher plant population, rectification could be effected by trimming the excess plants from the field. Healthier plants offer lesser incentives to termites. In contrast, planting of extra seedlings in anticipation of losses has also been suggested as a useful cultural practice under normal moisture conditions in termite endemic areas.

Application of neem or castor cake has been demonstrated to have a negative impact on foraging and recruitment of workers in some termite species. Mulches may be used to divert the population of termites from attacking the main crop in the field. More or less similar effect could be produced by providing alternative food sources within the planting area. For the woody species, good silvicultural practices contribute towards prevention of losses.

Use of barriers: The subterranean termites move below the earth surface. Infestation follows the detection of favourable or suitable food source by the scouts. The access of the scout and worker termites could be blocked through deploying barriers, which restrict the movement of termites through these devices. Barriers may be physical, chemical or biological. These are mainly used for protection of buildings, but may also be utilized to prevent the entry of termites from pre infested areas to non infested ones. Physical barriers could be sand or cinder barriers, termite shields, aggregate barriers etc., These barriers are supposed to be impenetrable to termites. Glass or glass like materials crushed to particle size of 0.5 - 1.5 mm in thin layers of 12 - 20 mm thickness have been tried successfully.

Chemicals incorporated with carriers or applied in a manner so as to form a shield around the area to be protected, act as chemical barriers. These could be used in combination with the physical barriers to ensure greater protection; or could be used alone.

Non food plants raised with the preferred host plants for termites may act as biological barriers. In a like manner, intercropping may also be a useful practice to lower termite injury in a field.

Irradiation: Termites may be exposed to the radiations of X-, gamma- or ultra violet rays, once their presence is ascertained in mound, nest or at source of food at the site.

Traps Baits: Making available concentrated sources of food at predetermined sites may lure termites to assemble there. The congregated population may then be exposed to toxicants or chemosterilants. The food material preferred by the termite species occurring at different sites may be utilized as trapping material. Chopped dried grass, bamboo, cartons etc., may be utilised for the purpose. Toilet paper rolls have been used quite successfully as attractants for termites. Of the many different chemicals tried, carbaryl, sodium fluosilicate and mirex are some that have found acceptance. Diiodomethyl para-toloyl sulfone (A-9248) @ 600 ppm suppressed 65 to 90 per cent activity of *Coptotermes formosanus* (Su *et al., 1991). Trapping and baiting may be carried out simultaneously or in succession.*

Plant repellents: The negative response of termites to the odour or taste of some synthetic or natural products may be used as a tool for integrated pest management. In the recent past a number of compounds have been tested for their repellency against the termites. Among the natural products, neem seed extract has been the most talked about one. Its a source of azadirachtin and other compounds with potent insecticidal, feeding deterrent, and insect growth regulator activity. Ishida et al (1992) had isolated 11 compounds of variable termite antifeedant potency from neem oil, including such products as deacetylgedunin, salanin, gedunin, 17-hydroxyazadiradione, nimbandiol, azadiradione, deacetylsalanin and deacetylnimbin.

Another group acting as antifeedant for termites is that of the limonoids. Obacunone and nomilin have shown antifeeding activity against *Reticulitermes* genus. Anthraquinone and furfural have been demonstrated to elicit repellent response in *Cryptotermes brevis* in Egypt (Moein, 1991).

Plant resistance: Use of plant material that exhibits tolerance or resistance to termite attack will result in lowered losses in areas of termite activity. Introduction in the silvipasture systems of such herbaceous and woody species that can withstand termite injury will certainly contribute towards the sustainability of the system. In areas of endemic termite incidence, it would be prudent to replace the high yielding but termite prone species, with the termite resistant species, even though the latter may have slightly lower yield potential. In a study Mitchell (1992) found that the species with less than 10 percent deaths due to termites in Zimbabwe were : *Acacia holoserica, A. albida, A. salicina, A. plectocarp, A. leptocarp, A. difficilis, Senna atomaria* and *Enterolobium cyclocarpum*. A particular plant species may not be found to be resistant to termites at all ecogeographical locations, as the invading termite species may be different at different sites. Therefore, tests need to be carried out for susceptibility or otherwise to termites in respect of every plant species to be introduced in silvipastoral system at any particular location

Chemical control: Despite the many disadvantages associated with insecticidal control, it will not be appropriate to wipe out altogether this method from IPM strategy for termite management. From the long persisting, environmentally hazardous insecticides, the stress has shifted to use of short lived but effective and relatively safer insecticides. Bifenthrin, chlorpyriphos, cypermethrin, fenvalerate, isofenphos, permethrin, deltamethrin, carbosulfan and trichlorphon etc., are the insecticides currently in vogue for termite control, in place of yesteryear's organochlorines.

Fungicidal control: Some species of termites maintain fungal gardens on which they rely for conversion of cellulose to digestible form, such a mechanism lacking in the gut of these species. Applying fungicides to termite nests or mounds or feeding sites results in destruction of fungi, thus rendering the termites to face starvation.

Microbial control: There are a number of micro-organisms that induce diseases in termites. These include insect baculoviruses, nuclear polyhedrose viruses, microsporidian Protozoa, entomophilic nematodes, bacteria and entomogenous fungi (mycoinsecticides). *Beauveria bassiana, Metarhizium anisopliae, M. flavoviride minus, Paecilomyces lilavacins* and *P. fumosorosus* have been found to be the entomopathogenic fungi for *Odontotermes brunneus*.

Biological control: Termites have a large range of predators. A number of insects, spiders, reptiles, rodents, birds and higher mammals find termites to be their main source of food. The assasin bug, *Rhinocoris marginatus* (host *Odontotermes obesus*), larvae and beetles of *Omphra pilosa* and the ant *Ophthalmopone hottentota* (on *Microhodotermes viator*) are some of the examples of insect predators. Among the spiders, *Ammoxenus amphalodes* and *Haplodrassus stationis* have been found predating over *Hodotermes mossamicis*. The gecko, *Hemidactylus frenatus* and *echidna, Tachyglossus aculeatus* have been found feeding on a number of termite species. Among the birds, the chat, *Myrmecocichla formicivora* feeds voraciously on *Hodotermes mossamicus* and the white browed sparrow weever, *Plocepasser mahali* has been observed preying upon *Odontotermes, Hodotermes* and *Trinervitermes* species. The green wood pecker, *Picus viridis levaillanti* and the bank myna, *Acridotheres ginginianus* feed on a variety of white ant species. Among the mammals, the ant eater aardvark, *Orycteropus afer* has been reported feeding on *Macrotermes sp., Hodotermes mosambicus* and *Trinervitermes trinervoides*, while the aardwolf *Proteles cristatus* has been a regular predator of all species of the genus *Trinervitermes*. *Hodotermes mossambicus* are also predated over by the bat eared fox, *Otocyon megalotis* and *Macrotermes* sp. by the bushbaby, *Otolemur crassicaudatus*. Other mammals feeding on termites include slothbear, *Ursus ursinus*, *Zaglossus*, *Myrmecophaga*, *Priodontes* and *Manis* species. The gorilla also feeds on termites at times.

White Grubs

These grubs pose serious threat to the legume fodder plants in rainy season. Plants with adventitious roots have the capacity to withstand grub injury to certain extent. Adults of these grubs commonly known as June beetles or chaffers come out from soil with the onset of monsoons and immediately settle down on nearest available vegetation for feeding. Neem, Khejri and Ber happen to be the preferred plants. They are a group of voracious feeders and defoliate the plants on which they settle for feeding, in a very short time. After being full fed, they mate and enter the soil again for oviposition. The grubs hatching from these eggs initially feed on humus and then attack the seedlings of crops sown in these fields.

For managing these insects, killing of adults is an effective way. The beetles are attracted to light in night which may be trapped and destroyed by burying, burning or dipping in insecticidal solution or oil emulsion . However, traps should be employed at a large scale on co-operative basis only, otherwise more harm will be done than good, if isolated efforts are made. The beetles may also be collected while feeding at night by jerking the host plant and then these may be destroyed. Dusting the host plants with insecticides (2% metyl parathion) or spraying (with .05% methyl parathion/fenitrothion/quinalphos) can also kill the beetles feeding on these plants. Soil ploughing exposes the grubs to natural enemies like crows and other birds. Additional cross or deep ploughing will expose more of the grubs to birds. Soil treatment with insecticides is a costly practice but may have to be resorted to at times when none of the above cited measures have been applied. The grubs are quite big in size and therefore the normal dose of insecticides has to be increased many fold for these insects.

It needs to be emphasized that for a successful white grub management programme, a campaign has to be launched, involving as many people as possible, to achieve best results. Killing of adults, exposing the grubs to natural enemies and then using insecticides in soil all this done together will ensure good control.

Hairy Caterpillars

The most common among these (Table 3) is the red hairy caterpillar, locally known as Katra. Occurrence of this pest is sporadic but whenever it attacks the crops, losses are colossal. Moths are white coloured with a line of red colour on forewings. Appearance of such moths in large number near source of light is an indication of the possible occurrence of the red hairy caterpillar. Younger stages develop on weeds etc., and then they shift over to the cultivated crops. The ideal time for destruction of the caterpillars is when they are developing on weeds etc., The younger stages are easily killed with insecticides . As the caterpillars advance in age they develop a hairy growth on body giving them protection from the contact of insecticides. The amount of pesticide required to kill full grown caterpillars is quite large.

Table 3. Some agricultural pests of the pasturelands

Defoliators / Seed feeders / Root eaters		Sap Suckers
Beetles and weevils	**Caterpillars**	
Adoretus sp.	*Aegocera venulia*	*Agonoscelis nubila*
Anomala sp.	*Agrotis* spp.	*Aphis craccivora*
Cylindrothorax ruficollis	*Alphaea vittata*	*Alphocoris sp.*
Cyrtozemia cognata	*Amsacta moorei*	*Antestiopsis cruciata*
Hypolixus truncatulus	*Argina cribraria*	*Bagrada cruciferarum*
Lachnosterna consanguinea	*Chilo* sp.	*Clavigralla gibbosa*
Luperomorpha nigripenis	*Creatonotus gangis*	*Clavigralla scutellaris*
Lytta tenuicollis	*Cryptoblabes* sp.	*Cletus signatus*
Monolepta signata	*Eublemma silicula*	*Cletus pugnator*
Myllocerus spp.	*Euproctis fraterna*	*Coridius janus*
Pagria signata	*Euproctis variens*	*Creontiades pallidifer*
Zonabris phalarata	*Heliothis* spp.	*Dolycoris indicus*
	Hymenia fascialis	*Dysdercus* spp.
	Marasmia trapezalis	*Empoasca sp.*
	Mythimna separata	*Exitianus indicus*
	Pelopidas mathias	*Graptostethus servus*
	Psalis pennatula	*Leptocentrus obliquis*
	Spodoptera exigua	*Mecidea indica*
		Nezara viridula
		Plautia fimbriata
		Piezodorus rubrofasciatus
		Ptyelus spp.
		Riptortus linearis
		Tricentrus bicolor

Manual picking of the caterpillars forms a good physical control measure. Children may collect the caterpillars of younger instars. However, it is not advisable to collect grown up caterpillars without a protective covering for the hands. Digging of trenches all around the field (at least 18" deep) deters the marching caterpillars from attacking field. Some plants may be cut and kept in trenches as feed for them after treating with insecticide. Only the peripheral plants for about 2-3 meters may be treated, but not the whole crop. The treated plants should not be fed to cattle at least upto three weeks.

Cutworms

These are serious pests of forage crops (Table 3). Stoutly built caterpillars feed on plants during night time. During day time they remain hidden under crevices in soil. Leaves of younger plants are devoured while older plants are cut at ground level. Raking the dust of any contact insecticide in soil kills the insect.

Army Worms

These insects occur in bands. Stoutly built caterpillars feed voraciously on the foliage and go on destroying fields after field-marching like army. The best time to control these insects is when they are young. Killing the marching caterpillars with sticks or beating with other device forms a cheap and effective measure, but needs to be done on a large scale. In order to avoid its further spread, the fields should be ploughed after cutting of fodder of annual crops.

Leaf and other Caterpillars

Leaf caterpillars (Table 3) are smooth green coloured insects which web together the leaves and then feed over them, making holes in the leaves. The webbed leaves do not contribute fully towards photosynthesis. Another type of caterpillars also appear in leguminous fodder crops which are black in colour and are covered with hair. They feed freely on leaves. There is yet another type of caterpillars which roll and fasten the leaves together and feed on them living inside. Lucerne caterpillars vaty in colour from pinkish brown to light green but are characterized by narrow dark longitudinal stripes on the back. The caterpillars are gregarious in nature i.e. occur and move in a group.

All the caterpillars can be killed by dusting or spraying the crops. It is easy to collect and destroy them in young stage. (For dusting use of 4% carbaryl or endosulfan dusts may be used. For spraying, .05% endosulfan is effective). But it does require a time of about 10-14 days before the treated fodder is used for cattle feed without any detrimental effects.

Aphids and Jassids

The fodder crops invite many types of sucking insects (Table 3). Aphids are more common on leguminous while jassids are found on all fodder crops. Aphids feed on tender parts and inflorescence while jassids have a wider range and may feed on leaves and older parts as well. Occurrence and spread of aphids is favoured by cloudy weather and humid condition. Aphids become particularly serious on inflorescence and developing pods. Jassids normally do not require any insecticidal treatment but at times may have to be controlled. For both these insects normally recommended systemic insecticides should be avoided in the fodder crops. Instead less persistent and safer contact insecticides should be used. Carbaryl (0.1%) of malathon or endosulfan (0.05%) may be sprayed on the crops. While spraying care should be taken to ensure that the spray is applied on both sides of the leaves/blades. If only ventral surface s treated, the insect, specially the jassids take shelter on the dorsal side and avoid contact with the insecticide. Usual waiting period of 10-14 days has to be observed in this case also.

While summing up it may again be emphasized that management of insect pests in fodder crops warrants special attention. Preventive measures have an important role to play in this case. For the soil dwelling insects anticipatory treatment ensures protection of crops. Regular visit to fields may give enough indication about the future attack of insects, if any, as most of these insects are spotted. Combining all measures of control in a befitting way ensures maximum protection to the fodder crops.

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NEEM - A POTENTIAL PESTICIDE FOR SILVI - PASTURE AND AGRO-FORESTRY SYSTEMS

Satya Vir and S.K. Verma

Introduction

Approximately 30 per cent of global food production, valued at more than US $ 100 billion, is lost annually to more than 20,000 species of various plant pests. Resource poor farmers in developing countries, with inadequate means of crop protection are particularly hard hit. Synthetic pesticides, while valued for effectiveness and convenience, can pose certain problems, including toxicity to non-target organisms, environmental degradation, and health hazards to farm households. They may also accelerate development of pest biotypes resistant to specific pesticidal chemicals. In developing countries, additional problems include non-availability of suitable materials and application equipments, supply uncertainties, high costs and inadequate knowledge of farmers about proper use of pesticides . The consequences of misuse, overuse and unnecessary use of insecticides have forced the entomologists to seek a new approach of pest control with minimum ecological disruption.

During the last 25 years, India has been able to increase agricultural production by about 50-60 per cent, but what is required to be done in the next 10 years is of immense magnitude. Unfortunately even today, there is no appreciation for this gigantic task. We require to produce about 230 million tonnes of food grain in the year 2000 AD as against the present level of about 180 million tonnes. For achieving this target, our resources of land, water, seed, fertilizers, and crop protection need to be augmented. As far as 'land' is concerned, it is generally agreed that more land than what is desirable ecologically is already under cultivation. For developing irrigation resources government is committed to increase these, as much as possible, but it is a very slow process as resources available are limited. In case of 'seeds' these are now available for a good range of high yielding varieties of almost all the principal crops which are suited for different regions. However, future work has to be carried out and seeds with several inbuilt qualities like resistance to pests and diseases are to be evolved.

Crop Protection Technology

Several alternate crop protection technologies are available, but unfortunately these have not been passed on to the farmers in . Even when the information is available inputs are either missing or beyond the reach of an ordinary farmer. Consequently a very little proportion of our farming community take the advantage of these technologies. So far pesticides have been the main weapon for the control of pests and diseases. Dramatic increase in yields of crops and trees are obtained when appropriate crop protection measures (mostly pesticides) are adopted as reflected in Table 1.

Crop Protection During Last 50 Years

The past 50 years saw a major evolution in the usage of crop protection technology and this mainly revolved around the production of several kinds of chemicals pesticides. Until the 2nd

Table 1. Effect of crop protection on yield in major crop

Crop	Yield (q/ha)		Increase in yield (%)
	Treated (q/ha)	Control (untreated) (q/ha)	
Rice	46.4	33.2	40.0
Jowar	35.7	15.5	130.0
Bajra	12.5	8.3	50.6
Maize	53.3	40.7	30.0
Mustard	5.4	1.4	285.7
Chickpea	17.2	12.3	40.0
Cowpea	16.1	9.4	71.9
Moth bean	9.2	5.7	62.2
Moong bean	12.0	9.3	77.5

world war, most of the pesticides belonged to the category of plant products or inorganic salts. Nicotine, rotenone, pyrethrum, lead arsenate, sodium/barium fluosilicate and like held the scene. However, with the discovery of DDT these were mostly relegated to the background and a whole new class of chemicals was synthesised and used. These mostly consisted of organochlorines, organophosphates, carbamates and other broad spectrum poisons. The world market today offers 120 insecticides, 95 fungicides, 26 nematicides, 11 rodenticides and 90 weedicides as compared to 24 pesticides available in 1930. In India, we are using 105 different kinds of pesticides of which 43 are now manufactured in the country. Our main researches during this period have been to find out the pest mortality after exposure to the pesticide in a known concentration. Only rare attempts were made to trace these chemicals in the components of agro-ecosystem.

a) Insect Resistance to Insecticides : Resistance to toxicity continues to be the most serious barrier for the successful use of insecticides. This was first evident when housefly, *Musca domestica L.* acquired resistance to DDT, simultaneously in Sweden, Denmark, Italy and US within two years after the first use of DDT. There are more than 119 insect species of agriculture importance, resistance to insecticides (Brown, 1969). The only hope of delaying or avoiding pest resistance is by pest management practices with reduced usage of insecticides and encourage control by natural enemies and cultural practices which destroy the resistance mutants before they can breed resistant progeny.

b) Outbreak of Secondary Pests : The use of broad spectrum and persistent insecticides make the pest control more problematic. These insecticides wipe out the natural enemies and as a result, the minor pests which are hither-to under the control of natural enemies breed enormously and reach major status. For example, the outbreak of rice hispa, *Dicladispa armigera* Olivier during 1969-72 and the brown plant hopper, *Nilaparvata lugens* in 1980-82 in Andhra Pradesh of India are the classical examples the outbreak of secondary pests.

c) Adverse Effects on Non-target Species : The generally applied broad spectrum insecticides are highly toxic to a great variety of animals. These insecticides are aimed at controlling about 1000 species of economically important pests. But these adversely affect 2,00,000 species of plants and animals such as natural enemies, pollinators and wildlife.

d) Hazards of Pesticides Residues : The insecticides during the course of application drift to long distances from the target site. It appears that about half of the total insecticide applied deposits on plant surface and only 1% reaches the target pest species. So the residues of highly persistent non-degradable insecticides are detected in plant produce, soil, air, water and in human and wild life tissues.

Integrated Pest Management

According to FAO panel of experts on integrated pest control, its definition runs as "A pest management system that in the context of the associated environment and the population dynamics of pest species, utilises all suitable techniques and methods in as compatible manner as possible and maintain the pest population at levels below those causing economic injury". The main objective of integrated pest management is to optimise pest control in terms of the overall economics, social and environmental values. There are several components of this system as follows:

Pest Surveillance : The first step for any integrated pest management is to have an overall idea for pest- host behaviour by continuous surveillance of trees and crops for developing pest population dynamics from different agro-climatic zones over a span of time. These surveys are also required to find out the economic threshold, which is the very basis of the concept of integrated pest management. The economic threshold of some of the important pests in India are given in Table 2.

Table 2. Economic threshold level (ETL) of some important pests.

Crop	Insect	ETL
Pulses and ground nut	Pod borer	2 larvae/metre row or 5% pods damaged
	Red hairy caterpillar	8 egg masses on 100 metre
	Gram caterpillar	2-3 larvae/metre row
	Leaf eating caterpillar	8 egg masses on 100 metre
	Whitefly	8-10 adults/ leaf or 20 nymphs/leaf
	Thrips	10 Thrips/leaf or 15-20 % affected plant
	Jassids	2 jassids/leaf
Sorghum	Shoot fly	10% dead heart or 1 egg/seedling in 10 plants
	Stem borer	10% plants with damage symptoms
	Midge	5 midge/ear head
	Ear head bug	10 bugs/ear head
Soybean	Girdle beetle	2% Plants infested
Mustard/Rapeseed	Aphid	30% plants infested or 50-60 aphids/10 cm shoot

Breeding pest resistant plants: Most resistance to pest is an economical and environmentally sound crop protection tool. Unfortunately breeding for resistance to pests is often a never ending process. The resistance tends to break down following the build up in nature of new races of the pathogens capable of attacking a variety earlier released for its resistance. For example wheat varieties 'Kalyan Sona' and 'Sonalika' released in 1967 had high degree of resistance to brown and yellow rust. 'Kalyan Sona' has become susceptible particularly to brown rust. Efforts are now made to release sorghum resistance to shootfly; pearl millet against downy mildew and ergot; pigeon pea to mosaic disease; groundnut to 'tikka', etc.,

Biological Control : In the past more emphasis was placed on inundation approach involving the mass breeding and release of indigenous natural parasites. Emphasis is now shifting to obtain more effective parasites and predators from other areas where the same or related pests occur. Some success has already been obtained for control of coconut caterpillar *Nephantis serinopa* by a Tachinid parasite introduced from Sri Lanka. Similarly encouraging results have been obtained in case of sugarcane scale insect which had become a very serious pest in the coastal regions of Andhra Pradesh of India. Predatory snails and hermit crabs have been found to be useful in controlling the Giant African snails which had become a menance in Andaman Islands *and the parts of Kerala and Assam in India. Successful biological control of Opuntia* and *Lantanax two very serious weeds, with the help of insect parasites was accomplished long back.*

Most of the successes achieved in the biological control programmes have been with the help of insect parasites and great attention has also been given to other agents like fungi, bacteria, viruses, nematodes etc. *Bacillus thuringiensis* has been commercially produced and ranks as major insecticides in the developed countries. It is hoped that there would be a substantial increase in the our efforts to imports, produce and evaluate natural enemies of our important pests.

Use of Indigenous Plant Material for Pest Control

Crude extracts from selected plant species and other materials of biological origin offer an effective method of pest control (Grainge *et al.* 1984), especially when used within an integrated pest management programme. More than 1,600 plants species reported to possess pest- control properties at varying degree (Ahmed, 1984). However, the pest-control effectiveness of these species in the field needs to be validated under specific agroclimatic conditions. Toxicological studies of promising materials should then follow to ascertain their safety to humans and the environment. Numerous studies in many countries have demonstrated the effectiveness of Neem tree (*Azadirachta indica*) extracts against more than 100 species of insects, mites and nematodes (Ketkar 1976; Grainge *et al.* 1984 and Satya Vir *et al.* 1993). One of the first ingredients isolated from neem, *Azadirachtin has proved to be the tree's main agent for battling insects. It does not kill insects, at least not immediately. Instead it both repels and disrupts their growth and reproduction.*

Extraction of Insecticide : Bioactive compounds are found throughout the neem tree, those in the seed kernels are the most concentrated and accessible. They are obtained by making various extracts of the kernel and, to a lesser extent, of the press cake. Although the active ingredients are only slightly soluble in water, they are freely soluble in organic solvents such as hydrocarbons, alcohols, ketones or ethers. The most common method for extraction of neem extracts are summarised below.

Water extraction: The simplest technique is to crush or grind the kernels and to make extract with water. They may, for example by steeped overnight in a cloth bag suspended in a barrel of water or by pouring the water into the bag and collecting extract. This crude extract can be used in the field or it can also be filtered and employed as sprayable emulsion.

Hexane extraction: If the kernels are grated and steeped in the solvent hexane only the oil is removed. The residue left after the hexane extraction still contain the main active limonoid ingradient and subsequent extraction with water or alcohol produce then in large (Satya Vir, 1995b).

Alcohol extraction: Alcohol extraction is the direct process for producing neem based pesticidal material in concentrated form. Limonoids are highly soluble in alcohol solvents. The grated kernels are usually soaked in ethanol, or in methanol. The yield of active ingredients varied from 0.26 to 6.2 per cent.

Pentane extraction: This is another solvent used for extraction of seed kernels but the extract so obtained differ from azadirachtin.

Formulations : Simplest neem pesticide is a crude extract. However, for more sophisticated use, various modifications can be made. These advanced formulations may convert neem extract in the form of granules, dust, wettable powders or emulsifiable concentrates. Aqueous extracts can also be formulated with soap for ease of application.

Method of Application : Neem extracts can be applied in many ways (Satya Vir, 1996). They can be employed as sprays, powders, drinches, or diluents in irrigation water. It can be applied to plants through injection or topical application either as dust or sprays. They can be added to baits that attract insects. Neem leaves and seeds and dry neem cake are ingredients in some mosquito repellents.

Chemical Compounds : The compounds extracted from different neem plants belong to a general class of natural products called 'triterpenes' more specifically "Limonoids". So far, at least nine limonoids have demonstrated the insecticidal properties but azadirachtin, salannin, meliantriol and nimbin are the best known and most significant. This *Azadirachtin* is a triterpenoid and first active ingredient isolated from seed. It does not kill insects at least not immediately. Instead it both repels and disrupts their growth and reproduction. This is one of the most potent growth regulators and feeding deterrents ever assayed. Structurally it is somewhat similar to insect hormones called "ecdysone" which control the process of metamorphosis in insects. It affects the corpus cardiacum which controls the secretion of hormones. On an average, neem kernels contain between 2-4 mg of azadirachtin per gram of kernel. The highest figure so far recorded is 9 mg/g for a sample from Senegal. *Meliantriol* is a triterpenoid which is basically a feeding inhibitor which causes insect to cease feeding. *Salannin* Another titerpenoid isolated from neem. This compound inhibits feeding but does not influence insect moulting *Nimbin and Nimbidin* Nimbin and Nimbidin have been found to have antiviral activity. Nimbidin is the primary compound of the better principles obtained when neem seeds are extracted with alcohol. It occurs in sizeable quantities about 2 per cent of the kernel . Certain minor ingredients also work as antihormones. Some of these minor neem chemicals even paralyze the "swallowing mechanism" and prevent insects from eating. Deacetyl azadirachtinol, isolated from fresh fruits, appears to be as effective as azadirachtin in assays against insects, but it has not yet been widely tested in field practices.

Effects on Insects

Neem extracts are medium to broad spectrum pesticides. Researches in different countries by 1993 had shown the neem extracts could influence almost 200 insect species (Table 3). These include many that are resistant to or inherently difficult to control with conventional pesticides.

Desert Locust : Recent laboratory research has shown that neem oil causes 'solitarization' of gregarious locust nymphs (Schmutterer and Freres, 1990). After exposure to dose equal to mere 2.5 litres per hectare, the juveniles fail to form the massive moving, marauding plagues that are so destructive to crops and trees. Although alive, they become solitary, lethargic, almost motionless and extremely susceptible to predators such as birds. The second approach is the use of neem oil enriched with azadirachtin prevents locust from developing into the migratory swarms. It apparently blocks the formation of the hormones and the pheromones needed to maintain the yellow and black gregarious form.

Cockroaches : Neem kills young cockroaches and inhibits the adults from laying eggs. Baits impregnated with "commercial preparation of neem-seed extract proved to retard the growth of oriental, brown-banded and German cockroaches. First instar nymphs failed to develop and all died within 10 weeks. Last instar nymphs exhibited retarted growth, and half of them died within 9 weeks.

Brown Plant Hoppers : Neem oil and neem cake are employed in Philippines against insect pest of rice especially brown plant hopper (Saxena *et al.* 1984). Five applications of neem oil emulsion sprayed with an ultra-low volume applicator is said to protect rice crops against this increasingly severe scourage.

Stored Grain Pests : Neem shows considerable potential for controlling pests of stored products. This is used in Asia from time immemorial. In the traditional practice, neem leaves are mixed with grain kept in storage for 3-6 months. The ingredients responsible for keeping out of the stored grain pests are not yet identified but they work well. In this connection repellency seems of primary importance. Treating jute sacks with neem oil or neem extracts prevents pests like *Sitophilus* spp., *Tribolium* spp. etc. from penetrating for several months (Satya Vir, 1989 and 90).

Neem oil is an extremely effective and cheap protection for stored beans, cowpeas and other legumes. It keeps them free from bruchid beetle infestation for at least 6 months (Satya Vir, 1989, 1990b and 1995a). The amount of oil used was 4-5 ml/kg of beans. Neem oil shows a strong ovicidal effect in bean seed beetle (bruchids), but its sterilizing and other influences may also be important in controlling these pests (Zehrer, 1984). Neem has also ben used in India to protect stored roots as well as tubers against potato moth.

Table 3. Review of the effects of neem products on different insect pests of crops, stored grain, animals and domestic stock of public health importance

Order	Insect	Effects
Diptera	Mediterranean fruit fly	Toxic and disrupts growth
Diptera	Oriental fruit fly	Arrests pupal development, retards growth, toxic to larvae
Diptera	Face fly	Toxic, reatrds growth
Diptera	Horn fly	Repels, retards and disrupts growth
Diptera	House fly	Inhibits feedings, disrupts moulting, repels
Diptera	Yellow fever mosquito	Kills larvae, disrupts moulting
Diptera	House mosquito	Toxic to larvae
Diptera	Rice gall midge	Toxic
Homoptera	Whitefly	Repels, inhibits feeding, retards growth
Homoptera	Brown plant hopper	Inhibits feeding, repellent, disrupts growth, mating failure and sterility
Homoptera	Green leaf hopper	Inhibits feeding
Homoptera	Large milkweed bug	Toxic, disrupts growth
Homoptera	Mealy bug	Repels, inhibits feeding
Homoptera	Milkweed bug	difficult in escaping the "skin" of the last moult disrupt molting
Heteroptera	Rice bug	Affects feeding behaviour, disrupts growth and development
Heteroptera	Green vegetable bug	Disrupts growth and development
Heteroptera	East African coffee bug	Disrupts growth and development and affects feeding behaviour
Hemiptera	Bean aphid	Reduces fecundity, disrupts moulting
Siphonoptera	Flea	Retards growth, repels, inhibits feeding, disrupts growth, eggs fall to hatch
Siphunculata	Head lice	Kills, very sensitive to neem oil
Dictyoptera	American cockroach	Reduce fecundity and molts, reduces number of fertile eggs.
Thysanoptera	Western thrips	Retards growth
Lepidoptera	Diamond black moth	Strongly suppressed larvae and pupae, retards growth, inhibits feeding
Lepidoptera	Webbing clothermoth	Inhibits feeding, disrupts molting
Lepidoptera	Gypsy moth	Disrupts growth, inhibits feeding
Lepidoptera	Corn earworm	Retards growth, inhibits feeding, disrupts molting
Lepidoptera	Pink bollworm	Retards growth, inhibits feeding
Lepidoptera	Fall army worm	Retards growth, inhibits feeding disrupts molting and toxic to larvae
Lepidoptera	Tobacco budworm	Inhibits feeding disrupts growth, toxic
Lepidoptera	Tobacco hornworm	Inhibits feeding, disrupts growth, toxic

Lepidoptera	Cabbage looper	Inhibits feeding
Lepidoptera	Leafminer	Retards growth, inhibits feeding , disrupts molting toxic
Lepidoptera	Serpentine leafminer	High pupal mortality, retards growth, inhibits feeding, disrupts molting, toxic larvae
Orthoptera	Migratory locust	Stops feeding, converts greagarious nymphs into solitary form, reduces fitness, adults can not fly.
Orthoptera	House cricket	Disrupts mottling
Coleoptera	Boll weevil	Inhibits feeding
Coleoptera	Cowpea weevil	Inhibits feeding, toxic
Coleoptera	Rice weevil	Inhibits feeding, disrupts molting, toxic
Coleoptera	Confused flour beetle	Inhibits feeding, disrupts molting, toxic to larvae
Coleoptera	Japanese beetle	Repels, retards growth, inhibits feeding, disrupts growth
Coleoptera	Red flour beetle	Inhibits feeding, toxic
Coleoptera	Khapra beetle	Inhibits feeding, disrupts molting, toxic to larvae
Coleoptera	Spotted cucumber beetle	Retards growth, inhibits feeding
Coleoptera	Mexican bean beetle	Retards growth, inhibits feeding disrupts molting
Coleoptera	Colorado potato beetle	Eggs fail to hatch, larvae fail to moult

Army Worm : Azadirachtin has proved an effective prophylactic against armyworm at extremely low concentration. It has, however, been found necessary to treat the crop before the insects arrive.

Colorado Potato Beetle : This a significant pest of North America and Europe is becoming increasingly resistant to broad spectrum insecticides. In experiments in Virginia low concentration of neem seed extract of 0.4%, 0.8% and 1.2% were tested in potato fields both with and without the synergist piperonyl butoxide (PBO). All treatments significantly lowered the potato beetle population and raised potato yields. The extracts containing PBO were the most effective. The spraying were most effective when the larvae were young.

Leaf Miners : The neem extracts when sprayed to control birch leafminer (*Fenusa pusilla*) were effective as commercial pesticides. Neem seed extract is approved formulation by U.S. Environmental Protection Agency for use against leafminers. Added to the soil, neem compounds enter the roots and move up into the crops leaves so that leafminers munching on the leaves get their molting hormones jammed, and they end up fately trapped inside their own juvenile skins.

European Corn Borer : Laboratory tests using neem products on the corn borer larvae produced 100 per cent mortality at 10 ppm azadirachtin, 90 per cent mortality at 1 ppm. Lower concentration (0.1 ppm azadirachtin) left the larvae apparently unaffected, but the adults that later emerged had grossly altered sex ratio (more males than females) and the few females laid fewer eggs and laid them too late (Arnason *et al.* 1985).

Mosquitoes : The larvae of a number of mosquito species (including *Aedes* and *Anopheles*) are sensitive to neem. They stop feeding and die within 24 hours after treatment. If neem derivatives are used alone, relatively high concentrations are required to obtain high mortality. The use of simple and cheap neem products seems promising for treating pools and ponds in towns and villagers.

Plant viruses: Neem derivatives are most effective in interfering with the transmission of plant viruses carried by insects. Trials in Philippines revealed that rice fields sprayed with neem oil had significantly lower incidence of the ragged stunt viruses, which affects rice and is transmitted by the brown plant hopper (Saxena *et al.* 1984). Mixture of neem oil and custard apple oil also interfered with the transmission of tungro viruses and the rice pest (Mariappan and Saxena 1984). Fields treated with urea and neem cake was found to be lower in viral diseases than those treated with urea alone. In India, neem leaf extracts reduced the transmission of tobacco mosaic virus that seriously affects several vegetable crops.

The neem tree thus have a considerable potential for agriculture and rural development, particularly in the developing countries like India. Furthermore, the production of neem pest control material at the village level would make rural communities less dependent on insecticides. Neem's supplementary uses in crop nutrition, livestock feed, in soap manufacture and medicinal uses make it valuable natural resource.

Role of Entomologist in Silvi-pasture and Agroforestry Systems

Basic informations on the entomology of silvipasture system in tropical areas and in particular from small farm situations, are scant This is due to the pre-occupation in the past with the entomology of sole cropping and the emphasis placed on research on cash crops, which often meant that resources were diverted to research on insecticides only. Data so far obtained indicate that the situations with regard to yield loss in silvi-pasture and agroforestry systems caused by insect pest and pest/predator/parasite relationship are very complex. Polyphagous insects are known to be attracted by mixed odours and thrive in a habitat providing two or more essential hosts in close proximity. Pest/parasite relationships according to very not only 'crop-trees relationship, but also as per cultivars, seasons and soil type. Differences in crop and tree heights, susceptibility and maturity and inconvenience to applicators while movement with existing machinery are other problems for pest suppression with pesticides under silvi-pasture and agroforestry systems. Entomologist have a vital role to play in further understanding of silvi-pasture and agroforestry systems and in enhancing their productivity.

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RODENT DAMAGE IN SILVIPASTORAL SYSTEMS AND THEIR CONTROL MEASURES

B.D. Rana and A.P. Jain

Introduction

Desert afforestation and pasture development programmes include silvipastoral practices as the most important component aimed at improving arid environment and to supply fuelwood, fodder, timber,etc. (Mathur, 1980). Introduction of silvipastoral systems, however, provided better shelter and continuous nourishment to free living rodents which leads to increase their populations thereby. adversely affecting the successful implementation of such desert development programmes (Rana, 1983; Jain and Tripathi, 1988 a,b). Such programmes are taken up either on wastelands/ fallow lands/bunds/common property resources which experience little human interference. Such areas thus become an ideal place for rodent breeding and shelter. Present communication embodies the integrated management practices to minimise the losses to various plant species of silvi-pastoral system in the arid lands.

Distribution of Rodent Pest Species

Some species of rodents show a clear distributional pattern in terms of various rainfall zones in arid ecosystem.

100-200 mm Rainfall Zone : The important rodent species inhabiting this zone are *G. gleadowi* and *M. hurrianae*. Tree plantations in this zone are *Prosopis juliflora, Acacia tortilis, A. senegal* and *Dichrostachys glomerata*. Likewise, main shrubs are represented by *Calligonum polygonoides* and *Ziziphus nummularia*. *Lasiurus sindicus* is the important forage grass species of this zone.

250-400 mm Rainfall Zone : Among trees this zone is represented by *A.tortilis, A. senegal, P. juliflora, P. cineraria, Tecomella undulata* and *Colophospermum mopane*. Important grasses are *Cenchrus ciliaris* and *C. setigerus*. Predominated rodent species are *M. hurrianae, Tatera indica, Nesokia indica* (Sri Ganganagar,Bikaner,Nagaur and Jhunjhunu districts).

400 mm and Above Rainfall Zone : Main tree plantations of the zone are *Albizzia lebbek, A. nilotica, Parkinsonia aculeata, Alianthus excelsa, Dalbergia sissoo, Cassia auriculata* and *Azadirachta indica*. Major rodent species are *M. hurrianae, T. indica, R. meltada, N. indica* and *B. bengalensis*.

Fifteen species of rodents have been identified to cause serious damages in different silvipastoral plantations in Rajasthan, viz., *Hystrix indica, Funambulus pennanti, Meriones hurrianae, Tatera indica, Gerbillus gleadowi, G. nanus, Rattus meltada, R. gleadowi, R. cutchicus, Golunda ellioti, Mus platythrix, M.cervicolor, Nesokia indica* and *Bandicota bengalensis* (Rana, 1983; Rana & Jain, 1984). The rodent pests and their association with major silvipastoral plantations are presented in Table 1.

Characteristics of Rodent Damage

Sandy Habitat: It covers a major portion of the Rajasthan desert and consists of older alluvial plains where due to severe wind action sand has deposited on the top horizon. These plains are characterised by the presence of calcareous zone at various depths varying from

Table 1. Predominant rodent pests associated with major afforestation trees, shrubs and grasses in arid areas

Plantation species	Rodent species
a) Grasses	
Cenchrus ciliaris	*F. pennanti, M. hurrianae, T. indica and M. platythrix*
Lasiurus sindicus	*G. gleadowi, G. nanus* and *M. hurrianae*
Panicum antidotale	*G. gleadowi* and *T. indica*
Dichanthium annulatum	*R. meltada, G. ellioti, T. indica* and *M. platythrix*
b) Trees	
Albizia lebbeck	*M. hurrianae* and *T. indica*
Anogeissus pendula	*H. indica, F. pennanti, R. cutchicus, M. platythrix* and *M. cervicolor phillipsi*
Prosopis cineraria	*G. gleadowi* and *M. hurrianae*
Prosopis juliflora	*M. hurrianae, T. indica* and *N. indica*
Parkinsonia aculeata	*M. hurrianae* and *T. indica, N. indica*
Acacia senegal	*R. cutchicus, M. cervicolor* and *H. indica*
Azadirachta indica	*H. indica, T. indica* and *R. rattus, F. pennanti*
c) Shrubs	
Ziziphus nummularia	*M. hurrianae, T. indica* and *Golunda ellioti*
Calligonum polygonoides	*G. gleadowi, T. indica* and *R. gleadowi.*

45-150 cm. However, in certain areas this zone may be very deep. Generally, the soil texture varies from loamy sand to sand clay loam except in areas which are covered with sandy dunes where the sand is deep. The sand dunes are the most important components of the desert landscape and are formed according to the direction and speed of the prevailing wind. Generally the vegetation is very sparse comprising mainly of the psammophytic desert scrubs. Stabilised dunes, however, bear a good tree vegetation particularly when it is protected by some village deity.

Association of rodents with sandy vegetation: Different rodent species are associated with different community of flora. In Barmer district where *Tephrosia purpurea, Aerva pseudotomentosa* and *Aristida* species were recorded in the ground cover, *Acacia senegal* occurred on this habitat in appreciable number and *Ziziphus nummularia* shrubs were also very common. The grass cover was, however, poor and represented by *Aristida funiculata, A. adscensionis* and *Cenchrus biflorus* were recorded. Rodent species associated with such vegetation community were Indian desert gerbil,*Tatera indica*, hairy footed gerbil, *Gerbillus gleadowi* and squirrels, *Funambulus pennanti* observed moving on the trees.

A community of *Eleusine compressa, Cyperus arenarius* with shrubs of *Calligonum polygonoides* was studied on the sandy planes interrupted by mobile as well as stabilised sand dunes. Such habitats are found in Bikaner district. Predominant rodent species were desert gerbil, *Meriones hurrianae, Tatera indica, Gerbillus gleadowi, G. nanus indus* and *Rattus* *gleadowi* were trapped from the compact soil (Prakash *et al.* 1971). The habitat in which *Lasiurus sindicus, Cenchrus biflorus* and *Blepharis sindicus* were present in Jaisalmer district, *G. gleadowi, G. nanus indus, M. hurrianae* and *Rattus gleadowi* were found abundantly. *Funambulus pennanti* were collected in the traps situated near the *Tecomella undulata* trees.

Major rodent species including *G. gleadowi, T. indica, Meriones hurrianae* and *R. m. pallidior* were trapped in a community of *Cyperus arenarius, Aristida* species and *Crotalaria burhia* situated on hill side sand dune in the Jhunjhunu district. Indian crested porcupine, *Hystrix indica* was also found in this habitat. Same habitat was also present in Churu district, north-eastern tract of the Rajasthan desert with partially protected *Prosopis cineraria,* the only tree species found in this region. Unlike, in the preceding community the desert gerbil, *M. hurrianae* was the most abundant species and *R. meltada* was absent. A plant community like *Sporobolus helvolus, Desmostachya bipinnata* and *Acacia jacquemontii* is present around Pali district. Among rodents, *T. indica* and *M. hurrianae* were predominant rodent species. Trapping around Jalor district was done on a hill side sand dune where *Panicum turgidum, Eleusine compressa* and *Dactyloctenium sindicum* associated with *Acacia jacquemontii, Lycium barbarum, Sericostemma pauciflorum* were common. The rodents collected were typical of the sandy habitat, viz. *M. hurrianae, G. gleadowi* and *R. gleadowi* though very low in number. Due to advent of Indira Gandhi Canal in the Sri Ganganagar district, the rodent fauna totally changed due to the change of flora of the area. A new species, *Nesokia indica* was recorded from this region, besides, *T. indica, M. hurrianae, Gerbillus* species and *Mus musculus.*

i) *Grasses:* The desert rodents usually prefer grasses which are also liked by sheep and other livestock in the desert. The rodent attack starts with the sowing of the grass seeds by digging up and feeding on the sown seeds. At later stage of grass growth, the losses due to rodents are immense. Rana (1983) reported severe rodent damage in *Saccharum munja* on dunes in Shekhawati region of western Rajasthan. At the onset of monsoon, the desert rodents, mainly *M. hurrianae, G. gleadowi* and *T. indica* feed on sprouting clumps of *C. ciliaris, C. setigerus, L. sindicus, Panicum turgidum* and *Dichanthium annulatum* pasture grasses. At one of the experimental pasture lands, the gerbil population was recorded to be as high as 477/ha. Annual food requirement of this size of rodent population is about 1,040 kg/ha, whereas, the total biomass production of the area was only 1210 kg/ha/year. Thus rodent left practically nothing for the livestock. The rodents are very versatile in their feeding behaviour. They feed on grass seeds in winter, rhizomes in summer and leaves, stems and flowers, etc., in monsoon season.

ii) *Trees:* There are two main kinds of damages to trees, viz. (1) debarking and (2) slicing of stem and roots. Plantations of *A. lebbeck, P. juliflora, Parkinsonia aculeata* and *A. tortilis* are much susceptible to the former type of damage when rodent gnaw about half a metre above the ground resulting into significant reduction in tree growth (Jain & Tripathi, 1988a). In the process of debarking, rodents destroy the lateral branches too.

Trunks of *P. juliflora, A. tortilis, A. nilotica* and *D. sissoo* have been observed to be completely sliced by rodents. *N. indica* has been reported to inflict losses to a tune of 4.5 and 10.0 per cent in plantation of *A. tortilis* and *P. juliflora*, respectively, in two months period in Nagaur district. Slicing activity results in complete death of the plant.

A. tortilis plantation in Bikaner district established for the purpose of sand dune fixation by Central Arid Zone Research Institute was devastated by rodents (Prakash, 1976). The slicing activity of rodent was mainly found beneath the soil surface. Similar damages have also been observed in *A. tortilis* and *P. juliflora* plantations at Gadra Road (Barmer) in western Rajasthan and in Great Rann of Kachchh, respectively.

iii) Shrubs: *Z. nummularia, C. polygonoides* and *C. auriculata* are devoured by gnawing activity of rodents which also provide fruits, an attractive source of food. Besides this, underground burrowing activities of rodents also cause severe destruction of these shrubs.

Rocky Habitat: This habitat is having very less vegetation. Most predominant vegetation of this area is *Euphorbia caducifolia* which has been considered as a degraded stage of *Acacia senegal- Anogeissus pendula* type of vegetation. This has become scarce and its place taken up by *Commiphora wightii* as in Jaisalmer district. *Salvadora oleoides* and *Capparis decidua* form the main woody species on the foot hills. *Prosopis cineraria* is almost absent from rocky habitat.

In the Barmer district where the foothills were covered with drifted sand having *Commiphora wightii, Eleusine compressa* type of plant community, *G. gleadowi* was trapped on foothill of sand dune. *F. pennanti* were collected near the *Acacia senegal, Mus p. sadhu* were trapped from the base of *Euphorbia caducifolia* and very common, *Rattus C. cutchicus* was collected from the rock crevices.

Rocky outcrops formed the main site in the Jaisalmer district where *Cymbopogon jwarancusa, Eleusine compressa, Oropetium thomaeum* formed the main plant community. Only rock rat, *R. C. cutchicus* was trapped. Same species were collected from a hillock near Jhunjhunu town, where the foothills was covered with drifted sand having *Tephrosia purpurea, Lycium barbarum* and *Aerva tomentosa* type of plant community. *Hystrix indica* was also recorded from this region.

Around Jodhpur mostly Malani rhyolite and sandstone rocky sites having *Tephrosia purpurea, Barleria acanthoides, Aerva persica* type of plant community, the rodents *R.c. cutchicus, Mus platythrix sadhu* and *F. pennanti* were recorded.

In the Jalor district, Jalor granite hill, about 400 m in height where plant community of *Oropetium thomaeum, Tragus biflorus, Cenchrus setigerus* and tree vegetation composed of *Acacia senegal* and *Anogeissus pendula* and in drainage channels trees like *Moringa concanensis, Azadirachta indica, Cordia gharaf* could be seen. Rodents trapped were, *R.c. cutchicus, M.c.phillipsi* and *F. pennanti.*

Hystrix indica, Rattus cutchicus and *Mus cervicolor* are the predominant rodents of the rocky habitats. Latter two species have been observed to destroy the inflorescence of *Euphorbia caducifolia* and *Capparis decidua.* Saplings of *A. senegal, Anogeissus pendula, Commiphora wightii* and *Salvadora oleoides* are also damaged by these rock dwelling rodents. Some of the grass species, viz. *Eleusine compressa, Aristida funiculata, Barleria acanthoides* and *Lepidagathis trinervis,* which are unpalatable to the livestock have also been observed to be partially damaged by rodents (Rana, 1983).

Forest Nurseries : The squirrels, *Funambulus pennanti* is one of the most destructive rodent pests in nurseries. Besides these, *H. indica, T. indica* and *M. hurrianae* are also serious pests in these areas. These rodents eat away the sown seeds and young seedlings of almost all the forestry species.

Soil Conservation: The desert gerbils threaten the soil conservation work by its extensive burrowing activity. Burrow openings are scattered in desert biome and as many as 14000 have been counted in an area of 100 x 100 sq.m. (Prakash, 1976). By tunnelling, the gerbils excavate fixed soils forming small mounds (about 1 kg soil) near each burrow opening. At this rate, gerbils unearth about 1700 kg soil/ha. This loose soil is blown away by strong winds increasing the area of sandy wastes and barren lands. In Shekhawati region, *M. hurrianae* was reported to excavate 61,500 kg/day/sq. km of soil in cultivated field and 10,43,800/kg/day/sq. km in uncultivated fields. Such phenomenon of soil excavation by desert rodents caused soil erosion.

The Management Technologies

Rodent management, as a rule should be a pre-requisite for the successful development of silvipastoral system in high risk areas such as Rajasthan. The active as well as freshly opened rodent burrows should be checked and pre-baiting(one kg bajra grain and 20 g groundnut/sesame oil) is suggested for two days only. On the fifth day, 2.0 per cent zinc phosphide should be added to the bait (i.e. 1 kg bajra + 20 g vegetable oil + 20 g zinc phosphide) and rolled deep into the active burrows at the rate of 6.0 g per burrow. After 8-10 days of operation, Bromadiolone (0.005 per cent) ready to use loose bait or wax cakes should be rolled deep in the freshly opened burrows for managing the residual population of rodents. In certain desert afforested rocky terrains, where it is difficult to approach the burrow openings, the scattering bait technique with utmost care may be adopted. The management operations are suggested to be carried out twice a year, i.e. (a) in May-June and (b) November-December.

In the forest nurseries, zinc phosphide baiting followed by Bromadiolone baiting or aluminium phosphide fumigation should be resorted to as a pre-requisite for establishment of nurseries and afterwards on a regular basis, i.e. twice a year.

The reduction in their damage after management operation was estimated to be 92.5 per cent, after achieving 90 per cent control success. The cost benefit ratio was worked out to be 1:1250 which includes fuel, fodder, small timber, grass, etc.,

Timing of the Control Operation: The basic principle behind any control operation lies in its economic viability, ecological soundness and sociological acceptability. Besides these, the knowledge of habits, habitat, breeding season, activity pattern and burrow structure of pest complex would also add to the success of the control operation. However, cost worthiness of the total operation in terms of material and manpower should also be properly assessed in advance.

Studies conducted on population and breeding cycles of rodents in different agro climatological parts of the country indicated that control operation is to be taken up before sowing/planting of crops in the fields. Studies on the population dynamics further indicated that lowest number of rodents occur during May and June. The population, therefore, comprises of adults only, which can ingest cereal baits. Analysis of their food habits revealed that acceptability of baits is maximum during summer months when there is general paucity of natural food. These results evidently reflected that summer is the most appropriate season when large scale rodent control operations should be taken up. The farmer is also comparatively free during summer months. Studies conducted at this Institute have clearly shown that the control operations are to be taken up on watershed basis.

Studies under social engineering activity on rodent control at CAZRI, Jodhpur, indicated that if control operations are taken up twice a year (i.e. May-June and November-December) regularly for 4 years, rodent population is reduced to 5% of the initial level corresponding to 95% reduction in losses to agricultural production and cost benefit ratio achieved was upto 1:247 (wheat crop), 1:900 (vegetable crops) and 1:220 (in houses). It is, therefore, generally recommended to undertake control operation twice, i.e. during extreme summer (i.e. before kharif season) and winter (before rabi sowing). This schedule is applicable only in the fields. Orchards, plantation crops, houses, godowns, poultry farms and other indoor rodent habitats, the basic approach for rodent control is based on the population of rodents present in the area and extent of damage observed. However, in these habitats, trapping and use of anti-coagulant poisons (Bromadiolone) is more effective. In such situations, control operation may be undertaken more than two times in a year.

Precautions during Application of Rodenticides: The main hazards to persons either directly or indirectly concerned with rodents and their control are the contraction of rodent borne diseases and the risk of accidental poisoning. The need to maintain high standards of personal hygiene at all times should be stressed upon. Rodenticides, if handled carefully and sensibly, should present no risk to non-target animals or people including the operator himself. Following precautions should be followed to avoid any risk.

- No eating , drinking or smoking should take place when live or dead rodents or poison baits are handled.
- All cuts and abrasions on the hands and arms should be covered before starting the work.
- Any rodent bites should be reported and sought medical advice.
- Poison baits should be prepared in well ventilated room and care should be taken not to breath in or absorb any poison.
- After poison bait preparation and field application, hands should be washed with soap properly.
- All poisons (pure chemicals, baits, etc.,) should be clearly labelled 'POISON' and held in a locked almirah and should be kept away from the reach of children.
- The poison bait should not be touched by bare hands. Any broad leaf or spoon or gloves, if available, should be used.
- Where poison baits are laid, the residents/owners of the area should be cautioned about the treatment so that children, livestock and pets can be kept away for a day or two.
- The poison bait should not be laid where the excess bait can not be picked up in order to prevent any later danger. A record should be kept of the number and location of baiting points.
- While placing the baits in the burrow, the poison baits should be rolled deep in the burrows to protect birds, livestock and other non-target species.
- Fumigation as a rule should not be tried in residential buildings. If aluminium phosphide isbeing used for fumigation in the field, the fumigant should be kept away from fire or lit cigarette, as it is highly inflammable. Do not handle the tablets, use an applicator or a long tube to insert them into the burrows.
- After the control operations, the left-over baits, should be picked up and dead rodents be collected and buried deep in the soil.

Antidotes : If any poison is absorbed or illness is suspected in relation to rodent control work, medical advice be sought immediately. Following antidotes should be administered in case of accidental poisoning due to rodenticides.

(i) *Acute poisons (Zn3p2, ALP)*: In case of poisoning through consumption of poison or baits call the doctor immediately but, mean while vomiting should be induced by giving mustard emetic. When the vomiting stops, give 6 gm of potassium permanganate dissolved in a glass of warm water. This oxidises the phosphide to phosphates. After 10 minutes, half a tea spoon full of copper sulphate dissolved in 250 ml of water should be administered. This will produce insoluble copper sulphide. After this, any purgative can be given.

(ii) *Anticoagulant poisons*: In case of accidental consumption of such poison, call the physician immediately. Vitamin K1 administration and blood transfusion are recommended.

Education and Training : Sufficient cost effective technologies have been evolved over a period to control the rodent menace, but these have not yielded satisfactory dividends. The reason being that the end users i.e., farmers are ignorant about the technologies. There could be several reasons for this. However, the most important reason is lack of education and training leading to unawareness among farmers. Through education and training we can increase the knowledge of end users. Besides this, their attitudes can also be moulded accordingly. We all agree that religious taboos are one of the major constraints in our society which hinder even initiation of rodent pest management programmes. This problem can only be overcome through proper education and training.

The rodent pest management programmes can only be successfully launched with the close co-operation and understanding of the public. In Rajasthan, at the time of sowing , farmers usually put 2-3 handfuls of seeds in the name of rodents and birds. This is not because they are not aware of the problems, but because of lack of knowledge about management technologies. On the other hand some people do not want to kill the pest at any cost. Therefore, their attitudes need to be changed. It is generally said , "You can teach a young parakeet but not the adult one". Similarly, to change the attitude of adults, who play a key role in decision making process, is a herculean task. Therefore, if we infuse the idea of rodent pests and their managements in the minds of school-going children, we may succeed in building a solid base of social consciousness which will encourage people to hate the damaging rodents and to take measures to manage them.

Role of media: Radio and Television are two strong media which can be utilised for mass education of farmers about rodent pest management technologies. If the enormous losses caused by rodents are brought to the notice of all, atleast a thinking against rodents can be generated. Once such a thinking is developed, programmes incorporating management technologies may be broadcasted/telecasted. Besides this, education of extension workers needs to be intensified on a priority basis. In every block one village should be made "rodent free" for demonstration purposes. Public can also be educated by short pamphlets, which should be profusely illustrated showing damages, and spread of diseases through rodents.

Training: It is the most important component in popularisation of any technology on a mass scale. Since rodent management technologies are easy to operate and are quick result oriented and cost effective, these can be translated into practice at farmers fields. But, for proper dissemination of knowledge on this aspect, all the states dealing with extension and education need to be invariably trained. This training may be divided into:

(a) *Apex Level Training*: This training is to be imparted to the Directors/Jt. Directors of Agriculture/Forest Departments. The contents of the course or methodology may emphasize on management of transfer of technology, the type of training required for lower strata, human resource management, molding the attitudes and behaviour of the people towards rodent control, and on effective communication. Further, procurement of inputs like rodenticides and baits, etc., should also be dealt in this training. The coverage of Government lands, Common Property Resources, Railway tracks, road sides, etc., should receive the highest priority for rodent control work, because these are the real breeding grounds of rodents.

(b) *Field Level Training*: The present Training and Visit (T & V) system is quite effective. Therefore, all the training programmes for Subject Matter Specialist to farmers may invariably include a package of rodent management technology. Since rodent management is a skill oriented training more emphasis is to be laid on practicals.

(c) *Training among Farmers*: Several voluntary organisations like, Nehru yuvak Kendras, Farmers' Club, Yuvak Dals and Mahila Mandals are working among farmers, Within these organisation "Rodent Control Squads" should be formed. The squads may be given vigorous training in rodent management techniques and on the availability of rodenticides and baits, etc., When the squads are formed, the media may be utilised to popularise the rodent management campaigns on community basis. Like "Van Mahotsav", a "Rodent Control Week" may also be celebrated before sowing/planting of the seeds/seedlings, i.e., in May-June and in October-November.

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POLICY ANALYSIS FOR SILVI PASTORAL ALLOCATIONS OF RESOURCE-MIX IN ARID AREAS OF WESTERN RAJASTHAN

Jagdeesh C. Kalla

Genesis

Arid Agricultural Sector in Western Rajasthan is characterised by rigid natural resource structure which are intrinsically unsuited for crop production. Availability of large arid areas endowed with sturdy natural vegetation in arid areas traditionally lead to expansive pattern of livestock production through pastoralism transcending a maze of politico-economic barriers and spatio-temporal determinants.

With the temper of time coupled with increase in human population inhabiting arid region, the increasing proportion of families resorted to allocation of land, human, material and technical resources in favour of crops. The process of prioritization of crops over livestock was conditioned, in no small measure, by policy palliatives pronounced and practised throughout the country including eleven districts of arid region in Western Rajasthan as well. This policy included high rate of input (seeds, fertilizer, water, electricity, pesticides) subsidisation and price (mainly wheat, gram, bajra among others) supporting mechanisms.

It has been estimated that of the present cropped area almost one third represents post-independent 'push' of combined onslaught of demographic and policy determinants. Of this recently allocated area of crops, nearly 70 per cent is primarily dry areas allocated either as a result of land legislations relating to distribution of surplus lands, irrigation, or simply allocational preference in anticipation of bettering economy by farmers by perceiving better returns over investment in crops over livestock enterprise-mix.

Several studies have conclusively revealed that increased total cereal production has principally been propelled more pronouncingly by 'area-effect' rather than productivity effect. Many a study have revealed significant decline in productivity per unit of land over time despite all policy supports. In times of perspective development, this has spelled substantial degradation of land and water resource through geo-physical (wind and water erosion)and policy factors (indiscriminate industrialisation near scarce water resources, mining, intensive cultivation of loose sandy soils). The process of degradation has been further accentuated by unbridled increase in livestock population (especially of small ruminants) as a risk diversification strategy. But the increase in size of animal populations with concomitant decline in grazing area have robbed livestock production of whatever natural economic edge it offered in past while retaining its eco-friendly stance. The situation, therefore, calls for rethinking on resource allocations processes in arid region.

The Options

The technological options available with science practitioners, unanimously call for inclusion of tree component into farming systems in arid region. One of the options of such inclusions include silvi-pastoral technologies (primarily for livestock production) for wastelands (private or public), social forestry (primarily for social good and prevention of incursion into reserve-forest resources for fuel, fodder and other regions), farm forestry (primarily to produce fruits, fuel, fodder and for checking of wind erosion and desiccation effect on biomass), Agroforestry (growing trees congenial and complementary to the crops), commercial or Corporate Forestry (Primarily for industrial use of forest productions for value addition) and Reserve Forestry (Primarily for protection of wild life sanctuaries, industrial production and supply of forest resources for other farms of forestry technologies. Reserve forests also are provided by legal framework to cater for the sustenance of tribal population living in forests and are endowed traditionally with rights of harvesting the forest produce.

The Silvi-pastoral Option for Waste Lands

The word waste is not absolute in meaning and instead has a high degree of subjectivity. In common parlance, the word waste land is used for (i) an uninhabited or sparsely inhabited and uncultivable region, (ii) areas incapable of habitation or cultivation producing little of no herbage, including barren, desert and no-covered region, (iii) area once cultivated but subsequently abandoned for some or other reason, (iv) a devastated region, (v) mine-spoilt lands, (vi) a piece of land not in any man's occupation and have common public ownership, or simply (vii) idle lands.

In context of arid lands the connotation of wastelands would include permanent pastures, long fallows, non-agricultural and mining wastes, land put to non-agricultural use, barren and uncultivable wastes, cultivable wastes. Such lands are inherently endowed with highly adverse natural constraints which make habitation and cultivation well nigh impossible. Going by several studies almost 40 per cent of the total geographical area distributed among 11 arid districts would be categorised as waste lands. Sizeable portion (around 55 per cent) has been in private domain used mainly for raising crops. The technology available for silvi-pastoral allocation cannot be a 'blanket' for both private and public domains.

Silvi-pastoral system is an integrated approach of wasteland management and water resources for providing higher rate of energy fixation on less productive lands. The systems is meant to augment leafy fodder, top feed, grazing and fuel and forest resources from wastelands. A simple and rather appropriate connotation of the term Silvipasture system would be grass farming in forest enclosure. The technology offers, without impairing the growth of trees, an extra yield of grass during the wet season and browse material in long days of summer seasons. The top feed from hardy trees and shrubs serve as an insurance against fodder scarcity in drought and famines. Grazing in forest enclosure under controlled conditions of rotational grazing and calendar-based lopping of trees would help generate eco-balance and enhance land productivity.

The technology of silvipastoral allocation of degraded lands constitute the following sequence of steps. These include:

- A systematic survey of land, bio-mass details and existing use.
- Providing fencing with the concurrence of potential users of the land. The ideal circumstances, a 'social' or a 'green' fencing would serve purpose.

- Selection of spots for tree plantation, clearing and pit digging before the onset of monsoon.
- Simultaneously preparing for reseeding the lands with grass seed pellets. If areas are large, aerial seeding can also be resorted to, on a wind-free, pre-monsoon day.
- Digging pits and filling them with mixture of sand, clay and manure; planting of seedlings.
- Supervision by the villagers themselves.
- Constant monitoring and replacement of casualty.
- Resorting to occasional life saving irrigation to saplings.
- For first five year cut and carry of grasses need to be followed.
- Tree and grass seed collection and use it to cover other areas.
- Regulate the lopping of trees and grazing of animals.
- Continuous management.

The allocation of traditional resource-mix for silvi pastoral allocations in arid areas have experienced considerable strain in the last four decades owing to the existing agricultural policy in the country. In the present context the policy revolves around monetary and non monetary measures. While non-monetary measure include allocation of imputed labour by society itself for development of degenerated lands in favour of silvipastoral allocation. The monetary measures, in turn, will be conditioned by mechanism of price, marketing, demand and supply of product-mix emanating out of silvipastoral technologies. One of the major non- monetary measures concerns the people's participation and the management of silvipastoral resource-mix in arid areas.

People's Participation-models and Methods : *Traditionally the management systems* of arid lands delineated for silvipastoral allocations were managed to the feudal dispensation by members of village society. It was mandatory for person to allocate the leisure man-hours to reseeding of pastures and growing of trees in pre-monsoon period, desilting of tanks and using the tank bed soils for regenerating land resources was very commonly followed. This was mainly done in lieu of fulfilling the feudal obligation, philanthropic need and social duty. With the growing productivity of labour because of increased intensity of land use for crop and livestock product-mix, the non-commercial component of agriculture in arid areas got considerably eroded. The models and methods of social participation thus received a serious set-back.

The current thinking on the regeneration of institutional in management of degenerated lands for silvipastoral allocations of land calls for community oriented management systems. Case studies from Orissa and Haryana have pointedly indicated the possibilities of success of involving people for joint management of silvipastoral technologies in degenerating land provided:

- The output mix including fodder, fuel and minor forest products are to be competitively priced for sale like any commercial enterprise in public sector.
- The inputs like plant saplings, manure, fertilizers, water and labour are to be subsidised affecting economic viability of silvipastoral technologies. The attitude of traditional

protectionism by Government sponsored forest management system is replaced by empowerment of local population for protection and use.

- Political intervention by powerful political interests in forced and illegal retaining of the mining rights in areas earmarked for silvi pastoral development are controlled.

Monetary Measures : The monetary measures for silvi pastoral allocation of resources would include:

- Input subsidisation at par with other agricultural crops.
- Creation of market structure for output pricing.
- Regularisation of price movement in relation with available quantities of plant and seed material output for evolving the mechanism of participatory methods for allocation of community resources by mutual understanding.

Public Versus Private Ownership : There is considerable evidence that sizeable chunks of degenerated lands which were primarily and traditionally allocated for silvi pastoral allocation got distributed under the private ownership. Though the technological input for both public and privately owned degenerated lands will remain the same, the market segmentation and operationalisation would have to vary. For, privately owned waste lands would need much more intensive individual obligation of monetary and non monetary variables through banks and insurance agencies. The public lands will, in turn need a joint social participatory action.

Research Policy : The allocation of research resources in favour of silvi pastoral research for continuing with: i) identification of new plant and tree resources, ii) development of systems technologies for silvi pastoral allocation of land resources, and iii)evolution of management systems involving human resources needs to be reviewed and enhanced. Actually a 2020 perspective plan with clear-cut milestone, activity and objective needs to be laid down now.

Concluding Remarks

Arid land in Western Rajasthan are endowed with basic fragility to be allocated for traditional land use of growing commercial crops. Even if they are irrigated, such lands should be allocated for low intensity use involving silvipastoral technologies where more fodder and top feed are made available to the growing livestock population. Unless a policy and rational allocation of degenerating lands in favour of silvi pastoral allocations are not made the very sustainability of natural resource base of desert will be put to permanent and irreparable jeopardy

ECONOMIC EVALUATION OF SILVI-PASTORAL SYSTEMS IN ARID REGION

M.L. Purohit

Introduction

Desertic and semi-desertic terrains in India constitute about 3.2 lakh square kilometres, of which hot Thar Desert is distributed in the states of Rajasthan, Gujarat, Punjab and Haryana covering eleven, seven, three and two districts respectively. The eleven arid districts of Rajasthan cover lion share of this region. These districts are Barmer, Bikaner, Churu, Ganganagar, Jhunjhunu, Jaisalmer, Jalore, Jodhpur, Nagaur, Pali and Sikar.

In order to evolve pasture development technology about 52 range management and soil conservation areas were developed in different types of major land form units. These areas were fenced and seeded with suitable grass species and trees.

Pasture is the only assured source of fodder for livestock population of this region. Large population of livestock, which exceeds human population, increases grazing pressure, as a result of which the pastures as well as grazing resources have deteriorated, both in plant cover and production. Recent studies reveal that deficiency of feed and fodder is more than 60%(Venkateswarlu *et al.*, 1992) due to existing vast herds of livestock, which roam over its sandy wastes nibbling at the scarce grass cover. In the absence of favourable conditions for agriculture, livestock raising is the most important alternative source of livelihood for the majority of rural population of this region. Livestock enhance risk bearing ability of the inhabitants of the region by providing employment and regular income even under scarcity periods. In this period inadequate forage and drinking water become one of the limiting factors in improving livestock production in arid and semi-arid regions of the western Rajasthan.

Livestock continues to be the mainstay of the arid region. However over the years, the continuous increase in livestock numbers and decline in area under common grazing lands has resulted in shortage in supply of forage in the region. In total livestock minor livestock like sheep and goats had 70% of the proportion. These small ruminants need top feed along with the dry fodder. The top-feed is available only when tree components are included in pasture development. Trees are raised along with the grasses of different species then this integrated system is known as silvi-pastoral system.

In this paper an attempt has been made to evaluate economic viability of silvi-pastoral system with optimum number of cows, and sheep as per the carrying capacity of the area. Separate economic evaluation has been illustrated for cow and pasture plot and sheep and pasture plot with tree components. In this paper three illustrations are taken from Jain and Joshi,1979; G.N. Bhati, 1992-93,93-94; and Harsh, 1993.

Methods and Concepts

To calculate the economics of silvi-pastoral system one should be clear about input costs and output gains during the growing period.

Inputs

Inputs may be defined as the economic goods and services required to raise a crop or trees or make products. These can be classified

I. According to their sources:

(i) Internal inputs are those which are made available on the farm by farmer himself and his family e.g. land, labour, capital seed, water, etc.

(ii) External inputs have to be initially obtained from outside.

II. According to use:

(i) Direct inputs are those which go direct into the biological production processes e.g. seed, fertilizer, growth regulator, insecticides, pesticides, etc.

(ii) Indirect inputs help to provide favourable condition for plant growth and plant products e.g. machinery, implements, buildings, etc. Building are inputs in the sense that proper upkeep and storage of various assets and produce against climatic and other hazards are ensured by them. The value of the inputs is expressed in terms of the current prices.

For a number of inputs like land, building, machinery, etc. the full value is not taken into account while calculating the economics. Only land revenue or rent in a particular year is taken into consideration. For implements, machinery etc. only depreciation is counted in a given period.

Outputs

Output may be defined as a final result of action and interaction of various inputs during the cropping season. Farming to be gainful enterprise one must watch the relationship of benefit to cost. In farming, cost has two main categories, fixed cost and variable cost.

Fixed costs: These are the obligatory expenses of overhead nature and have no relation with the success or failure of the crops e.g. taxes, building and other assets, depreciation, insurance, rent, interest on fixed cost, permanent labour wages, etc. These have to be borne even if nothing is produced on the farm. On the other hand, these are not increased due to the increased output. Fixed costs are usually the initial costs in setting up the enterprise and are usually of non-recurring nature. These are also termed as sunk costs.

Variable costs: These are the recurring expenses related to the farming operation and are subject to change with the quantity of the inputs and their cost. Increased use of more fertilizer to produce more grain, or increase in the prices of fertiliser, seeds, tractor fuel, insecticides and pesticides or charge for temporary labour, veterinary and other service charges, etc. result in the increase in variable costs.

Variable cost is the most important decision making factor for the farmer as to what and how much to produce. Fixed cost do not matter in taking routine production decisions on a farm.

Benefits

The main product obtained after harvesting of either seasonal, annual or perennial crops and their market value become total returns/gross return. By-products like 'bhusa' (straw), stalk, stover etc. may also provide returns like the main product and the value may be added to the gross return. Gross benefit reflect the total cash gain of a farmer by selling his farm produce and by-product, interest accrued on capital, hiring charges, or any other income.

Profitability is defined as the difference between the gross benefit minus total cost. It is also called net benefit or net profit. Larger the net profit, more profitable is the venture. To decide upon whether to continue the level of production, or to decrease or increase the level of enterprise, two major considerations need to be done.

(i) If gross benefit is more than the total cost (variable plus fixed cost), continue the venture till additional expenditure of inputs (added costs) do not fall short of added benefits.

(ii) If gross benefit are less than total costs (variable plus fixed costs) but still greater than variable cost, continue the venture till the additional expenditure of inputs (added costs) do not fall short of added benefits. Strategy in the first case is to maximise the benefit but in the second it is to minimise the loss. When net benefit is divided with total cost, the ratio obtained, is known as benefit cost ratio (generally known as B/C ratio). It shows the profitability of the crop. It is one of the most important indicators for choosing any enterprise or crops on the farm.

Economics of Crops

It is essential to study the economics of different crops so that rational decision is arrived at for choosing the best one, in the course of time. The crops may be annual or seasonal, which last for only one season or one year e.g. bajra, jowar, moong, moth, guar, til, wheat, mustard, sugarcane, cotton, etc. Perennial crops are garden plants or trees which have deep roots like jujube, date palm, goonda , kumat, khejri pomegranate, myrrh or guggal,s etc. It is easy to calculate benefit and cost of annual crops on the basis of net profit (benefit) per annum per hectare. But it is somewhat difficult and rather complicated to find out benefit and cost of perennial crops because income is generated after some gestation period and continues over time from year to year. Merely on the basis of one year benefit and cost data, it is difficult to find out the real profitability owing to the recurring expenditures over time.

Illustration for silvi-pastoral system: Time element is involved to evaluate the economics of long duration of trees and pastures. The present value of future return or the cost is calculated as :

$$\text{Present value} = \frac{\text{Future value}}{(1+r)t}$$

Where, r = Interest rate per rupee
t = Number of year

Taken for example, interest for Rs.100 for 5 years @ 5 percent would make the total Rs.125 by simple interest rate, but with compound interest rate it will become Rs.127.63. If the Rs.127.63 is discounted with 5 percent the present value remains Rs.100 only. Therefore, it is essential to use this formula in evaluation of a perennial crop like grasses and trees. The steps used are to find out the cost and return structure (Rs./ha) for pasture plot with trees in different years.

- Starting from site preparation, purchase of grass seeds,planting, of trees, weeding, fertilizer, insecticides, irrigation, thorn fencing, pruning, spraying, maintenance and watch and ward, harvesting, tools and sprayers used, depreciation on fixed capital and interest.
- Return per annum from grasses, grass seeds, dung, offspring, trees (twigs for fuel) etc. would be counted for all the years.
- Find difference between returns and costs each year and prepare cash flow.
- To judge the economic viability of silvi-pastoral plantation in arid zone, discounted benefit and discounted cost are to be used for finding benefit/cost ratio. The following 5-criteria are used for economic evaluation viz.,

(i) Net present value (NPV) = $\sum_{t=(1+r)t}^{n=12} \frac{Bt}{(1+r)t} - \sum_{t=(1+r)t}^{n=12} \frac{Ct}{(1+r)t}$

(ii) Discounted benefit and Discounted cost ratio(DB/DCR)= $\sum_{t=1}^{n=12} \frac{Bt}{(1+r)t} \Big/ \sum_{t=1}^{n=12} \frac{Ct}{(1+r)t}$

(iii)Annuity (A) = $NPV \Big/ \sum_{t=1}^{n=12} \frac{Bt}{(1+r)t}$

(iv)Pay back period (PBP)= $\sum_{t=1}^{n*} \frac{Bt}{(1+r)t} - \sum_{t=1}^{n*} \frac{Ct}{(1+r)t} = 0$

(v)Internal Rate of Return (IRR) = $\sum_{t=1}^{n*} \frac{Bt}{(1+r)t} - \sum_{t=1}^{n*} \frac{Ct}{(1+r)t} = 0$

Where,

Bt = Benefit accurable incidental to silvi-pastoral system in year 't'.

Ct = Cost incidental to silvi-pastoral system in year 't'

t = Number of year (n) representing the life of silvi-pastoral system cover cumulative costs for the life.

n = Total life of silvi-pastoral system.

n^* = Number of years to be found out.

r = Interest rate per rupee i.e. 10%, 11%, 14%, 20% and 25% per annum or so.

r^* = Rate to be found out.

IRR=It is the rate of discount which makes present value of benefit and cost stream equal.

In an economically viable silvi-pastoral system:

i) NPV is greater than zero.

ii) DB/DC ratio is greater than one

iii) 'A' is greater than existing average value productivity of silvi-pastoral system per hectare.

iv) PBP is the less than total life of silvi-pastoral system, actually shorter the PBP better it is, and

v) IRR is greater than prevailing bank interest rate,cash flow of silvi-pastoral system with discounted benefit and cost @ 11% discounted rate is shown in Annexure I.

Similarly for 10%, 11%, 20%, 25% can be computed.

Steps in economic evaluation for silvi-pastoral system

1. NPV = sum of column 5 - column 4
2. DB/BC ratio = sum of column 5 divided by sum of column 4.
3. Annuity = NPV divided by sum of column 7.
4. PBP = when cumulative sum of column 2 is equal to sum of column 3. if both are equal than locate the year in which the costs will be paid by benefit flow.
5. IRR = Least positive discount rate + difference between positive and negative discount rate multiplied by [NPV positive / (NPV positive - NPV negative]

Illustration I from Pasture Development on Private Lands

The cost benefit analysis has been done separately for two types of silvi-pastoral plot (i) a unit of two cows and 2 ha. plots, (ii) a unit of ten sheep (9 sheep + 1 ram)and 2 ha pasture plots. Cost-benefit analysis deals with the capital investment, fixed and maintenance cost, returns, net income, pay back period, cost-benefit ratio, internal rate of return and sensitivity analysis.

Fixed and maintenance cost for a period of 12 years, for 2 ha cow/sheep and pasture plot is set out in Table 1. Returns from cow/sheep trees and pasture plot in Table 2. and Financial Analysis of 2 ha cow/sheep pasture plot in Table 3.

Table 1: Fixed and maintenance cost, for a period of 12 years, for 2 ha cow/sheep and pasture plot

Components	Years											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Fencing	-	57	57	57	57	57	57	57	57	57	57	57
2. Animal health cover	-	120	120	120	120	120	120	120	120	120	120	120
3. Mortality of animals-		50	75	75	75	75	75	75	75	75	75	75
4. Labour charges	100	50	50	50	50	50	50	50	50	50	50	50
5. Reseeding	-	-	-	100	-	-	-	100	-	-	-	100
6. Fertiliser	-	-	-	50	-	-	-	50	-	-	-	50
7. Cattle feed for cows	-	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
8. Loan interest (11%)												
i)For cow on Rs.2680	-	295	265	236	206	177	147	118	59		30	-
ii)For sheep Rs.1747	-	192	173	154	135	115	96	77	58	39	20	-
9. Repayment of Loan instalment												
(i) For cows Rs.2680	-	268	268	268	268	268	268	268	268	268	268	268
(ii) For sheep Rs.1747	-	174	174	174	174	174	174	174	174	174	174	174
Total												
i) For cow unit	100	2140	2135	2256	2076	2047	2017	2138	1958	1929	1900	1752
ii) For sheep unit	100	643	649	780	611	591	572	703	534	515	503	452

Table 2. Returns from cow/sheep and pasture plot of 2 ha area

Components	Years											
	1	2	3	4	5	6	7	8	9	10	11	12
I. *From cows (Two)* :												
i) Milk	-	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320
ii) Offsprings	200	200	200	200	200	200	200	200	200	200	200	200
iii) Dung	-	100	100	100	100	100	100	100	100	100	100	100
iv) Grass seed	25	25	25	25	25	25	25	25	25	25	25	25
v) Trees	-	-	-	700	700	700	700	700	700	700	700	700
Total	25	4645	4645	5345	5345	5345	5345	5345	5345	5345	5345	5345
II. *From Sheep (1 Ram + 9Ewes)*												
i) Wool	-	200	200	200	200	200	200	200	200	200	200	200
ii) Lambs	-	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125
iii)Manure	-	150	150	150	150	150	150	150	150	150	150	150
iv) Grass seed	25	25	25	25	25	25	25	25	25	25	25	25
v) Trees	-	-	-	700	700	700	700	700	700	700	700	700
Total	25	1500	1500	2200	2200	2200	2200	2200	2200	2200	2200	2200

Table 3. Financial Analysis of 2 ha cow/sheep pasture unit

Variables	Years											
	1	2	3	4	5	6	7	8	9	10	11	12
I.For cow and pasture unit												
1. Capital investmen	-	1020	3000	-	-	-	-	-	-	-	-	-
2. Fixed & maintenance cost	100	2140	2135	2256	2076	2047	2017	2138	1958	1929	1900	1752
3. Total investment	1120	5140	2135	2256	2076	2047	2017	2138	1958	1929	1900	1752
4. Returns	25	4645	4645	5345	5345	5345	5345	5345	5345	5345	5345	5345
5. Net income(4-3)	-1095	-495	2510	3089	3269	3298	3228	3207	3387	3416	3445	3593
6. Cumulative total investment	1120	6260	8395	10651	12727	14774	16791	18929	20887	22816	24716	26468
7. Cumulative returns	25	4670	9315	10660	20005	25350	30695	36040	41385	46730	52075	57420
8. Simple B/c Ratio	0.02	0.09	2.18	2.37	2.57	2.61	2.65	2.50	2.73	2.77	2.81	3.05
II. For sheep and pasture unit												
1. Capital investment	1020	1600	-	-	-	-	-	-	-	-	-	-
2. Fixed & maintenance cost	100	643	649	780	611	591	572	703	534	515	503	4523
3. Total investment	1120	2243	649	780	611	591	572	703	534	515	503	452
4. Returns	25	1500	1500	2200	2200	2200	2200	2200	2200	2200	2200	2200
5. Net incomes(4-3)	-1095	-743	851	1420	1589	1609	1628	1497	1666	1685	1697	1748
6. Cumulative total investments	1120	3363	4012	4792	5403	5994	6566	7269	7803	8318	8821	9273
7. Cumulative return	25	1525	3025	5225	7425	9625	11825	14025	16225	18425	20625	22825
8. Simple B/c Ratio	0.02	0.67	2.31	2.82	3.60	3.72	3.85	3.13	4.12	4.27	4.37	4.37

Illustration II from Integrated Farming Systems at CAZRI

Five systems viz., Agro-forestry, Agro-horticulture, Farm-forestry, Agro-pastoral and silvi-pastoral were established during 1990-91 at the onset of monsoon rains at CAZRI Farm Jodhpur. It was an integrated approach and therefore scientist from different disciplines joined this programme. Arable crops were sown every year in the systems. Where it was included grass, trees, horticultural plants were established in the initial year but the casualties were replaced in consecutive years.

Out of five integrated systems, silvi-pastoral system was found more economical from second year on-wards and started to give more returns over variable costs. The fixed costs were not included due to experimental plots of the Institute.

Data pertaining to various operations and returns from experimental plots were used for the studies under Integrated Farming Systems Research from a plot of 2.25 ha of silvi-pastoral systems for three years 1990-91, 1991-92,and 1992-93. The costs and returns flows were estimated at the prevailing market rates, same is set out in Table 4.

Table 4. Silvi-pastoral system (Integrated Farming Systems) 1990-91 to 1992-93

Year	Total area	Total variable cost/ha	Gross return/ha	Returns over variable cost/ha
1990-91	2.25 ha	1426	818	-608
1991-92	2.25 ha	1356	3502	2146
1992-93	2.25 ha	2190	7266	5076
Average of three years	2.25 ha	1657	3862	2205

The table reveals that in initial period silvi-pastoral system was not economical but as the number of years increases the total variable costs, gross returns as well as return over variable cost/ha increased. In third year returns over variable cost is just more than double of the second year.

Percent distribution of total costs over three years is set out in Table 5. In silvi-pastoral systems three years data revealed that cost of all the components decreases and became nil upto third year. Cost proportion of labour components increases as the age advances. In third year 100% cost incurred over labour only and increased by three times over initial year i.e. 1990-91.

Table 5. Percent distribution of total costs in silvi-pastoral system

Year	Tractor	Seed and planting	Labour	Fertilizer	Insecticides and Pesticides	Water Tank
1990-91	18.23	39.52	34.28	0.33	2.18	5.46
1991-92	8.03	24.58	52.81	8.19	0.49	5.90
1992-93	-	-	100.00	-	-	-

Illustration III Multi-purpose Trees in Association with Grasses

In addition to fuelwood plantation, trees can be grown in silvi-pastoral system. One case study is cited of *Acacia- tortilis*. Data revealed that by adopting two tier system the total returns per unit of land is higher than pure pastoral system, same is set out in Table 6.

Table 6. Economics of silvi-pastoral system with *Acacia tortilis* and grasses after 7 years of establishment

Treatment	Fuel yield q/ha		Grass yield q/ha		Total revenue (Rs. /ha)	
	G_0	G_1	G_0	G_1	G_0	G_1
S_1	60	50	-	55.8	3000	3895
S_2	32	28	-	52.9	1600	2793

Spacing: S_1 = 5 x10m planting distance
S_2 = 10 x 10m planting distance.
G_0 = Trees without grass.
G_1 = Trees with grass.

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ANNEXURE -I

Years	Acutal cost-Benefit		Discounted costs-benefit at 11% discount rate		Discount rate			
	Costs	Benefits	Costs	Benefits	10%	11%	14%	20%
1	1120	25	1009	23	0.909	0.901	0.877	0.833
2	5140	4645	4174	3771	0.826	0.812	0.769	0.694
3	2135	4645	1561	3396	0.751	0.731	0.675	0.579
4	2256	5345	1487	3522	0.683	0.659	0.592	0.482
5	2047	5345	1231	3170	0.621	0.593	0.519	0.402
6	2047	5345	1095	2860	0.564	0.535	0.456	0.335
7	2017	5345	972	2576	0.513	0.482	0.400	0.279
8	2138	5345	928	2320	0.467	0.434	0.351	0.233
9	1958	5345	766	2090	0.424	0.391	0.303	0.194
10	1929	5345	679	1881	0.386	0.352	0.270	0.162
11	1900	5345	602	1694	0.350	0.317	0.237	0.135
12	1752	5345	501	1529	0.319	0.286	0.202	0.112
Total	26468	57420	15005	28832		6.493		

(1) NPV = 13827.0

(2) Discounted benefit and discounted cost ratio = 1.92

(3) Annuity = 2110.0

(4) PBP = 3 years

(5) IRR = 104.02%

MANAGEMENT OF COMMON PROPERTY RESOURCES FOR AUGMENTING FORAGE PRODUCTION

J. Venkateswarlu

Introduction

The common property resources (CPRs) among others, include pastures, unreserved forests, fallow lands and uncultivable wastelands. We can also bring the 'social' wastelands into this ambit. The 'social' wastelands are those where ownership is either ambiguous, absent or is common. Unlike other CPRs, these have largely good soils. It is common knowledge that there is acute grazing pressure in many states of India except in states like Karnataka. The position in some selected states of the country is as follows:

Selected States	Grazing pressure (ACUs*ha)	Existing carrying capacity (ACUs/ha)
Andhra Pradesh	2.17	1.17
Karnataka	1.04	1.09
Maharashtra	2.24	0.97
Madhya Pradesh	1.62	0.84
Gujarat	6.03	0.76
Rajasthan	7.68	0.68

* ACU is adult cattle unit. Conversion factor for other animals are 1.25, 0.17, 0.17, 0.50 and 1.5 for buffalo, sheep, goat, donkey and camel respectively.

The above data clearly brings out two factors viz.,

(i) In low rainfall areas, the farmers like their living more with livestock (e.g.. Gujarat, Rajasthan).

(ii) In the process there is enormous pressure on grazing lands in such region (arid) leading to further degradation of the grazing areas. And there is a qualitative change in the livestock composition.

Degradation of CPRs

We shall now look into the changes in the quality of grazing lands and the livestock composition before discussing the means to enhance the productivity of the CPRs.

Changes in the Quality of Grazing Lands : Each region, if allowed to fully evolve, will have the climax species of grass(es). For example :

Climate	Climax grass cover
Tropical, Sub tropical	*Sehima-Dichanthium*
Semi-arid, Arid	*Dichanthium-Cenchrus-Lasiurus*
Humid, Per-humid	*Phragnites-Saccharum*

Generally we qualify grazing lands into different classes by relating to the per cent cover with climax grass. For example :

Class	Per cent cover with climax grass
Excellent	75 - 100
Good	50 - 75
Fair	25 - 50
Poor	0 - 25

As the degradation intensifies, not only the climax grasses decrease, but species of poor edibility increase. For example, upto 250 mm rainfall, there will be predominance of *Lasiurus sindicus* along with *Haloxylon salicornicum* on sandy plains and *Panicum turgidum* and *Calligonum polygonoides* on sand dunal areas. Very few tree species of *Salvadora oleoides* and *Prosopis cineraria* are present in such habitats. In the rocky terrain, grasses are sparse. So are the trees. Sparse vegetation through *Commiphora wightii, Euphorbia caducifolia, Acacia senegal* and *Salvadora* sp. could be seen.

In higher rainfall zone (250-400 mm) the plains support *P. cineraria, S. oleoides* and shrub cover of *Capparis decidua, Ziziphus nummularia* and *Indigofera oblongifolia* and grass cover of *Cynodon dactylon, Desmostachya bipinnata, Cenchrus ciliaris* and *Dichanthium annulatum*.

The processes of degradation occur due to overgrazing as well as droughts whose vicissitudes are more as the rainfall decreases. In arid eco 1-1 system during first few years we will be seeing low perennial grasses like *Eleusine compressa,* and *Dactyloctenium sindicum* covering the ground sparsely. Then we will see species like *Tribulus terrestris* and *Indigofera cordifolia*. Amongst grasses, we will see *Aristida funiculata* and *Cenchrus biflorus*. Among tree species *Prosopis juliflora* and *Euphorbia caducifolia* will be dominating.

In such an event the native farmers look for alternative forages. Among others, they include shrubs like *Aerva persica, Calligonum polygonoides, Calotropis procera* and *Opuntia ficus indica*; trees like *Azadirachta indica* and *Phoenix dactylifera* and grasses like *Saccharum munja*. In waterlogged area species like *Typha angustata, Saccharum spontaneum* and *Arundo donex* provide forage under extreme conditions of scarcity.

Changes in the Quality/Composition of Livestock : With the degradation of pasture and other CPRs, the quantity of fodder decreases and the type of fodder varies. The grass species are the first casualty followed by bushes and lastly the coppiciable plants. (*Albizia lebbeck, Tecomella undulata, Leucaena leucocephala, Calligonum polygonoides, Capparis decidua* and *Ziziphus nummularia*). In the process, the browsing sheep become the first affected species and consequently goat population increases. For instance, in west Rajasthan, the population of different livestock would be as follows:

Type of livestock	Livestock population (Millions)	
	1956	2001*
Cattle	3.91	3.39
Buffaloes	0.75	1.78
Sheep	4.75	7.88
Goat	3.49	15.61

* Projected

The increase in sheep is 83.6 % over 45 years while that of goat is 347.3 % during the same period.

Improving Fodder Yield

Having seen the enormity of the problem of fodder availability for the ever increasing livestock population, we have to make serious attempts to improve the yield of forage from various types of CPRs.

One important way to improve fodder availability is silvipasture system in class IV, V, VI and VII lands. Most of them on community lands. A simple way to rejuvenate these areas is social fencing. Another could be social fencing but after replanting the area with suitable trees and grass species. Some details :

Social Fencing for Natural Revegetation : Normally either barbed wire fencing or trench- cum-mound would be suggested for fencing. But in this case the beneficiaries mutually decide not to trespass the proposed area with their livestock, but allow the same to regenerate over a period of 3-4 years. By that time the natural flora and fauna will reappear and by consensus the area could be utilized for grazing/cutting grass, coppicing/pollarding or lopping the trees for top feed etc.

To achieve total participation, about half to one-third area be socially fenced at the first instance and cyclically the other area taken up.

Such areas can be enriched further with additional grass/tree seed sown after pelletising (described elsewhere). Also it should be our endeavour to remove unwanted shrubs/trees that have overpowered the useful grass/trees due to over-exploitation.

Regeneration of these areas that had been virtually barren would have a salutary effect in capturing rainwater from moving out fast, providing more opportunity time for it to enter the soil and thereby recharge the ground water. This intangible benefit should be highlighted. Also the wind and water erosion would be considerably reduced.

Rejuvenation and Social Fencing : It is shown that these CPRs can be retrieved to a considerable extent with the introduction of MPTs and new species of grasses and fodder legumes. For example:

Ecosystem	Present Vegetation	New System
Arid	Sewan grass with dominance of several undesirable species like *Cenchrus biflorus*, *Tephrosia purpurea*, *Calotropis procera*, and reduced *Ziziphus nummularia*	Improved Sewan grass + regularly planted (100 plants/ha). *Z. nummularia alongwith Salvadora oleoides and S. persica*
Semi-arid	Reduced Sehima with dominance *of Heteropogon. Chrysopogon* and undesirable *Bothriochloa*	*C. ciliaris + Stylosanthes hamata + A. nilotica and Agave, A. catechu* and *Hardwickia binata*

Pasture Development

Permanent pastures as CPRs is a common feature in most of the villages in India. About 4 % of the reporting area in India is under permanent pasture. The present productivity is very low and the improvements suggested later could increase the productivity as well as the carrying capacity.

Av. Rainfall	Average yield of forage (t/ha)		Carrying capacity* (ACUs/100 ha)
	Present	Improved	
Below 250	0 - 0.2	1.0 - 1.5	22.5 - 30.0
250 - 400	0.2 - 0.3	2.0 - 2.5	50.0 - 60.0
400 - 600	0.3 - 0.5	2.5 - 3.5	70.0 - 90.0

* The figures relate to improved pastures.

The main steps involved in the pasture improvement are :

- Clearing the area of bushes that are undesirable
- Select the improved species of grasses and fodder legumes as detailed below :

Rainfall zone	Improved grassed	Improved legume(s)
< 200	*Panicum antidotale* *Lasiurus sindicus* *Cymbopogon*	- - -
200 - 400	*C. Ciliaris* *C. setigerus*	*Clitoria ternatea*
400 - 600	*C. ciliaris* *Chrysopogon contortus* *Heteropogon contortus*	*Stylosanthes hamata*
> 600	*Panicum maximum* *Napier hybrid* *Setaria sphacelata* *Sehima nervosum*	*Stylosanthes hamata* *Siratro*

- Formation of Furrow-ridges at an interval of 6-10 m depending on the slope of the land. May be formed along with contour or across the slope these bunds.
- Wherever possible, the soil surface may be partially opened up to :

  (a) Improve rain water entry *in-situ*, and

  (b) Enable broadcast seed set *in-situ* without being blown off.

- The seed rate varies. In the case of grass, it is 7 kg/ha while for silvipasture system, it is 12 kg/ha. But the seed rate can effectively be reduced by pelletizing the same with FYM and fine soil in 1:1:3 proportion using a table spoonful of DAP each time. For pelletizing, this mixture may be placed in a rotating wheel (back tyre of a tractor) which is wetted using a knap-sack sprayer. Pellets of 0.5 to 1.0 cm size will be formed. They should be dried in shade. The seedling emergence will be superior with better vigour with pelletised seed. Only 2 kg grass seed and 3 kg tree seed need be used. In view of the scarcity of seed availability, pelletizing helps in covering large areas. It also works out cheaper.
- Sowing time should coincide with the monsoon showers.
- Addition of P_2O_5 through single super 1-1 phosphate @ 20 kg/ha is recommended as

  (a) The soils are depleted of native phospate due to intensive feeding in the top few centimetres of the top soil , and

  (b) The addition of phosphates invigorate the decomposition of the native soil organic matter and more N be released leading to better growth of grasses/plants.

There is no need to worry of loss of some organic matter and it would be recouped very soon in the pastoral system. In the semi-arid Alfisol region of Telengana, 3 years of pasture improved soil organic matter from 0.22 % to 0.50 %, almost 2 1/2 times. In arid Rajasthan, the improved pastures added 2.3 to 2.6 t/ha of root biomass in the first 30 cm soil in 5 years.

The Institute of Rural Management, Anand (IRMA) studied at 6 places the communal efforts made by voluntary agencies.

Main findings of these studies are :

- Assign property rights on the newly developed CPRs to individual poor families with technical back stop largely from voluntary organizations.
- Encourage community involvement in the development of CPRs reducing indispensability of the powerful local leadership.
- Encourage group consensus in decision making and also to avoid possible conflicts.
- Let small groups be responsible for smaller units of CPRs.
- Provide incentives both at small group level as well as individual level.
- See that all the participants have access to the gains.

Epilogue

The CPRs are the most over-exploited areas in any village. The good lands are usurped by the mighty. The pastures are overgrazed and trees are felled. The earlier system of protecting the CPRs through revenue raised by nominal charges levied on grazing are now defunct.

That the CPRs are on the upper elements of a given watershed and would contribute to runoff as well as ground water recharge are lost sight off. In fact, rejuvenating CPRs :

- Reduce erosive velocities of runoff water from above,
- Minimise soil erosion/deposition on arable lands that lie in the lower elements of the slope in a given watershed; and
- Provide more time for the rainwater to enter the soil for recharging the groundwater.

This is besides providing adequate fodder for the livestock.

FORAGE PRODUCTION : THE SUSTAINABILITY ISSUES AND THE FARMING SYSTEMS PERSPECTIVE

H.P. Singh

Introduction

As identified during the Rio Conference in 1992, the arid, semi-arid and dry sub-humid zones spread over an area of 5 2 billion hectares of the world are prone to desertification Among these the arid areas are particularly vulnerable The reasons are well known the fragility of natural resources, climatic limitations and human factor Growing population pressure forces the people to cultivate the marginal lands which ought to be put under permanent vegetation Secondly, the perennial vegetation is indiscretely used to feed the increasing numbers of livestock These two factors have been gradually uncovering the land area of its vegetation since centuries and setting the process of desertification through soil erosion by wind and runoff actions (Singh and Venkateswarlu 1991)

The Human Factor

As stated above, the scenario of degradation has been shifting from bad to worse due to human intervention Such actions though unwise are quite expected The people pressed to wall with such adversities of natural resources and climate, in their quest for means to meet their priorities and obligations, are forced to look at what is available today with complete disregard to future Extending cropping to uncultivable lands, allowing overgrazing of common property resources (CPR) and cutting whatever vegetation that is available for forage, are the easiest of options available to them Obviously, therefore the subsistence farming has been in vogue to make out a living on a fragile resource base

Since we have to live with the climatic conditions as they are and quality of soil resource cannot be dramatically improved in a short time, the central issue in sustainable development of these areas is human ecology

Forage - The Major Issue in The Control of Desertification

Animal husbandry has been traditionally the main source of livelihood in risk prone arid and semi-arid regions This is particularly true for small holders Landless pastorilists also constitute a big section of rural society in these regions By and large uncontrolled grazing is the way of life practised traditionally Animals are left to fend for themselves This practice is a formidable constraint for developing permanent forage resources of trees and grasses which are also so vital for arrest of desertification (Venkateswarlu et al, 1992) Therefore, communities have to be mobilized to appreciate this grave limitation and develop a new social order A possible solution could be development of a small fraction of holding as silvi-pasture, by each and every land owner having livestock The pressure on community grazing lands could thus be greatly reduced These lands could then be left to landless graziers (pastorilists) Such stake holders in the rural society can be organized by the Extension Service to manage these lands as silvipastures It is then only that desertification can be truly controlled By augmenting forage supply through silvi-pasture, animal husbandry can be put in place as the central component of production system on ecologically and economically viable terms for sustainable development of these regions

Sustainability Issues

Sustainability of earth's natural resources is anticipated to be one of the most crucial problems of the period beginning 2000 AD Policies and programmes for logical conservation of these resources have to be addressed with all seriousness if we are to succeed in meeting the requirement of food, fodder, fiber and fuel for present and future generations

The Governing Council of the UNEP defined sustainable development as development that meets the needs of the people without compromising the ability of future generations to meet their own demands and does not imply in any way encroachment upon national sovereignty Sustainable development involves within and across the national boundaries It implies progress towards equity and the existence of a supportive international economic environment leading to sustained economic growth and development in all the countries For achieving ecological resilience and economic growth, the maintenance, rational use and enhancement of the natural resource base come into sharp focus

Sustainability has several definitions Commonalities among them are

- Equity for today's stakeholders of the natural resources,
- Equity for future generations,
- Long term approach by living on the interest without depleting the principal,
- Productivity enhancement to meet population and economic growth and
- Environmental enhancement

Considering the general consensus as on the issue of sustainability,sustainable agriculture means a farming system, which on a continuous basis enhances the productivity and economic returns, protects the environment and conserves the natural resources and finally leads to improved quality of life of people (Benbrook 1991)

Sustainable development means a policy that meets the needs of the present generation without destroying the resources sustenance of posterity There can be no sustainable development if the resource base is depleting or deteriorating The degeneration in productivity caused due to resource degradation is particularly alarming in the fragile arid and semi-arid ecosystems It is thus a result of land abuse caused through soil erosion, increased biotic activity and deforestation

Efforts for obtaining sustainability have to be launched at a grass-roots movement We need to realize that people are an important part of the process to achieve the goal It primarily revolves round sustainable land use and linked to cultural demands When land use and ecological carrying capacity of the land are not compatible, the land degradation sets in, Cultures change, Land use changes They both have to be compatible No one knows exactly what the future holds But it can be imagined by creativity and vision All these are enhanced by creating awareness (Venkateswarlu J-personal communication)

Evidently the immediate causes for unsustainability include most importantly, the land use Indirect causes at the national level include land tenure and the policy environments within which farmers and the herders operate At regional and inter-national levels trade and aid policies come into play

Sustainability issues being addressed by Research Centres include soil degradation, desertification, soil erosion by wind and water, deterioration of soil structure, loss of nutrients, salt accumulation, clearing of tropical forests, waterlogging and techno-genic processes like mine spoils and industrial effluents, degeneration of genetic diversity, variation/change in weather/climate, maintaining growth in productive agricultural systems (irrigated) to reduce pressure on rainfed lands, promoting change for upgrading production in less productive systems and pest/disease and integrated nutrient management From these issues a number of sustainability indicators can be identified that can help in development planning at the district, regional and national levels

Farming System Approach of Technology Development, Assessment and Transfer

The single line commodity and integrated research approaches for technology transfer were highly successful in high input high yielding production systems practised primarily in industrialised and developed countries and also in high capacity irrigated regions of tropics In these situations technologies developed through applied agricultural research were readily adopted by the farmers for they had a dramatic effect on the yields of crops However, these approaches for technology transfer in areas of Agro-forestry, etc , did not make much impact on resource poor farmers in low rainfall and risk prone rainfed areas of arid and semi-arid regions This failure stems in part from inherent difficulty of the task Of late, it has been recognized that unlike irrigated areas, it is extremely difficult to develop sustainable technology for heterogeneous agro-ecological and socio-economic conditions of small holders in arid and semi-arid regions The problems are complex characterized by a variety of environmental and socio-economic stresses Mixed farming comprising crop/forage production and animal husbandry for risk aversion has been the mainstay of subsistence of such farmers Therefore, technology has to be such that addresses to the whole production system rather than solving individual and isolated problems(Singh 1996) A true Farming System Research(FSR) in such regions may comprise dryland farming, agro-forestry/forage production, livestock husbandry, management of CPR'S, rehabilitation of degraded lands and utilization of limited water resources including saline-sodic water, all in complete integration This realization in the scientific community in mid-seventies the world over, marked the beginning for production or farming systems research

FSR is essentially an extension of on-station research to synthesize and develop technologies from research results relevant to client needs for wholesome development of their farming system Hence, Research Station back up is necessary for FSR The FSR has to be undertaken on fields of farmers with their full co-operation and involvement Further, it has to be complementary to the on-station research It should support, within research, a problem solving approach which is fundamentally oriented to farmers as the primary clients

Planning of FSR requires perfect understanding of what the farmer is already doing Three sets of information are, therefore, necessary

- Socio-economic conditions of people, their perceptions, priorities, requirements and Indigenous Technological Knowledge (ITK) in use,
- Resource conditions,and
- Technology developed at the research stations

These logistics are then carefully analysed to effect a balance between resource conditions and farmers requirements with respect to choice of component technologies for application and testing To begin with, greater focus should be on ITK based refinements Strict prescriptions of component technologies developed at the Research Stations should be avoided Necessary adjustments should be incorporated to offer baskets of options as per clients requirements and priorities The options with regard to forage production for instance, could be as follows

- Planting of trees and grasses on field boundaries
- Silvi-pasture on degraded lands
- Agri-pasture
- Horti-pasture
- Agri-silviculture

If required, alternative technologies for farmers sharing common problems can be developed by conducting experiments on their fields Farmers complete involvement is absolutely necessary both in planning the programme and execution i e , a bottom up approach It is then only that the farmer will function as a real executor of the programme and extension workers role will be that of a facilitator, which is the basic philosophy of on farm client oriented research (OFCOR) or FSR

Therefore, for augmenting forage production, the entire farming system needs to be addressed to The sustainability goal can be reached only with such an integrated and holistic approach in resource poor areas of arid and semi arid regions

Sustainability Indicators

Sustainability as a goal, encompasses physical, biological and socio-economic domains The goals may not be reached fully if there are limitations in any of these components Therefore, the biological and ecological foundations of plant productivity should be continuously probed to find answers to the problems that may threaten the actions directed at reaching the sustainability goal by not meeting the dynamism of economic and social aspirations of people

Vigorous developmental efforts are being pursued the world over for management of resources and their utilization for plant production Owing to ever increasing population pressure and economic growth, however, the sustainability of these efforts particularly in dryland sub-sector of arid and semi-arid regions having fragile resource base and preponderance of small and marginal farmers, is under clouds We do not know whether the programmes and technologies being implemented are sustainable Just increase in yields that may be a temporary development cannot be taken as a measure of sustainability A wide range of indicators cutting across biophysical, socio-economic and institutional features, can only indicate the sustainability or otherwise of a system, by their integrative analysis and judicious application

The following sets of indicators can be relevant for assessing the sustainability of integrated farming systems in arid and semi-arid regions

Physical and Environmental

i) Soil quality

a) Fertility, fertilizer use

b) Status of physical degradation

c) Runoff loss of water and poor soil moisture regime

d) Status of chemical degradation

e) Status of microflora,and

f) Residual toxicity, use of plant protection chemicals

ii) Above ground environment

a) Status of permanent vegetative cover

b) Dust load,and

c) Emission of gases

iii) Groundwater (depth and quality)

Biological

i) Biomass yield (food grain/fiber and fodder)

ii) Quality of produce

iii) Bio-diversity

iv) Commodity diversification

a) Crop diversification

b) Livestock quality and number

Socio-economic and Policy Related

i) Land use

a) Cultivated area

b) Degraded lands

c) Culturable wastes

d) CPRs - grazing lands, water bodies.

ii) Rural employment

iii) People's participation in development

iv) Quality of life of people

v) Size of holding

vi) Absentee land lord status,and

vii) Government policies, incentives and facilities.

1)Physical and Environmental

The issues of sustainability of the production systems under this category generally encompass the resource degradation processes and measures undertaken for their reversal and amelioration. The restorative interventions could be physical/mechanical (ridging/bunding etc.), chemical (fertilizers, plant protection chemicals, gypsum) and biological (raising of trees and grasses on marginal wastelands).

Unlike the slogans of organic farming or no-input/low input agriculture, sustainable agriculture does not mean the elimination of off-farm inputs. This underlying truth is now universally recognised. Even in North America where so much alarm was raised to environmental pollution by agricultural chemicals, many conventional farming systems are quite sustainable and may continue to be so. The inherent philosophy of sustainable agriculture is to reduce the dependence on environmentally risky off-farm inputs and costly mechanical treatments by placing greater reliance on management and integrative/alternative approaches

i) Soil Quality

a) Soil fertility and fertilizer use: Status of soil fertility can make a good index of sustainability. The nutrients utilized in biomass production not only must be replenished but their level raised a shade higher progressively to meet the need for continuous growth in productivity. Maintenance of soil fertility is realized through crop residues/underground biomass, crop rotations with legumes, application of manures and judicious use of fertilizers. Unlike North America, in India and many developing countries, use of fertilizers is far from adequate in dry lands to realize the full potential of crop performance. Hence, in sharp contrast to developed countries, it is under-use of fertilizers in rainfed lands of arid and semi-arid regions of developing countries which by contributing to low yields, has been causing sustainability concern. Though greater reliance should be placed on crop rotations, use of organic manures etc., the threshold for use of fertilizers needs to be worked out that can be used as a sustainability indicator along with other indices; contents of soil organic matter and nitrogen. Other nutrients i.e. phosphorus, potassium and micro-nutrients have not been found as limiting the soil productivity of drylands in India except for few specific agro-climatic situations.

b) Physical degradation of land resources: Soil erosion caused by runoff and wind action is by far the most formidable problem of India and many other developing Asian and African countries. Whereas, driven by high wind regime, sandy soil texture, poor vegetative cover and reckless land use, wind erosion is at its menacing best in Thar desert of North-West India, Sahel, Sahara and to a lesser extent in China, erosion by runoff is a widespread problem in most of the third world countries. This constitutes the greatest threat to sustainability of rainfed farming system. Extent of soil loss, silt load in runoff and gully formation, etc. could be identified as main indicators of sustainability in such ecosystems. Deterioration of soil structure due to inadequate management is another physical process that limits productivity. Indices of soil structure like porosity, water stable aggregates, hydraulic conductivity, strength of surface crust in soils vulnerable to formation of crust due to impact of rain drop, could also have merit as indices of soil quality.

c)Runoff loss of water and poor soil moisture regime: Loss of rain water from croplands as runoff is the other equally important segment of resource depletion that occurs concomitant to the process of soil erosion. Obviously, since plant yields in rainfed lands are more limited by water supply than any other factor, loss of water in runoff constitutes a serious threat to the sustainability of rainfed farming system. Runoff from watersheds can be gauged at suitable points in the surface drainage net work.

d)*Chemical degradation - salt accumulation*: Arid and semi-arid regions are more liable for accumulation of salts in crop root zone due to evaporation pull. Another front of stress to plants is thus opened in addition to moisture stress. Soil salinity-alkalinity status (salt content, pH, ESP, etc.) can thus indicate the quality of soil in areas vulnerable to salt accumulation in the soil profile.

e)*Status of micro-flora*: Status of micro-organisms conducive to efficient conduction of processes leading to decomposition of organic matter, biological nitrogen fixation, etc. has its unique role in soil fertility. In rainfed lands moisture and temperature stresses can affect the population of beneficial micro-organisms and their activities adversely.

f)*Residual toxicity - Use of plant protection chemicals*: Excessive use of plant protection chemicals and weedicides leaves toxic residues in soil. Threshold levels of the use of these chemicals need to be worked out to limit their use by putting in place techniques of IPM.

ii) Above Ground Environment

a)*Status of permanent vegetative cover*: In areas prone to wind erosion, one of the basic recommendations for their efficient management is provision of permanent vegetative cover of trees and grasses. Apart from adding organic matter to the soil through leaf litter and underground biomass, the extensive root network of trees and grasses contributes in binding the soil particles together. Consequently, the erodibility of soil by runoff and wind action is also reduced. Additionally, the oxygen added by trees to the atmosphere is another dimension of their positive role in enhancement of the quality of the environment. Permanent vegetative cover on the land surface, thus could be an important index for sustainability of rainfed farming system in arid and semi-arid regions.

b)*Dust load*: Dust load in the atmosphere is an index of wind erosion. Apart from abrasive action on leaves, when dust settle on vegetation, transpiration is retarded that may affect plant performance in some situations.

c)*Emission of gases:* In general, agricultural activities have lesser effects on air pollution than does industry although dust may be a problem in certain areas as mentioned above. Excessive use of agricultural chemicals may cause emission of some gases like N_2O, CH_4, CO_2 and CO, etc. into the atmosphere. According to estimates of EPA, in USA the fraction of fertilizer N lost to atmosphere as nitrous oxides ranges from 0.001 to 0.05% for nitrate, 0.01 to 0.1% for ammonical fertilizers, and 0.5 to 5% for anhydrous ammonia. It was further observed in the EPA report that methane concentration has been increasing steadily at the rate of 1% per year since 1982. Domestic animals and paddy fields were identified as the principal sources of methane emission.

iii) Groundwater (Depth and Quality)

In arid areas groundwater lies either too deep or is brackish in quality, considerably limiting its economic exploitation. One of the approaches of runoff management is its preservation in aquifers. Excess runoff from watersheds is diverted to such points to recharge groundwater. This water is used for domestic and livestock consumption and for protective irrigation of crops during droughts. Such micro-environments thus constitute important links in the mechanism for survival of people during droughts in many areas. Thus, the quantity and quality of such groundwater may be significant for sustainability of farming systems in these locations.

2) Biological

This group of sustainability indicators mainly dwells upon the plants, micro-organisms, animals and their outputs as a continuum. An equilibrium among these components of biological domain needs to be established through technological intervention to preserve and upgrade the ecosystem for human well being on a sustainable basis. Several processes tend to operate seemingly as separate entities but are closely interrelated. Isolated interventions to control one process may vitiate the equilibrium. Integrated system approach is thus warranted for any endeavour having sustainability aspirations; whether assessment of sustainability of the farming system/s in vogue or R&D efforts to reach this goal.

i) Biomass Yield

Yield is the ultimate output of the farming system enterprise. All agricultural research and extension efforts are centrally directed to increasing the yields of food grain, fiber and fodder The concept of sustainability entails that we must live on the 'interest' and the 'capital' (the basic resources) should remain intact. Even this may not be tenable from a true sustainability consideration. The case in point is that 'capital' should also be progressively enhanced. It is then only that 'interest' will also progressively increase for meeting the requirements of people caused by increasing economic level and growth in human and livestock population. This underscores the importance of increase in yields along with improvement in the quality of basic resources for sustainability of the farming systems in arid and semi-arid regions.

ii) Quality of Produce

Quality of produce is equally relevant to the producer and to the consumer. The farmer gets a good price for good quality produce that adds to his income and finally, to the quality of his life. The good quality food leads to better health of people and livestock. Healthy livestock leads to better milk/meat/wool production as also to better draft power for various agricultural operations A mutually rewarding and healthy relationship between produce and consumption thus comes to stay which helps in the long range viability and sustainability of the whole system.

Protein content, varietal purity, safety from diseases and palatability (fodder) are some of *the attributes of the quality.*

iii) Bio-Diversity

Apart from conservation of resources, biotechnology is our greatest hope for sustaining agricultural production system for all times. Perhaps the greatest contribution that biotechnology can make lies in its potential application as a tool to evolve cultivars that can produce yields utilizing the limited resources more efficiently. It can bring about dramatic increases in yield per unit area and time. Such improved cultivars can withstand drought, weeds, pests and can be induced with inherent capacity to perform with minimal nutrient supply. Other important area in which biotechnology can play a significant role is nitrogen fixation. Further, such improvements obviously are not one time. These can constitute a continuous process with the openings of newer and newer horizons by research and explorations. Now, what the biotechnologists need is a great deal of bio-diversity in the ecosystem to bring into reality such blue prints of plant types. The wider the variety of germplasm, the greater scope they can have for tailoring the desired plant types. All out efforts are thus required to preserve bio-diversity to bring into reality our goal of sustainable agriculture.

iv) Commodity Diversification

a) *Crops*: The greater the range of crops (food, fodder, fuel) and their varieties grown by a farmer the lesser would be the risk of their failure due to drought and infestation by pests and diseases. Different crops have different root zones. Thus, soil profile is explored more efficiently for nutrients and water. Legumes add nitrogen to the soil. Fruit crops add to the income and improve the quality of nutrition of the farmers. Fodder trees (like *Prosopis cineraria* in western Rajasthan) provide rich top feed for the animals and so do the grasses. In the olden days, farmers in western Rajasthan used to sow seed mixtures of pearl millet, moth bean, mung bean, cluster bean and sesame in the field having good stands of *Prosopis cineraria*, *Ziziphus nummularia*, *Z. rotundifolia* and in some areas also grasses like *Lasiurus sindicus* and *Cenchrus ciliaris*. This traditional system though subsistence oriented, was successful in those days. The continuous increase in population resulting in over exploitation of resources has since vitiated this survival mechanism. However, the principle involved is still quite relevant. The different crop commodities including tree crops for fruit and fodder and grasses can be grown in a mutually beneficial design adopting intercropping/agro-forestry approaches and crop rotations.

b) *Livestock quality and number*: Mixed farming i.e. arable crop production + animal husbandry, is ideal for reaching the sustainability goal. The fodder produced from grasses and trees (top feed) - vital for conservation of resources, is readily utilized by the animals. Manure produced by the animals is recycled into the soil to maintain and upgrade its fertility. The animal products of milk, meat, wool and skin/hide generate additional income and cash to spend on social/cultural obligations, raising the standard of living and purchase of inputs for crop production and nutrition/health of animals.

The quality of animals and their desirable number, however, have far reaching consequences to sustainability. A large herd disproportionate to size of holding (for producing fodder) cannot be sustainable. Overgrazing of common pasture lands would be a logical consequence in such a situation. Despite this, the animals in such larger numbers will continue to be underfed leading to health hazards and thus to low production.

The trade off central to this vital aspect here is encouraging farmers to maintain good quality herds of the size depending upon the availability of fodder from their own resources and from CPRs. Desired range in species of animals is also warranted to reduce risk of outbreak of epidemics and diseases.

In most agro-ecological situations of India there is only one effective rainy season beginning middle or end of June and lasts up to October. In many rainfed areas, thus, the farmers have work only for half of the year. Mixed farming can alleviate this situation. Additional rural employment is created that has been one of the central issues of current agricultural policy in India and perhaps in other developing countries as well.

3) Socio-Economic and Policy Related

As mentioned earlier, it is nothing sort of a grass root movement that can lead to sustainability. The farming system in practice must be understood by research and development personnel alike in order to assess the present status of sustainability and identification of ways and means to reverse the trend if the system is unsustainable; or enhance and upgrade the present status further. Equally important in this arena are the political will and government policies and programme. These two again are inter-related. Technological intervention though based on people's perceptions and priorities, would not be so successful unless supported by realistic policies based on vision and foresight instead of populistic and piece-meal programmes.

Indicators of sustainability that may be relevant under this group are discussed here.

i)Land Use

a) *Cultivated area* : Area under cultivation has a close bearing on sustainability. Many farmers with larger and fragmented holdings are not able to sow their entire land for race with time after onset of monsoon, or due to labour peaks. Production diversification can help overcome this limitation. Increase in cultivated area due to cultivation on marginal and sub-marginal lands is a negative indicator. On the other hand, if such increase is due to bringing culturable wastes under production a positive indicator of sustainability is the case.

b) *Degraded*: Area under wastelands has a direct bearing on sustainability. Soil erosion (wind and water) and salt accumulation, are the main processes responsible for land degradation. Increase in area of such lands is an indication of unsustainability and vice-versa. However, if with some ameliorative actions these lands can be put under pasture and tree lots, it can add to the sustainability of the system substantially.

c) *Culturable Wastes*: As mentioned in the section on cultivated area, less productive lands are sometimes left from cultivation for a variety of reasons. The productivity of such lands can be upgraded with better management. However, if the farmer does not have adequate means to use them for arable farming, silvi-pasture approach can be implemented for production of fodder and fuel on one hand and conservation of land resource against degradation processes, on the other. Such efforts will be conducive to the sustainability of the system. Whereas existence of large chunks of culturable wastes and increase in their area will obviously indicate unsustainability of the farming system.

d) *CPRs - grazing lands, water bodies*: Common lands are no man's lands. The social norms fixed in ancient times for their utilization have gone into oblivion with increasing population pressure of both human and livestock. The present day village grazing lands present a pathetic sight with hardly anything to graze. These at best serve the purpose of providing open space for animals to move around and nibble on the hardiest of species which have tolerated the pressure but possess nothing in the name of nutrition. Same is the case with the other important CPR - the village pond/s. They hardly get filled even to the half of their capacity owing to encroachment on their catchments for cultivation. Hence, many a times there is no water for consumption of animals and domestic usage. Farmer's precious time is lost in bringing water from distant places, which otherwise could be utilized in managing their land and livestock resources. Deposition of silt load, carried in runoff in ponds and reservoirs resulting in progressive depletion of their storage capacity is another dimension of the problem.

Presence of grazing lands having desirable plant species and water supply to ponds and their storage capacity can therefore be important indicators of sustainability of the farming system.

ii)Rural Employment

As mentioned in the section on commodity diversification, farmers in arid drylands have occupation only for half the year in many areas. Besides, with increase in population and fragmentation of holdings, there is no enough work for the available manpower even for six months of the year. The result is migration to urban areas. Since there is an ultimate limit in cities to accept such migrants, slums are created where people live in all round miseries- shameful for humanity. Therefore, apart from mixed farming with desired emphasis on animal husbandry, agro-based industries need to be established in rural areas to provide employment.

Apart from ensuring availability of labour during peak periods, such efforts would help augmenting productivity per unit of available man power by its rational utilization.

iii) People's Participation in Development

As already mentioned, sustainability is a goal that can be reached only by a grass root movement. No development effort can be sustainable without people's participation. Reliance on farming systems can help reaching this goal of grass root movement. Hence, the degree of people's participation in development programmes can be a true indicator of sustainable development.

iv) Quality of Life of People

Enhancement of quality of life of rural folk on a progressive and sustainable basis is the ultimate aim of agricultural development in the rural sector. The system cannot be sustained if it has subsistence orientation. Progressive enhancement of socio-economic conditions of farmers is therefore, a reliable indicator of the sustainability of the production system in practice.

v)Size of Holding

Fragmentation of holdings due to inheritance laws tend to make them uneconomic. Diversification - so important from sustainability considerations, cannot be put in place in small holdings of one or two hectares. Hence, thresholds for economic holding size need to be worked out.

vi)Absentee Landlord Status

In India, many land holders are employed in other sectors. Consequently, they give their land either on rent or on barter to small, marginal and landless farmers. Such farmers are averse to developmental efforts for the land does not belong to them. This farming practice thus has a clear cut subsistence orientation - an indicator of unsustainability.

vii) Government Policies, Incentives and Facilities

Technological interventions and government policies must go hand in glove in order to reach the goal of sustainable development. Apart from developing facilities for easy agricultural loans (single window system), marketing infrastructure, insurance, support prices, easy availability of inputs, other sectors of rural development like medical/health care, education, recreation and communication etc. have to be suitably addressed to, from overall sustainability considerations. Such facilities, can provide a healthy environment and enhance the quality of life of people. Villages can become places worthy for living putting a curb on migration to cities.

Government policies should also address to inheritance laws and absentee land holders Suitable laws have to be put in place to discourage such trends. Apart from agriculture related policies, incentives and facilities, general rural facilities as discussed above, can also be used as indirect indicators of sustainable agriculture in rainfed areas.

An important feature of the indicators of sustainability discussed above is that they are interrelated with each other. A discussion on land use in isolation with disregard to government policies, land degradation processes and people's requirement and participation in programs giving wide technological options, would be futile. Similarly, forage production can not be separated from livestock management. Arable farming has also to be addressed simultaneously in close integration as the production of food for the family is the first priority of small holders. For the same reasons study on one or two indicators may not reveal the true scenario. All of them have to be evaluated together in a programme mode using computer.

Some overlapping in the indicators is also conspicuous. This can not be avoided for they are interrelated. Some of them also appear to be tentative at this stage. On-farm research on application and development of sustainability indicators would truly indicate their merit to enable identification of the most suitable ones.

Practical application of the indicators can play a vital role in planning of R & D efforts with regard to technologies for production of arable crops, fodder-fuel trees/shrubs and livestock management in an integrated manner. The farming systems approach with sustainability considerations at the forefront can effectively answer the problem of poor forage supply in arid and semi-arid regions. Animal husbandry can thus be put in place as the central component of the production system for sustainable development of these regions poor in natural resource endowments.

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SOCIAL ASPECTS OF SILVIPASTORAL SYSTEMS IN ARID REGIONS

L.P Bharara

Introduction

Increase in human and livestock population is one of the major issues in propagating and strengthening silvipastoral land use systems. Growing population pressure results in land use practices that are increasingly destructive for soil, water and vegetation resources. Fallow periods are shortened and cultivation is extended to the areas unsuitable for cultivation. Communities with static farming and traditional technology face various problems of over exploitation of natural resources in order to meet the increasing demands of food, fodder, fuel and water resources. This has resulted in deterioration of resources causing low productivity, low income, poverty, deforestation and nomadic and semi-nomadic pattern of living associated with migration and pastoralism. The misuse of land use system involving cultivation of sub-marginal land, overgrazing of rangelands, over cultivation, deforestation and cutting of vegetation and depletion of wood cover affecting various land use systems specially silvipastoral system in the area.

Research on agroforestry and silvipastoral systems were initiated at the Central Arid Zone Research Institute (CAZRI) Jodhpur, India in the early seventies. Though some studies on socio-economic aspects related to alternative landuse system are available(Bharara 1970,1988,1989,1991,1992; Ballabh and Saxena 1992; Brumer 1991; GOI 1987)but empirical studies on farm trees,their significance, changes over time, relationship with agrarian structure and farming systems, etc. are still lacking. The present paper discusses socio-economic issues and prospects of silvipastoral land use systems in arid zone of Rajasthan.

Traditional Silvipastoral Practices in Arid Rajasthan

The appropriate silvipastoral system for arid lands will depend on the physical, economic and social considerations. There are two essential and related aims as (i) the system should conserve and improve the site and (ii) at the same time optimise the combined production of tree crops including food, fodder, fruits and grasses.

Twenty to thirty years ago, an acre of field sown with bajra contained about 100-120 plants of Bordi. However, with the recent introduction of tractor, majority of the bordi plants are removed and the density per acre has reduced to only 25-30 plants in many cases. Most knowledgeable farmers admit about the reduced number of bordi plants, its excellent feed, fencing and food values, and suggest for exploring ways to have more number of this plant . Farmers look forward to science for telling them the practices to be adopted for such modifications including row to row and plant to plant distances, etc.

Khejri termed as a king tree in the arid Rajasthan grows well in combination with crops like Bajra, legumes (moth-moong) and oilseeds. The density of this tree traditionally preferred and maintained in one acre area put under crops, was about 25 to 35 trees. Vertically straight plants were allowed to grow while the deshaped ones were removed. As in case with bordi, the introduction of tractor for cultivation purposes has affected the density of these trees in the field boundaries and farmers would prefer to learn more if ploughing through tractor could also help them to retain the number of trees traditionally present in the fields.

Khejri well known for livestock feed (leaves), vegetables (Sangariya), fruits (Khokha) and timber, when unlopped enriches soil through leaf-fall. It may be pertinent to recommend here that those engaged in research for soil amelioration may intensify efforts for providing recommendations to the farmers regarding optimum number of khejri trees that could be taken per unit area and to suggest the improvement in the package of practices being followed by the farmers for growth of these trees.

The trees like Banwalia (*Acacia nilotica*), Vilayati babool (*Prosopis juliflora*) and shrubs like kair (*Capparis decidua*), Phog (*Calligonum polygonoides*) are also important and useful and found mainly on the borders of the field. These plants produce fuel, fodder and fencing material but disregarded by the farmers for agro-forestry due to their negative effects on the crop. However, looking to their importance, possibilities to grow them with the crop specifically on the field boundaries in a more systematic manner should be explored so that the farmers can get the benefits from these easy growing desert plants.

Awareness of the traditional silvipastoral practices reveal the importance of developing greater knowledge on the past and present activities of the dwellers pertaining to silvipastoral system. This provides lead for developing new knowledge which could subsequently bring about improvements in the package of traditional practices and provide suggestions for effective adjustment according to the changing situations. Developing or improving upon the traditional shrubs and trees grown in combination with crops and a search for alternatives assumes further significance, specifically in the backdrop of change in the system of agricultural operations.

Some Social Aspects Affecting Silvipastoral Land Use Systems

Human Population Oriented: 1. Increasing human population-a serious stress on the natural resources, 2. High fertility norms, 3. High growth rate, 4. Low literacy rate, 5. Social organisation, 6. Occupational rigidity, 7. Migration for livelihood, 8. Scattered form of settlement and 9. Lacking basic community facilities.

Agricultural Oriented Aspects : A. *Ownership pattern* 1. Scattered distribution of land owned, 2. Uneven distribution of land, 3. Predominance of small and marginal farmers, 4. Traditional agricultural practices, 5. Subsistence crops grown, 6. Declining man-land ratio, 7. Increasing cultivated and net area sown, 8. No fallowing of cultivable land and 9. Decreasing land fertility-crop yield / unit area.

B. *Cultivation of sub-marginal lands:* 1. Land use intensity far exceeds the limits set by its natural use capability, 2. Cultivation in the very dry areas and on the slopes of sand dunes, 3. Crop-cultivation pushed into sub-marginal lands exposing it to high erosion hazards and decreasing productivity, 4. Increase in waste lands due to irrigating fields with saline ground water, leading to increasing salinization of cultivable land, 5. Impact of tractorization leading to increase of land use intensity and 6. Decrease in length of fallowing periods and land under fallow system.

C. *Overcultivation :* 1. Expansion of cultivation resulting in increase of cultivated area, 2. Erosion of soil and loss of water due to hill side farming; ploughing of dunes, marginal and sub-marginal lands, 3. Uneconomical land use, 4. Reactivation of sand dunes due to biotic interference and 5. Soil erosion.

Livestock Population Oriented : 1. Increasing number of livestock 2. High growth rate 3. High pressure viz. density per unit of grazing land as compared to an optimum desirable pressure 4. Livestock composition-changes in number-predominance of sheep and goats 5. Overstocking tendency to cover risks 6. Overgrazing (too many livestock for existing vegetation to support) 7. Consequent decrease in available pasture 8. Traditional animal husbandry practices 9. Livestock migration and pastoralism 10. Lopping or felling of trees during lean period 11. Decreasing livestock produce,and 12. Use of cow dung for fuel purposes.

Vegetation Oriented Parameters : 1. Changes in nature and extent of vegetation species 2. Degradation of rangelands/grazing areas 3. Decreasing permanent pastures and other grazing lands 4. Over exploitation of grazing lands 5. Low productivity of grazing lands 6. Declining carrying capacity of village pastures 7. Increasingly low quality of grasses 8. Decrease in high quality of grasses, shrubs and trees,and 9. Cutting of trees, shrubs and grasses for sale for earning.

Socio-Climatological Parameters : 1. Inadequate rainfall (extent, distribution, etc.) 2. Severe drought intensity 3. Frequent drought occurrences 4. Deep water level (underground) and increasing salinity affecting quality of underground water 5. Availability of rainwater-lacking storage facilities,and 6. Non-availability of well water for irrigation.

Farmer's Perception Towards Alternative Land Use Systems

Of the various types of farming in practice-agriculture pastoralism, ago-pastoralism and silvipastoral are the most predominant. Agriculture as the main sustenance resource is followed by more than 60 per cent of the households of Rajput, Peetal, Bishnoi and Rajpurohit communities. While pastoralism is the main earning source of hardly 5 per cent of the total households belonging to Raika community. Agro-pastoralism is most commonly practiced by more than two-third of the total households of these communities having a combination of agriculture and livestock as the major sources of livelihood. The most productive farming type preferred is combination of various farming systems. Agriculture and pastoralism being more risk prone needs to be supplemented with other alternative farming types. People prefer to have a multi-component system of farming viz., agro-pastoral, agro-silvi-pastoral or agro-silvi-horticulture-cum pastoral (Table 1).

Social Groups Influencing Silvipastoral System

The role that the tree and shrubs of silvipastoral systems can play in animal production in the area is itself influenced by the role animals play in society. There are various kinds of social groups concerned with animal production and these have far reaching implications on agroforestry. The groups identified are:

The Pastoral Group: These are groups (Raikas and Sindhi Muslims) where animal rearing is the main occupation. This group includes nomads, semi-nomads and transhumants. They are traditionally in close association with their animals, constantly searching for pasture and not interested in change. The pastoral people as a whole are considered particularly well-adapted to the use of their environment.

The Agropastoral Group: These (Rajputs, Jats, Bishnois, etc.) are mainly dependent on agriculture but some also practise animal husbandry. This groups is in favour of settlement. The agropastoral group is increasing faster than the pastoral group and in many places encourage

Table 1. People's perception towards proportionate income and risks involved (%)during various alternative land use systems followed by the desert dwellers

Predominant land use system	% Income from different components of land use system and risks uncovered during average year				
	Agriculture	Pastoralism	Silviculture	Horticulture	Risk uncovered
Agriculture	65	-	-	-	35
Pastoralism	-	60	-	-	40
Agro-pastoralism	50	30	-	-	20
Pastoralism-cum agriculture	35	45	-	-	20
Agro- silviculture	60	-	15	-	25
Agro- silvipastoral	45	30	10	-	15
Agro-horticulture	55	-	-	15	30
Silvi-pastoral	-	45	35	-	20
Agro-pastoral -cum-horticulture	40	35	5	10	10

desertification by continuously pushing cultivation towards the more arid areas that are less and less suitable for sustainable agriculture.

The Mixed Farming Group: This group consists mainly of settled farmers (Rajputs, Jats, Ghanchis, Bishnois, etc.) who invest in more or less sophisticated forms of fodder production and management of herds and flocks. There are several silvipastoral technologies that could help this group to achieve relatively ensured return, for example crops for fodder or small fodder banks.

Crop Farmers: This group (Rajputs, Jats, Muslim, Bishnoi, etc.) is very much similar to the previous one and consists of farmers who are deeply involved in crop production and have few animals. They get fodder from the agricultural by products and are likely to be more concerned with silvipastoral system than animal production as it will also increase the amounts of agricultural by-products, many of which are a source of fodder.

Nature and Extent of Grazing Resources

The grazing lands are defined as extensive, unfenced areas, mostly under natural vegetation, where animals (wild and domesticated) graze. They are mostly unfit for arable farming and are thus maintained for grazing purposes. Grazing lands, at a world level, are an important resource for livestock sustenance. About 47% of the global land surface, 332 million hectares, is classified as grazing land. In India this constitutes 40% of the total area sustaining about 406 million livestock. It is more alarming in the fragile ecosystem of the arid zone of Rajasthan where 23 million livestock, out of 49 million in the whole of the state of Rajasthan, survive on these grazing lands which constitute about 40% of the total area (Table 2).

The vegetation resources on these lands are sparse and affected by drought. The nature and extent of grazing resources available vary from region to region depending upon the topography and climate. The grazing resources are pastures and other grazing lands i.e. forests, miscellaneous tree crops, cultivable waste lands and fallows lands. A variety of grazing systems are practiced in different climatic zones where pastoralism is predominant.

Table 2. Grazing resources available in the arid zone of Rajasthan, Rajasthan state and India, (1989-90) in thousand hectares

Grazing resources	Arid zone of Rajasthan	Rajasthan	India
Forest	312 (1.5)	2163 (6.3)	67334 (22.1)
Pastures	871 (4.2)	1876 (5.4)	12002 (3.9)
Misc. tree crops and groves	67 (0.3)	82 (0.2)	3462 (1.1)
Cultivable wasteland	4541 (21.8)	5741 (16.8)	15451 (5.1)
Total fallow land	2850 (13.7)	3770 (11.0)	22872 (7.6)
Total grazing area available	8641 (41.5)	13602 (39.7)	121121 (39.8)
Total geographical area	20822 (100.0)	34235 (100.0)	304213 (100.0)

Percent of total geographical area is given in parentheses

Utilisation of Village Grazing Lands

Village grazing lands are overgrazed by the ever increasing livestock population which reduces their regenerating capacity and keep them at a low level of productivity, soil is deficient in minerals and organic matter contents due to the migratory nature of livestock. For most of the years, forest lands confined to the fringes are excessively grazed. Trees are heavily lopped. Vegetal cover has been removed and the soil is exposed to accelerated erosion. Trees have gradually been replaced by shrubs. The forests are reduced to the open thorn scrub type. Overgrazing of common grazing lands is an issue of considerable importance in the arid zone of Rajasthan. Overgrazing leads to desertification. Abusive grazing during the last 40 years has considerably reduced the productivity of these lands. The external costs of this abusive grazing are evidenced by accelerated soil erosion, decreased water absorption, decreased livestock carrying capacity and degraded wildlife habitat which in turn produce less revenue, etc. In addition to the common lands admitting communal ownership rights, the public (State) lands which include forest lands on which grazing is allowed under stress periods, are in a state of degradation. Unregulated grazing suppresses the growth and vitality of the forests and gradually degrades them. The problems become more severe during drought years.

The greatest single factor contributing to the decline in the productive potential of grazing lands is mismanagement of livestock. Overgrazing, if unattended will cause any area of grazing land to deteriorate. The number, spatial distribution and kinds of animals and the seasonal pattern of the grazing must all be controlled if grazing lands are to be maintained in productive condition for higher yields and profits.

Livestock, irrespective of type, are generally grazed on the village grazing lands like nadi ka Agor (adjoining basin of tank or pond), Oran lands and Gochar Bhumi. Barren and uncultivable lands, harvested fields, magra (rocky and gravelly) and fallow lands are also used for grazing purposes. Utilisation of these grazing lands reveals that there is overgrazing and degradation of these rangelands. About 80% of grazing lands, locally called Gochar lands, are in poor range condition, and according to one study undertaken in the districts of Barmer, Bikaner, Churu, Jaisalmer and Jodhpur, the grazing incidence per cattle unit is two to six times higher than the particular type of grass cover should be expected to carry. This is mainly due to social, institutional and infrastructural factors. Common grazing lands are not maintained and are exploited at will by individual herdsman and nomadic pastoralists. Extensive areas covered with nutritious grasses are under-utilised because of water shortage, while there is overgrazing on pastures with water facilities.

From July to October during the kharif cropping season, animals graze on common village grazing grounds or other public land and fallow land. After the harvest they also graze on the cropped fields, with sheep and goats following cattle. All public and private lands, except those under rabi crops, are thus open to every grazier as long as grass is available. Effective grazing involves frequent changes in grazing arrangements (number of graziers, sub-divisions of the herd on the basis of age, sex, lactation period, etc.) according to the availability and distance of fodder and water and is usually carried out by family members, often children, or hired graziers. While from July to November, grazing takes place mainly in the immediate vicinity of the village, in the extremely arid areas in the west a traditional system of rotational grazing is followed, where herds move in the rainy season to interdunal areas where grasses grow around dug out ponds (tobas). Pastures around the villages are thus preserved and only used once the interdunal pastures have been exhausted. Indiscriminate grazing in the interdunal areas has led, in recent times, to a rapid degradation of these grass resources and rapid decline in forage production.

Livestock Migration and Pastoralism

Livestock migration associated with pastoralism is a predominant characteristic of the area. It is considered to be an ameliorative measure of drought and practised by the livestock owners. While out-migration with livestock is an efficient way of avoiding scarcity conditions and maintaining productive assets even in drought periods, it does put a tremendous strain on men and animals. Lack of forage and exhaustion due to travelling long distances in search of water leads to high animal mortality, and a drop in yields of milk and wool. Migration also increases the danger of diseases which takesa heavy toll. Moreover herds are often harassed by thieves and are increasingly forced to pay penalties, grazing fees and taxes to local villagers . Due to political reasons traditional migration routes have also been blocked.

Constraints in Development of Grazing Lands

Continuous increase in livestock and the human population, together with the legal sanction of allotment of unoccupied lands for cultivation have resulted in a reduction of grazing lands accelerating wind erosion and land degradation processes. Livestock migration and pastoralism coupled with weakening symbiotic relationship and emerging conflicts among the sedentary and the nomadic pastoral communities over the use of grazing resources; lifestyle of different users ranging from landless livestockmen to landlords with livestock; people's perceptions and attitudes towards resources use and useless livestock, adversely effect the improvement of grazing lands. Land use changes including marginal and sub-marginal lands under cultivation rather than pasture development; increasing tendency of rearing livestock by non-livestock rearing caste groups, deforestation and the cutting of vegetation for firewood and charcoal; lack of common interest, joint ownership and people's participation in developing grazing lands;

religious sentiments towards protecting non-productive and diseased livestock; illiteracy, conservatism and scattered settlement patterns, all hamper the development of grazing lands.

People's religious sentiments towards protecting and preserving local vegetation; village councils enforcing norms and conventions for utilising grasslands; traditional systems of collecting rainwater for the regeneration of grasslands; regulation of grazing according to carrying capacity; developing new pastures, and imposing reasonable fees; involving people and village institutions, will all help the development of grazing lands.

Silvipastoral Land Use System-policy Implications

One of the most important policy implications relates to the perceptions of the various groups of people involved in alternative landuse systems development in arid areas. On one hand the farmers themselves have clearly perceived the problems faced by them due to a decline in supply of needed forest products in the common forest land. They have started reacting to the situation by increasing the quantity of trees on their private farm land. They are very tree conscious and aware of their dependence on trees for the survival of their subsistence farming lifestyle. However, many government officials and policy planners perceive that the farmers lack an awareness of their dependence on trees and lacking knowledge, expertise, or ability regarding the cultivation and management of trees on their private land.

Traditional land use system suggest that people take active interest in tree cultivation and protection provided it strengthens their production system. The main policy implication for arid areas is, therefore, to develop trust between the intervening agency and the people. How to do this is a big question? This finding highlights the importance of research and action plan in the area of people's participation. A radical solution to this question might be that people would participate in silvi-pastoral system, tree protection, etc. provided the programme is economically beneficial to them. By corollary, they will not participate in any land use system etc. for the sake of environment and for larger societal considerations. Therefore, the programme related to silvipasture should be based on economic considerations or for enlarging their subsistence base. This is a necessary condition for success. Growing trees on private agricultural wastelands (as opposed to good quality land which can support more labour intensive annual crops) is both socially and economically desirable activity

The function of silvipastoral system is precisely to look into problems of land use systems involving grass, forestry and livestock. This would certainly need a change in our research approach. To begin with there is a need to appreciate the fundamental characteristics inherent in all such systems: that they provide multiple outputs from the same unit of land in a sustainable way and that in some form or another interactions occur between the two or more constituent plant species, one of which at least is a woody perennial (tree or shrub, etc.). We are to deal with relatively elaborate systems for which programmes of investigations need to be established that encompass more complex space and time dimensions than those normally encountered in agriculture and forestry. While we explore the problems and possibilities of intimately mixing trees and grasses sometimes in conjunction with animals as secondary producers, it is bound to bring into focus constraints requiring new lines of research approach like i) shade tolerance of various agricultural species, ii) forest species which protect the soils but do not reduce the energy levels of the understorey, iii) breeding programmes (both forest and tree species and in crops) utilising attributes and characteristics necessary for successful and efficient grass production, and iv) the plant (topfeed)-animal interactions and their management.

A strategy for silvipastoral system-animal husbandry based regeneration of arid areas should include:

- Strict operation of Rajasthan Soil and Water Conservation Act.
- Land use according to its capability and need.
- Stopping the allotment of denuded forest land for arable cultivation.
- Prohibition of carriage of fuel wood and encouragement of community and farm forestry.
- Barring free and uncontrolled grazing in areas which are highly erodible and where erosion has already destroyed the fertile layer of the land.
- Formulating a sound forest and vegetation policy
- Providing incentives for protection and plantation of trees in farm lands.
- To enforce village panchayat and social legislation for protection and plantation of trees in farm lands.
- To encourage people's participation by enforcing vocational literacy programmes.
- Making use of traditional knowledge, attitude, aspirations, perception and motivation of the farmers influencing adoption of technology for increasing resource productivity.
- To enforce desert care code highlighting socio-ecological ethics of environmental conservation strategies to be followed by the pastoralists during migration, at camping sites and while returning from migration. This includes:
- Establishment of pastoral net work viz. pastoralists, agro-pastoralists and grazing lands, coexistence and a forum on grazing lands development.
- Manageable unit of livestock
- Sustainable land use criteria for grazing of livestock
- Judicious watering pattern to be followed,and
- Maximum Production with limited and diversified resources.

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FARM WOMEN AND THEIR PARTICIPATION IN EXTENSIVE ARID SILVIPASTORAL SYSTEMS : AN ASSESSMENT

Pratibha Tewari

Introduction

On the threshold of twenty-first century, we find that condition of our womenfolk, particularly those of rural community, is still very deplorable. In view of the tremendous contribution that women are making and can yet make, it is not a matter of little concern, rather a time has come when it has been realized that, for speedy and overall development in any agriculture or related sectors, their involvement needs to be properly assessed and known.

Women constitute 50 per cent human resource of the country and they also form part of the mainstream of agricultural production (Devdas *et al*, 1988). But how did such a "visible" group of persons remain "invisible"? In fact, in the production-oriented programmes for rural development, there has been very little or practically no effort to evaluate the role played by rural women (Mitra *et al.*, 1988).

Rural women besides performing household work, have been traditionally and predominantly engaged in crop farming, plantations, animal husbandry and dairying activities. Historians believe that it was women, who first started cultivation of crop plant, and initiated art and science of farming, and even today they are traditionally acknowledged for their efficient seed selection ability (Swaminathan 1985). Whatever, the status of rural women in different farming system is there today, how less is the appreciation and recognition for their extensive contribution in these sectors, but it is beyond doubt that women have played and continue to play a key role in the conservation of life support systems, be it is agri-culture, forestry, animal husbandry, fisheries or any thing else like traditional agro-forestry/silvipastoral systems etc., etc. This paper attempts to discuss the role of farm women in agriculture sector, with special emphasis on silvipastoral systems which is being traditionally practised in arid and semi-arid regions of Indian subcontinent since time immemorial.

Extensive Silvipastoral System : What is it ?

The concept of agro-forestry/silvipastoral systems that is wide spread among thinking politicians, landuse managers and technocrats and is even accepted by some researchers, is that it is a technology particularly suitable for resource-poor marginal lands, even for wasteland. But if we examine critically such two tier/three tier systems, we will find that such practices are age old traditions in many arid and semi-arid parts of Asia and other tropical countries. For example, in arid part of western Rajasthan, which accounts for 60% total hot arid regions of India, growing trees and shrubs in arable land or in pastures is being practised since time immemorial. Thus, though integrated with agriculture and pastures, agroforestry/silvipastoral systems are well defined part of landuse of this region. These large tracts of land having widely scattered trees of 'Khejri'*(Prosopis cineraria)*,'Rohida' (*Tecomella undulata*),'Jal'/Pilu'(*Salvadora* spp.) and shrub like *Ziziphus spp.* with undercrops of food grain or pasture species are best examples of extensive system. Similar type of systems with different sets of woody species and food grain/pasture species are also common in semi arid regions, where productivity is low due to limitation of soil/or climate.

Intensive systems are of two types, First ones, are more typical of productive areas with fertile soil and abundant rainfall, and developed in specific socio-economic-cultural environment within a period of time. Multistoreyed home gardens of Kerala, India are best example of such intensive systems. Second type of intensive systems comprises mainly man engineered silvipastoral/agroforestry systems, which are often found in form of improvement in already existing extensive systems on location and site specific basis in smaller areas. They are infact resultant of technological interventions. However, for discussing present topic we are more concerned with extensive systems.

Women' Participation in Agriculture Sector of India : Some Facts

Recent census of India estimated an all India economic participation rate of 21% for women and 53% for men in agriculture and closely related allied sectors. Almost 50% of rural female workers are classified as agricultural labourers and 37% as cultivators. The corresponding proportion of male rural workers are in reverse, with 55% as cultivators and 24% as agricultural labourers. The proportion of total number of female workers in agricultural and closely related sectors have remained more or less similar in last few decades, however, their number in actual cultivators' category is dwindling. On the other hand, there is more of less increase in the category of female agricultural labourers (Table 1).

The statistics on participation rate of women in agriculture and closely related sectors are far from reality. In fact, the number of women workers in rural areas are understated and this is primarily because of fact that women are seen more as housewives and mothers, even when they perform productive non-domestic work related to crop and animal husbandry within the premises of their homes or on their own farm. The magnitude of farm women's involvement in major farm operations can be judged by the figures given in Table 2.

When women are so vital component in agricultural scenario of the country, the statistics of census on women' participation in agriculture and closely related sectors appeared to be misleading. Similar views are expressed in this respect by Gulati (1984) and Rohini Nayyar (1987). Similarly, in the sector of animal husbandry, the contribution of women in different kind of operations is of very high order (Singh 1987; Singh and Bhattacharyya, 1987). For example, women' participation rate in, fodder collection activities is around 50-60%, care and feeding of animals is around 70-80%, grazing activities is around 40%, preparation of milk product is around 50% and marketing dairy products is around 60-65%.

In addition to above mentioned discussion, there are several other closely related allied sectors of agriculture in which rural women folk participate in sizeable quantum. Having such a vital role in life support systems, which women are continue to playing since ages has not been assessed properly. The main reason behind this is gender bias attitude of planners, technocrats,

Table 1. Farm women engaged in agriculture and closely related allied sectors in India

(In thousands)

Year	Total number of female workers	Total numbers in agriculture	Cultivators	Agricultural labourers
1951	40,539	31,062 (76.6)*	18,386 (45.3)	12,694 (31.3)
1961	59,402	47,274 (79.6)	33,103 (55.7)	14,171 (23.9)
1971	31,298	25,060 (80.1)	9,226 (29.6)	15,794 (50.5)
1981	46,000	35,230 (76.6)	14,985 (32.6)	20,250 (44.0)

*Figures in parenthesis are percentage of total rural female workers

Source: Modified from Byra Reddy (1988).

land-use managers and even thinking politicians. The research and developmental work in women related aspects is also gender biased both socio-economically and politically.

Arid Silvipastoral System: Participation of Women

The economy of western Rajasthan, India which is commonly known as *Thar* desert is primarily based on livestock and traditional silivipastoral system in the region (extensive system) are the support base for such a huge quantity of livestock. The following discussion is essentially related to arid western part of Rajasthan state, India.

Table 2. Important farm operations in which farm women participate

Farm operation	% involvement of women
Sowing	60-65
Transplanting	80-85
Weeding	72-77
Harvesting	70-80
Winnowing	50-70
Threshing	70-75
Drying	90-95
Storing	90-100
Milling	30-40
Marketing	10-20
Land preparation	10-15
Seed bed preparation	15-20
Raising Seedlings	10-15
Irrigation	20-30
Plant protection	10-20
Organic manuring	25-30
Chemical fertilizer application	20-30

Source : Modified from Byra reddy (1988)

Livestock

It would be perhaps highly important from silvipasture point of view to assess the livestock pressure in the arid part of western Rajasthan. Twelve districts in this part of the country suffer from different degree of aridity. For example, we take three district of arid western Rajasthan viz., Jodhpur (average total annual rainfall-300 mm), Barmer (average total annual rainfall-200-250 mm) and Jaisalmer (average total annual rainfall-150 mm). These, three districts accounts for 26% area of Rajasthan state (342346 sq. km). The livestock population in these three district is set in Table 3. Thus density of these domestic animals is 69.2 animals/km^2, which is too high to see the available grazing resources in these three district.

Table 3. Livestock population in three arid districts of western Rajasthan (in lacs).

Animal	Districts		
	Jodhpur	Barmer	Jaisalmer
Cows/ bullocks	5.27	4.91	2.61
Buffaloes	0.98	0.48	0.01
Sheep	11.47	11.57	8.76
Goats	7.34	1.33	4.17
Camel	0.49	0.47	4.45
Ass/mules	0.09	1.09	0.24
Total	25.64	19.85	16.24

Source: Anonymous (1988a, b,c)

Human Population Trends and Literacy Rate

Total human population in above paid three arid district is 3.03 million. Trend of male and female population in these districts are given in Table 4. It is evident from table 4 that with increasing aridity there is gradual decline in human population.

The density of human population in this tract is approximately 34 persons/sq. km, which is quite high if we compare other desert regions of the world. Population engaged in agriculture

Table 4. Trends in total and rural population in three arid districts of western Rajasthan.

Particulars	District		
	Jodhpur	Barmer	Jaisalmer
Total population			
Male	8.74	5.88	1.34
Female	7.94	1.09	1.09
Total	16.68	11.19	2.43
Only rural population	0.98	0.48	0.01
Male	5.70	5.36	1.16
Female	4.85	4.85	0.94
Total	10.88	10.21	2.10

Source: Anonymous (1988a, b,c)

and closely related sectors is 6.64 lacs, which is only 21.3% of total population of the areas. Details of male and female rural population engaged in this sector is given in Table 5. From

Table 5. Rural population engaged in agriculture and closely related allied sectors in three districts of westerm arid Rajasthan

Particulars	Districts		
	Jodhpur	Barmer	Jaisalmer
Male (in lacs)	2.44	2.5.	0.45
	(42.8%)*	(46.6%)	(38.8%)
Female (in lacs)	0.65	0.39	0.03
	(12.5%)	(0.39%)	(3.2%)
Total (in lacs)	2.09	2.89	0.48
	(28.4%)	(2.89%)	(22.9%)

Source: Anonymous (1988a, b,c)

*Figures inside parenthesis is percentage of total rural population in respective district.

these data it is apparent that participation of women in this sector is very low. Infact, these statistics is somewhat misleading, because women' role is just considered as mother and housewives, though they are highly involved in farm operations. This clearly reflects the gender bias attitude of planners, decision makers, politicians and other government functionaries. Participation of women force in this life support system never given due weightage which they actually deserve. Illiteracy among female population appeared to be major factor which always denied and continue to denying their true place and power. Table 6 includes data on literacy trend in three arid district of Rajasthan which is being discussed as an example.

Women' Contribution Pattern in System Functioning

Women in arid regions are rarely empowered to take up the full responsibility of their households, land and livestock. As we are well aware that women' participation in operations related to agriculture are of very high magnitude. In arid regions of India, fuel wood is main source for domestic energy needs. Seventy per cent domestic energy is derived from fuel wood,

Table 6. Literacy percentages in male and female population of three arid district of western Rajasthan

Particulars	District		
	Jodhpur	Barmer	Jaisalmer
Total (urban + rural population)			
Male	37.71	20.04	24.35
Female	14.47	4.71	5.24
Total	26.64	12.29	15.80
Rural population only			
Sheep			
Male	24.91	16.22	24.35
Female	2.74	1.71	5.24
Total	14.24	9.33	15.80

Source: Anonymous (1988a, b, c)

20% from crop residues and 10% from dung cakes. Similarly, to sustain such huge quantity of livestock traditional silvipastoral systems are main source of fodder in form of grass and leaves of various tree species.

Trees + grass + livestock are main component of silivipasture system. Human being are primary beneficiaries of the system. Thus all these four components, have vital role in system functioning. It is very difficult to assess the quantum of participation of human population in such extensive systems and more over, there is no data base available in this subject from anywhere in the country. To asses the role of farm women in silvipastoral system in respect of their participation, two examples are briefly considered here.

Example 1: Under lab to land Programme (LLP) of CAZRI, Jodhpur: Two villages viz, 'Lunawas' and 'Narnadi' in Jodhpur district were selected to assess the participation of women in such system. The area is pre-dominantly rainfed with scattered trees of *P. cineraria* (Khejri) and bushes like *Ziziphus spp.* From July to September, a number of forage species including nutrient grass like *Cenchrus ciliaris* are available in ground floor. To study the participation rate of adult females, 100 ladies in the age group of 16 to 60 years were randomly selected and data on their participation rate in agricultural (sole) and in components of silvipastoral systems were gathered through pre-tested schedule. Details of the study are presented in Table 7.

It is evident from this data while male population is relatively more involved in sole agriculture activities, the female population has dominant participation in components related to silvipastoral systems. If we assess the over all role of female population in the domain of these two life support systems, we find that participation of women is of much higher order than male population.

Example 2 : An exercise through participatory rural appraisal (PRA) approach was conducted recently in a cluster of six villages viz., Narva, Manai, Jakharo ki Dhani, Bidkali, Palri Pawara and Parli Mangalia) located in Jodhpur district of Rajasthan. In all the villages, man and women facilitator groups separately participated to assess the contribution of man and women folks in components of silvipastoral system of the area. An assessment and appreciation of the contribution of female population in silvipasture related activities in this cluster of six villages can be judged from the following facts, which emerged through the PRA exercise conducted in the area.

(a) Within the cluster of these six villages, the land area of an order of 500 ha is under traditional (extensive) silvipastoral system with 'Khejri' (*P. cineraria*) and 'bordi' (*Z. nummularia* and *Z. rotundifolia*) as dominant woody component. Palatable grasses like *Cenchrus ciliaris* constitute ground flora with other numerous herbaceous species.

(b) On an average, each house hold had 2.7 domestic animals (cows buffaloes, bullocks, sheep and goat).

(c) On an average, adult males were active 10.5 hours in a day, while the corresponding value for females was 14.6 hours.

Table 7. Percentage of participation of male and female population in sole agriculture and in component of silvipasture system in village 'Lunawas' and 'Narnadi'

Activity	Female	Male	Jointly
Agriculture			
Seed procurement	-	95	5
Field preparation	-	67	33
Fertilizer procurement	-	72	28
Fertilizer use	7	26	67
Seed treatment	50	30	20
Pesticide procurement	10	64	26
Pesticide application	4	77	19
weeding	25	34	41
Interculture operations	16	26	58
Harvesting of crops	14	10	76
Threshing	35	53	12
Marketing	6	88	6
Labour on others field	43	13	44
Silivipastoral components			
Forage (fodder) harvesting	52	19	29
Top feed harvesting	45	31	24
Carrying fodder	62	30	8
Fuel wood harvesting	81	19	-
Cow dung collection	100	-	-
Making dung cake	95	-	5
Feeding animals	71	14	15
Milking	81	-	19
Animal care (Medical)	4	90	6
Aninmal care (domestic)	79	16	5
Animal grazing	45	45	10

(d) Adult males spent predominant part of their time (63 to 68%) on activities directly related with farm operation and/or other income generation activities like trade and business. On the other hand, adult females spent their time mainly on silvipastoral components related activities (36.4%). These include harvesting of forage grasses, harvesting of top feed, fuel wood harvesting, cow dung collection and dung cake preparation, milking of animals, animal care, etc. This was closely followed by time share on house hold chores (35.0%). Women spent rest of the time in farming activities, small scale economic activities in some cases, like tailoring, social engagements, etc.

(e) In the cluster of villages studied, it was found that fuel wood cater the demand of 70% of total domestic energy requirements, 20% domestic energy needs are met by crop residues and 10% by animal dung.

(f) Participation of male population in activities related to silvipastoral system component (mainly fuel+fodder+livestock) is too low (only 20% of time is devoted by male population in this sphere) as compared to female population.

These two examples are mere reflection of the magnitude of rural women' participation in agriculture and closely related allied sectors in arid zone. Conditions in other parts of the country is more or less similar. But even then the participation of women in such vital life support systems and that too in such a high magnitude could not get the recognition upto that extant which they deserve. As mentioned earlier that literacy rate of women in arid zone of India is very poor and over all situation in entire country is more or less similar barring few exceptions. Perhaps this is the most important reason which prevent the woman folks to assume the charge of decision makers in these sectors, which they in fact dominates both in numbers and multi-facet duties they perform.

Conclusion

Many scientists believe that the work they do is socially and politically neutral and to a certain extant this is true, but when agro-forestry and/or silvipastoral research and developmental activities are concerned, we find that only rural poor are portrayed as their primary beneficiaries and as such they have a bias towards a particular section of the society (Hocking 1991). This is also true when we analyse gender issues in many fields of agricultural research and development. Infact, the picture of farm women is that of a submissive, illiterate, ignorant and assetless females who have been caught in the webs of traditions and customs (Singh and Bhattacharyya 1988). In true sense, the over burdened and under nourished rural women performing all sorts of operation in agriculture and allied sectors, which involve drudgery and physical labour are "farm women".

When the participation of women in agriculture and closely related allied sectors like extensive/traditional silvipastures of arid zone is concerned, it is highly essential to identify and define linkages between these systems for long term sustenance (in terms of energy input and output). For example, highly productive modern agricultural systems of USA are quite inefficient from over all energy point of view, as 5 to 10 units of energy input from various sources are required to produce single unit of food energy (Steinhart and Steinhart 1974).

In light of above mentioned observations the agro-ecosystems of our country and that of especially in arid zone must be highly inefficient from over all energetics point. In such situations, it is essential to analyse thoroughly the human energy inputs in agricultural systems of arid zone. Unfortunately, we have no such data base at the moment. But it is sure, when such studies will be conducted, the energy input from female population in arid agro-ecosystems will definitely exhibit many fold higher quantum compared to male population.

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VIABILITY AND ACCEPTANCE OF SILVIPASTURE SYSTEM IN ARID REGIONS OF RAJASTHAN

V. K. Misra

Introduction

Shortage of fuelwood and fodder exists in many parts of the country specifically in arid regions and rainfed areas. Due to low rainfall cropping intensity in such areas is also low and dependence of people is more on the livestock production such as milk, meat, wool etc. Due to high grazing pressure depletion of vegetation on common as well as private marginal lands continues unabated causing serious soil erosion due to wind and seasonal rains.

In order to meet rural biomass needs more specially of fodder and fuelwood in desertic areas of Rajasthan, The National Tree Growers' Co-operative Federation (NTGCF) has initiated a Tree Growers' Co-operatives Project since 1987 in Ajmer and Jaipur and Dausa district. The project is funded by the Swedish International Development Authority (SIDA).

The aim of the project is to organise Village-level Tree Growers' Co-operative Societies that would take up the task of transforming the village wastelands into a green resource for meeting fodder, fuelwood and biomass needs of the rural community in a sustainable manner. The co-operatives thus organised under the project seek 30-40 hectares of un-cultivable revenue wasteland for regeneration/plantation. Assistance is also provided to the members for plantation of trees and grasses on private marginal lands.

The Village-level Tree Growers' Co-operatives acquire the membership of the National Tree Growers' Co-operative Federation (NTGCF) and are represented on its Board which is the supreme body for taking policy decisions about the organisation. In order to provide requisite support to the project and to review its progress from time to time a State Level Co-ordination Committee (SLCC), chaired by the Agricultural Production Commissioner, has also been constituted The secretaries from the Dept. of Co-operation, Finance, Environment & Forests, Rural Development are members of SLCC and the MD, NTGCF is the member-convenor.

The Federation is also initiating marketing activities at the village, regional and national level for wood and non-wood tree produce. These include sale of fodder and fuelwood at the village level, setting up of small wood processing units at the district level and collection and sale of medicinal plants to the pharmaceutical firms. The project is now being extended to Bhilwara district also where a large number of villages have sufficient area of wastelands and shortages of fuelwood and fodder persist.

SIDA assistance is available for a similar project in Orissa also where agroclimatic and ecological conditions are diagonally opposite to that of Rajasthan. Besides, Canadian International Development Agency (CIDA) is also providing assistance of 20 million Canadian dollars for the implementation of a similar project in AP, Gujarat and Karnataka. Sufficient funds are provided under the project for soil & water conservation work and plantation of trees and grasses on the leased land.

Besides the co-operatives have also initiated installation of smokeless chulhas and biogas plants for conservation of fuelwood and environmental improvement. Energy conservation programme is being funded by the Ministry of Non-conventional Sources of Energy, Govt. of India. The project also provides financial assistance to the Tree Growers' Co-operatives for training and extension programmes. These include training of the members of the managing committee of TGCS in Natural Resource Management, Environmental Education Programme and programme for women in decision making and management of the Tree Growers' Co-operatives.

An Overview of the Project Districts

Significant variations exist in the socio-economic, environmental and edaphic conditions of Ajmer and Jaipur/Dausa district. In Ajmer co-operatives have generally been leased rocky and hilly areas practically devoid of soil cover whereas in Jaipur and Dausa a good number of co-operatives have ravinous land and also desertic areas with shifting sands. The species of trees and grasses which naturally grow in these districts are *Acacia nilotica, Acacia nilotica* var. *cupressiformis, Prosopis cineraria, Parkinsonia acculeata, Tamarix articulata and Prosopis juliflora.* In private cultivable and un-cultivable lands a good number of *Prosopis cineraria* and *Acacia* trees are protected by the farmers for fodder, fuelwood and pods. In sandy areas of Jaipur and Ajmer farmers have planted a large number of *Ailanthus excelsa* trees mainly for fodder. Such plantations have generally come up on the bunds of the cultivated plots and also in small blocks of private wastelands. The leaf fodder from *Ailanthus excelsa* is generally lopped twice a year after the trees have attained 3-4 years of age. It generates significant cash income to the Tree Growers' and has a positive impact on soil conservation. Other species of trees indicated above are also heavily lopped for top feed. So far as grasses are concerned *Lasiurus sindicus* is the main species and which grows naturally in highly sandy areas with scanty low rainfall. *Cenchrus ciliaris* and *Cenchrus setigerus* are naturally growing in semi arid areas with comparatively better moisture status. In the villages where Tree Growers' Co-operatives have been organised, efforts have been made to take up plantation of appropriate species of trees and grasses on the common and private wastelands.

Status of Fodder and Fuelwood

There is persistent shortage of fuelwood and fodder in the project districts except in some irrigated areas of Jaipur and Ajmer. The shortage increase after monsoon season and reaches climax a little before the next monsoon season starts. Harvesting of fodder from Government owned forest and non-forest lands and storage for lean periods is a common feature. Transportation of fodder from somewhat little surplus areas to the areas of acute shortage is also observed. Conservation of crop residues and top feed is also done. Pods of *Acacia nilotica, Prosopis cineraria, Prosopis juliflora* in green or dry form are collected and fed to the animals as protein supplement. Leaves of *Ziziphus nummularia* (Pala) are collected from the wastelands and stored as hay for animal feeding. Fodder remains the main plight of the cattle owners and farmers of Rajasthan.

So far as fuelwood is concerned, scarcity is prevalent in most parts of the project districts. However, dung cakes, shrubs, crop residues and wood of *Prosopis juliflora* and *Acacia nilotica* form major source of fuel in rural Rajasthan. The prices of fodder and fuelwood vary from place to place within Rajasthan but are significantly higher than that of other States which are endowed with better rainfall and vegetation.

Growing rural and urban demand for fuel and timber are the main reasons for deforestation in various parts of Rajasthan where forest cover may not be more than 4-6% of the total geographical area. Due to seasonal migration of human and livestock population in search of water, fuelwood and fodder, it is difficult to organise installation of biogas plants and fuel efficient smokeless *chulhas* (cookstoves). So far as solar cookers are concerned, high cost prohibits its popularisation in the rural areas. As such options for improving energy situation in Rajasthan are fewer with many constraints.

In view of the above the best strategy is to regenerate unproductive grass lands and village commons into a green resource for meeting village biomass needs.

Acceptability of Silvipastoral System

A lot of research work has been done by the scientists on silvipastoral system. Various combinations of trees, shrubs and grasses have been recommended for different agro-climatic conditions. However, in practice scientific silvipasture system does not exist in any part of the country. Fact is that any systematic plantation of trees, shrubs and grasses in a two or three tier system does not suit to the Indian farmer whose land holdings and resources are limited. They prefer to protect naturally growing trees in low density within the cropped area provided species growing therein do not cast shade on the crops underneath or harbour insects/pests. Besides the farmers have serious apprehensions about trees sheltering birds causing damage to the crops. In Rajasthan the menace of white grub which defoliates even Neem and subsequently affects food/cash crops has resulted into farmer's tough attitude against tree plantation even on the farm bunds. Tree plantation is also affected by myths and superstitions. In some areas people do not prefer to have *Acacia nilotica* var. *cupressiformis* due to superstitions. So far as species like *Prosopis cineraria* and *Acacia nilotica* var. *telia* is concerned, farmers prefer to have low density scattered tree population for seasonal lopping of fodder, pods and firewood. Species like *Ailanthus excelsa* are exotic and were introduced in Rajasthan only a few decades ago. It is being planted in small blocks of private wastelands and on the farm bounds mainly for leaf fodder. When the trees are 3-4 years old, the lopping starts and farmers get good remuneration out of it. Older trees are occasionally harvested for timber purposes.

As far as plantation of grasses is concerned pelleted seeds or root slips of improved varieties of *Cenchrus ciliaris* and *Cenchrus setigerus* are being planted on the common land leased to the TGCS. These grasses establish within two years and prove to be a good source of income to the TGCS. Another grass *Sacchrum munja* is being planted on the boundaries of private as well as common land, over gully plugs and check dams for effective soil conservation. In most locations *Acacia* species planted at a spacing of 3 x 4 meters or 4 x 4 meters has been found appropriate for satisfactory growth of grass planted underneath. *Sacchrum munja* is widely used for thatching and rope making and provides good income to the co-operatives in the initial years.

Most co-operatives do not permit grazing in the common land plantation as it uproots tussocks of grasses and hampers biomass production. Generally the grasses are harvested once or twice during and after monsoon and sold to the needy members on headload basis or through auction. However, existence of spiny and coarse grasses naturally growing on TGCS plantation make manual harvesting difficult. Since there is no grazing the term pasture in a plantation of trees and grasses does not fit well. The scientific models on Silvipasture developed and recommended by the Scientists have failed to impress farmers due to above mentioned reasons.

Some Practical Options

In a state like Rajasthan, fuelwood and fodder problem is serious and farmers handle it in a most practical way. They utilise crop residues and natural grasses harvested from common private lands during post monsoon period when green vegetation is fully grazed. During October to June trees are lopped for fodder twice and top feed thus obtained is fed to the animals solely or mixed with dry fodder. Acacia and Prosopis trees planted/protected within the cultivated area in low density and *Ailanthus excelsa*/neem trees planted on the farm bunds are the main source of top feed. Plantation of trees and grasses in a systematic manner as suggested by the Scientists is almost non-existent or confined to surplus wastelands owned by big farmers. Keeping this situation in view some practical options for promoting silvi-fodder plots are described below:

Farm Bund Plantation : Farm Bund plantation of such species of trees and grasses which do not interfere with the cropping system are acceptable to the farmers. More research work is needed to determine compatibility and spacing of various species of trees and grasses with the crops grown by the farmers, frequency and method of lopping. Development of appropriate hand tools for lopping and economics of farm bunds plantation also needs to be looked into for the benefit of the farmers.

Development of Village Pastures : Considerably large areas of extremely degraded and un-productive village grazing lands are available in Rajasthan. In the absence of any institutional structure, paucity of funds, excessive pressure of grazing and improper management, degradation of such lands is un-abated. If people co-operate grazing lands could be converted into excellent silvipastures where various trees, bushes and grasses recommended by the Scientists could be planted and rotational grazing can be followed as is being done by the Tree Growers' Co-operative Societies. Due to the fear of social unrest administration is reluctant to allow any organised productive activity on common grazing lands. However, under the Tree Growers Co-operatives Project limited efforts have been made to lease out a portion of village grazing lands to the Tree Growers' Co-operative Societies for the purpose of fodder and fuelwood production. With the consent of Panchayat and residents of the village The Government of Rajasthan should consider this option for improving fodder and fuelwood situation in the state.

Micro Block Plantations : Small blocks of undulating infertile private lands available with the farmers can be planted with trees and grasses to meet their needs and also for sale to other nearby farmers. In order to establish techno-economic feasibility of silvi-fodder plots on private lands NTGCF has organised demonstration plots ranging from 1/4 to 1/2 an acre owned by the farmers. More research work is needed to develop appropriate combinations of trees, grasses and legumes which could provide green fodder for the extended period. In these plots a mixed flora of *Acacia species*, *Ailanthus excelsa* and improved stains of grasses like *Cenchrus ciliaris* and *C. setigerus* and *Lasiurus sindicus* could be planted for higher biomass production.

Silvi-fodder Plots on Village Commons and Degraded Forest Land

Development of Silvi-fodder plots has been done in more than 100 villages of Ajmer, Jaipur and Dausa where Tree Growers' Co-operatives has been organised. Highly unproductive barren lands have been transformed into silvi-fodder plots by fencing, soil and water conservation practices and systematic plantation of trees and grasses. The main problem in expanding the project activities is lack of updated information on the availability of wastelands, reclassification of such lands which are recorded as cultivable and have degraded with the passage of time and complicated procedures for handing over such lands to the institutions at grass roots. Large areas of degraded forest lands are also available where regeneration activity could be initiated with people's participation. However, inspite of clear-cut guidelines from the Central Government, the forest bureaucracy of the state has been reluctant to negotiate Joint Forest Management programme with the people's institutions. If marching sands of Rajasthan are to be halted, appropriate measures would have to be taken by the Government of Rajasthan to green more and more desertic and unproductive areas with people's participation.

Extension of Tree Growers' Co-operatives Movement

During past seven years more than 100 Tree Growers' Co-operatives have been organised in the above mentioned three districts of Rajasthan who have transformed 1806 hectares of wastelands into an oasis. NTGCF possesses sufficient experience to deal with the administrative, social, technical and manual problems in the development of viable co-operative infrastructure for the management of natural resources. This experience could be used in organising the rural people's institutions not only for regeneration of wastelands in other districts but also for conservation and management of other natural resources such as forests and water bodies. For a state like Rajasthan, Silvi-fodder production system is most appropriate and should be promoted in a well organised manner. Researchers, policy makers and implementors would have to consider practical problems in establishment of silvi-fodder production units on common as well as private land and prove the techno-economic feasibility of the system for its adoption by the farmers of Rajasthan.

NATIONAL TREE GROWERS COOPERATIVE FEDERATION LTD. TREE GROWERS' COOPERATIVES PROJECT

CUMULATIVE PROGRESS AS ON 30. 9. 95						
Particulars\SHTs	Gujarat	Rajasthan	Orissa	A.P.	Karnataka	Total
	Kheda, Godhra, Baroda	Jaipur, Ajmer, Dausa	Ohenkenal Angul	Chittoor, Cuddappah	Kolar	
PROJECT INITIATION	1986	1987	1987	1987	1989	
Tree Grower's co-operative soiceties (TGCS)						
organised	68	95	46	48	48	305
Registered	56	92	38	39	33	258
Functional	64	90	46	42	42	284
MEMBERSHIP						
Male	6075	6234	3728	1671	2754	20462
Female	1288	2408	384	556	349	4985
Total	7363	8642	4112	2227	3103	25447
REV. WASTELAND (RWL)						
Leased (ha.)	1693	2270	93	560	539	5101
Plant. permission (ha.)	0	0	1233	2424	602	4259
Total area available (ha.)	1639	2270	1326	2984	1142	9360
R W L PLANTED (ha.)						
Area planted	1451	1782	618	578	590	5020
Under natural regeneration	21	23	173	172	20	409
Total Green Cover	1472	1806	791	750	610	5429
Trees planted ('000)	2236	1765	1001	1087	888	6978

Trees survived ('000)	1498	1342	801	696	560	4896
Survival %	67	76	80	64	63	69
PRIVATE LAND (ha)	197	718	18	0	168	1101
Trees planted ('000)	530	710	12	35	255	1543
Trees survived ('000)	265	355	9	0	140	769
Survival %	50	50	74	0	55	50
Saplings distributed ('000)	72	273	149	49	14	557
Survival %	59	14	52	56	0	
ENERGY CONSERVATION						
Chullah Installed	2318	2251	340	371	1045	6325
Biogas plant installed	657	4	1	10	13	685
TRAINING PROGRAMME						
SHT personnel trained	2318	2251	340	371	1045	6325
TGCS staff trained	318	312	102	129	212	1073
ORIENTATION PROGRAMME						
Farmers oriented	1574	642	289	1194	989	4688
Women's orientation camps	42	64	47	16	17	186
No. of women oriented	1793	1759	1346	339	518	5755
Environment Edu. Camps	19	11	0	1	0	31
No. of participants	2171	1320	0	16	0	3507

PROCUREMENT ACTIVITIES (Wood & Norwood Produce)

CUMULATIVE PROGRESS REPORT AS ON 30.9.95

Particulars/SHTs	Gujarat	Rajasthan	Orissa	AP	Karnataka	Total
Babul Pods (MT)	1126.5					1126.5
Neem Seeds (MT)	110.3	0.7				111.0
Timer wood (CMT)		15.3				15.3
Fuelwood (MT)	378.1	911.2		12.5	229.5	1531.4
Fodder (MT)	1206.3	34.2	2.6	18.9	12.2	1274.2
Munj grass (Bundles '000)		59.1				59.1
Ker (kg)			65.0			65.0
Leaves for cup/plate making ('000)	400.0		73.4			473.4
Wooden Pallets ('000)			104.4			104.4
Eucalyptus poles (No.)	1523.0					1523.0
Bamboo (No.)	178.0					178.0
Mahua Flower (MT)			56.9			56.9
Tamarind (MT)			1.9	33.0	2.0	36.9

DEMONSTRATION OF TECHNOLOGY FOR FODDER PRODUCTION AT FARMER'S FIELD – A CASE STUDY

M.S. Yadav and S.S. Rathore

Introduction

Agriculture is mostly unstable and gamble due to hostile agroclimatic conditions of arid region. Animal husbandry is therefore one of the main stay of local population of this region. Grazing areas have been considerably shrunk and on the other hand, livestock population has increased by manifold over the last 3-4 decades, resulting in scarcity of forage. The productivity of common grazing lands has decreased due to over grazing and impairment of ecological balance. It is therefore essential to develop the degraded pasture lands, increase the productivity of common grazing lands as well as to motivate individual farmers to bring their lands under pasture production to meet the fodder as well as seed requirement. In view of this, Central Arid Zone Research Institute initiated three projects on degraded pasture land as detailed below.

Projects for Technology Demonstration

Project No. 1. Pilot project on demonstration of technology for fodder production in degraded pasture lands.

Project No. 2. Pilot project on demonstration of technology on saline degraded lands and sand dunes.

Project No. 3. Pasture development and seed multiplication of range grasses and legumes.

Implementing agency was Central Arid Zone Research Institute, Jodhpur, and duration of Project 1 and 2 was 1989-90 to 1993-94; and that of project 3 was 1989-90 to 1994-95

Target Area

Project No. 1 and 2 - Pasture development in saline and degraded lands: 200 ha at farmers fields at Tilwara and Budiwara. Target group was farmers of arid zone of Rajasthan. for Project No. 1 and 2.

Project No. 3 - Pasture development and seed multiplication at CAZRI, C. R. Farm Jodhpur and its Regional Research Stations at, Pali and Bhuj in 50 ha lands..

Problem Identification

- The productivity of degraded land of the western Rajasthan is quite poor, their production potential is 300-400 kg/ha. Due to heavy grazing pressure and erosion of soil, fertility is deteriorating day by day.
- In Western Rajasthan famines are common and arable farming is a risky enterprise. Under such situation grassland husbandry is considered one of the best alternative of arid zone development.
- Animal husbandry is one of the main occupation of the farmers of arid region and pasture grasses are the main source of roughage but are in short supplies and shrinkage in community grazing lands.

- Non-availability of seeds of improved varieties.
- Lack of technical know-how of pasture establishment.

Constraints

- Non-availability of good quality seed.
- The difficult task of establishing pasture on degraded lands requires precision adherence to proper seed rate, depth and method of sowing etc. to overcome problems of germination of light seeds.
- Costly venture to fence the grasslands to protect from a stray cattle and wildlife.
- High seed production costs of grasses being shy seeders.
- Lack of scientific training of grassland management.
- Inadequate availability of farm machinery for field operations and harvesting of grasses.
- Resource poor farmers unable to bear high cost of pasture development.

Objectives of the Projects

- To check further degradation of pasture land through the development of appropriate technology for establishment and sustainable production.
- To develop and demonstrate alternate land use system for sustainable production on degraded lands.
- To develop suitable measures for *in situ* moisture conservation for the establishment of silvi-pasture.
- To study the economic feasibility of the development of pasture lands.
- Rehabilitation of degraded lands through pasture for increasing fodder production.
- To meet the large demand of seeds for pasture development.
- Transfer of technology by organizing training programme.

Technology Package

Selection of Site : Two villages Tilwara and Budiwara were selected. Soils were sandy loam to sandy in texture having pH 8.8, EC (dSm^{-1}) 0.67 and organic carbon 0.16 per cent. Area was devoid of vegetation with average rainfall of 200 mm. Wind velocity is quite high during the period of March to June resulting in serious wind erosion.

Selection of Pasture Species : *Cenchrus ciliaris* var. Marwar Anjan CAZRI-358, *Cenchrus setigerus* var. CAZRI-76. *Lasiurus sindicus* var. CAZRI 319 and *Panicum antidotale* var. CAZRI-347 were chosen for pasture development programme. *L. sindicus* were sown in duny and sandy area. *C. ciliaris/setigerus* pasture were developed in sandy soil. *Cenchrus* spp are widely adapted to agroclimatic conditions from low rainfall to high rainfall areas. *Panicum antidotale* and *Sporobolus marginatus* were grown in saline soils.

Development of Site : For proper protection of area from stray animals and preventing other damage in the area to grass and tree, trench cum mound fencing was done which proved very economic and appreciated by farmers. This kind of fencing was constructed by digging a trench of trapezoidal shape of 5 feet wide at the top, 3 feet wide at the bottom and 3 feet deep. The excavated earth was heaped in a uniform manner on the inner side of the trench also with a trapezoidal cross section of approximate 3 feet width at the top, 5 feet width at the bottom and keeping the edge of mound about one feet away from the edge of the trench. Live fencing with *Acacia tortilis, A. nilotica, Prosopis cineraria* and *P.. juliflora* on bunds of trenches was done at farmers fields.

Land Preparation : Before the establishment of pasture proper cleaning of field and soil working are essential. The soil working should be as thorough as is done for normal agricultural crops. The land should be properly ploughed with disc-culti-harrow and all unwanted vegetation grubbed out and cleaned.

Sowing Method : Two methods of sowing were employed :

Sowing of seed behind cultivator: Seeds of pasture species were mixed with moist sandy soils 3-4 times the volume of seeds and drilled uniformly behind the cultivator in lines 50 cm apart immediately after the first effective showers in 8 to 10 cm furrows at a depth of not more than 1 to 2 cm under the soil.

Pelleted seed sowing: The establishment of *Lasiurus sindicus* and *Dichanthium annulatum* is more assured by transplanting of rooted slips or seedlings compared to direct seedling. However, transplanting is not practicable for pasture development programme on large scale due to scarcity of water in arid region of Rajasthan. In order to have better establishment of *L. sindicus and D. annulatum* pastures on large scales, the seed pelleting is most appropriate. Pellets are prepared by mixing seeds of grass, FYM: clay and sand in proportion (by volume) 1:1:3:1 using sufficient quantity of water for preparing round pellets (of the size of about 0.5 cm diameter). Each pellets containing 2 to 3 spikelets. Pellets are prepared in hot months, dried and stored. Pellets were prepared by pellet making machine. It is a simple rotary tyre device designed by Dr. M. S. Yadav at CAZRI, costing Rs. 3000/-. The pellets were placed in lines 50 cm apart or broadcasted. Sowing operations were carried out before the first effective rainfall of monsoon.

Seed rate: For optimum establishment of pastures *Panicum antidotale* seeds are sown @ 2.5 kg/ha and *Cenchrus ciliaris* and *C. setigerus* @ 5 kg/ha each whereas comparatively higher seed rate i.e. 7.5 kg/ha is recommended for *Lasiurus sindicus*. Seed rate is reduced to one-third in case of pelleting as compared to direct seed sowing.

Fertilizer application : Super phosphate @ 40 kg/h were applied as basal dose at the time of land preparation 40 kg N/ha per year was applied in two split doses before flowering.

Moisture conservation : A tractor drawn pitting discer has been designed and developed which is capable of creating 60,000 micro- pits per hectare and would impound additional water to the tune of 8 mm/ha, besides this interculture operations were done between furrows of grass once or twice in rainy season which helped in moisture conservation(Paroda et al 1980 and Das *et al.* 1977).

Weeding: Removal of weeds from the field between the rows of the sown grasses in the first year of sowing ensures better establishment of the pasture and its production.

Raising Shelterbelt : Shelterbelt is a barrier of trees intended for the conservation of soil and moisture and for the protection of forage. Shelter belt was created by seeding with tree species in two rows, namely, *Acacia tortilis, A. nilotica, A. senegal* and *Prosopis cineraria* around 15 ha area to create live shelter belt along the field boundaries.

Silvi-pastoral System : Emphasis was given on indigenous trees/shrubs species plantation in silvi-pastoral system. Species like *Prosopis cineraria P. juliflora, Acacia tortilis, A. senegal and Tecomella undulata* with the management of tree canopy, proper spacing between rows and plants of woody species were used. The productivity of top feed and fuelwood in silvi- pasture system was three to four times higher over pure pasture. The system is useful in nitrogen build up in the soil. In addition, fodder trees and shrubs will ameliorate the micro-climatic conditions. Many of the tree species are economically important for fuel and timber. With a view to develop silvipastoral system, 30 cm high ridge were created by disc plough at 12 to 15 M distance across the slope before grass seeding. Tree seeding was done on the ridges. The system also prevent the runoff from the field.

Horti-pastoral System : *Ziziphus mauritiana* and *Cenchrus ciliaris* were used for horti-pastoral system. *Z. mauritiana* was planted one year ahead at the spacing of 6 x 6 m^2, for its better establishment. Cenchrus ciliaris were planted between two rows of *Z. mauritiana*. Yield data on grasses and ber was recorded for three years at C.R. Farm Jodhpur (Table 1). The data in Table 1 clearly shows the additional advantage, the farmers can get from grass fodder and seeds.

Table 1. Yield of grasses and grass seed

Year	Grass hay yield (q/ha)	Seed yield (kg/ha)
1993	4.69	10
1994	12.09	30
1995	32.90	25

Horti-pastoral blocks were developed at Tilwara in farmers field in 5 ha. Survival and growth of ber plant were poor due to lac of irrigation facilities, high temperature and drought conditions.

Pasture Utilization : Pastures were utilized in two different ways. Harvesting, preserving for feeding to the livestock, and grazing. This system was followed in seed multiplication project, whereas in the project based at farmers fields it was harvested in the year of establishment, in the second year grazing was introduced, in the third year again pasture was harvested and presented for feeding to the livestock. In the fourth year controlled grazing was introduced as per the carrying capacity of the pasture. Data revealed that *Cenchrus ciliaris, C. setigerus* and *Lasiurus sindicus* provided 35, 20 and 40 q/ha dry matter yield averaged over two years under cut and carry system. On grazing of medium pasture of *C. ciliaris* carrying capacity ranged from 25 to 35 cattle per year per 100 hectare.

Budget : The budget of Project No. 1, 2 and 3 during 1990-91 to 1993-94 is as below :-

Project No 1. and 2	
Receipt	Rs. 13,12,000
Expenditure	Rs. 4,04,278
Balance	Rs. 9,07,278
Project No. 3	
Receipt	Rs. 12,66,571
Expenditure	Rs. 11,29,708
Balance	Rs. 1,36,863

Monitoring Details

Every year pasture plots were inspected by the seed monitoring team comprising coordinator NAEB, IGFRI, Jhansi and representatives of National Seed Corporation and Rajasthan state seed certification agency. Seed certification was done by the team. Seed production figures were sent to Coordinator, NAEB, IGFRI, Jhansi. Seed, thus produced in the project was supplied to users. *Cenchrus ciliaris* variety CAZRI 358 was found comparatively better for seed production besides giving high fodder yield under drought conditions. Detail observations on isolation distances, percentage of off-type plants, infestation of disease and insect pests, genetic purity and crop stand, crop performance for fodder and seed yield were recorded every year.

Progress of Work

Detail of work and yearwise progress on different projects is given in Table 2. Under project on Pasture establishment and seed multiplication a pasture of *C. ciliaris* and *C. setigerus* was established in 30 ha at C.R. Farm, Jodhpur, 10 ha at RRS, Bikaner, 5 ha at RRS, Bhuj and 5 ha at RRS, Pali. On an average 20 q. seeds of pasture grasses and legume were produced and supplied to 63 agencies per year (Table-3).

Farmers Fair : Farmers fair was organized at Tilwara on 21st Oct. 1991. Technologies of pasture development were demonstrated in the fair.

Training Programme: As per the objectives of the project training course on Range grasses and legumes for Wastelands : establishment and seed production was organized from 17th to 22nd April,1995 at RRS, Bikaner. Twenty one participants from different state departments, like Sheep and Wool, Soil Conservation, KVK's Agricultural department, NGO's attended the course. On the completion of training they prepared a plan of pasture development for degraded lands of western Rajasthan.

Table 2: year wise progress of projects at Tilwara and Bundiwara in Barmer district

Technology	1990-91	19991-92	1992-93
PROJECT 1			
Location - Tilwara			
1. Establishment of *C. ciliaris* pasture	45 ha area	35 ha	25 ha
2. Establishment of silvipastoral block	3 ha	20 ha	20 ha
3. Establishment of budded ber block	10 ha	-	-
4. Trench cum mound fencing	Prepared in 5500 metre length	Completed in 8000 metre length	-
5. Live fencing	650 running metre along project boundary	-	-
6. Shelter belt	650 running metres along project boundary	15 ha area along field boundary	-
7. Tree plantation of *P. cineraria P. juliflora, A. tortilis, A. senegal*	10,000 plants along field boundary	Observe 75% survival	70% survival
8. Establishment of improved strain of *C. ciliaris* and *C. setigerus*	-	5 ha area	Maintained pasture
9. Studies on effect of jalshakti	-	-	*Jalshakti* – 5 to 20% mixed with grass seed and studied in 6 ha
10. Studies on method of sowing	-	-	3 ha by pelleting
11. Fertilizer trial	-	-	Conducted by different doses of fertilizers. Soil working found optimum for maximum forage and seed production
PROJECT 2			
Location - Budiwara			
1. Establishment of budded ber block (with high RSC water)	5 hac area	-	-
2. Establishment of plant on duny land	Over 5000 plants of *P. juliflora* and *A. tortilis*	80 % survival	Observed 70% survival. In addition to this plants were established on dunes in 10 ha at Bithuja village
3. Reclamation of saline soil	Surveyed the area and prepared plan	Reclaimed salt affected land in 50 ha by gypsum application.	*Rabi* and *kharif* crops were taken successfully in reclaimed soil with gypsum
4. Hortipastoral programme	-	10 ha area	

Table 3. Breeder seed production of desert grasses

Year	Seed yield (q)	Revenue realized (Rs.)	No. of agencies served
1989-90	9.00	-	52
1990-91	15.20	14,078	91
1991-92	22.62	77,176	65
1992-93	16.84	53,663	72
1993-94	27.21	164,098	59
1994-95	15.30	87,726	47

Benefits Obtained

Technical

- Awareness about the improved quality of seeds.
- Training programme was organized for the benefit of technical persons engaged in pasture development and seed production of range grasses and legumes.
- Infrastructural development - Man power, farm- machinery and seed store have been created. The Centre is now in a position to produce good quality seed and to meet its demand for further multiplication of seed.
- Gathering of working knowledge and skill in the operation of large seed production programme in range grasses and legumes.

Ecological

In 200 ha degraded lands pastures have been established and they are performing well. In Rajasthan this technology is strongly needed and being adopted by farmers. Besides this seed was distributed to about 63 agencies every year. They have established the pastures in the degraded lands of Rajasthan as well as other part of the country. The project was beneficial for improvement of environment.

Future Strategy

- There is need to strengthen research on developing drought hardy, high yielding nutritious and aggressive varieties of pasture grasses for different habitat of degraded lands.
- To increase the availability of good quality seed, seed production net work has to be built up at national level.
- To maintain the productivity of pasture for longer period, grazing should be allowed as per the carrying capacity.
- More emphasis should be given to silvipasture system rather than development of pure pasture.
- To make Pasture development programme successful, there should be involvement of farmers by forming cooperative societies at village level.

There is need to create awareness among farmers by putting demonstration at farmers' field and organizing training at village level.

References

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