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RESTORATIVE FORESTRY AND AGROFORESTRY IN HOT ARID REGION OF INDIA: A REVIEW

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ABSTRACT : Arid zones cover about 19% of the entire land surface of the world. Although contribution of arid zone in the world economy is negligible, yet its effect on the environment of the world, e.g., desertification, pollution, water use and global warming is very well recognized. To combat desertification, and related issues, management of restorative forestry and agroforestry with special reference to Indian arid zone is discussed in this paper. Trees have great role in conserving arid ecosystems, and provide several services to mankind, which makes them an intricate part of man-livestock- tree agriculture continuum, therefore, selection of species, their plantation and management in various land forms of arid zone can be a undisputed option to restore the arid lands, prone to desertification. Issues of agroforestry, selection of species, their plantation and management on various landforms of arid zone namely dunes and hummocky terrain, sandy plains, shallow soils areas and rocky gravelly terrain and salt affected soils, are also discussed. Besides pastures and silivipasture are equally important in rehabilitation of degraded lands of hyper arid as well as salt affected runs of Gujrat.

Key words: *agroforestry, arid, arid landforms, forestry, restorative forestry and agroforestry, desertification control, planting technique, Thar, trees.*

INTRODUCTION

Conservative estimates reveal that arid zones and their advances effects around 600 million people directly or indirectly world over (Tewari and Harsh, 1998). Desertification encompassing different land degradation processes represent a struggle of survival between man and land. GLASSOD database indicates that 349.6 million ha of land in arid zone is affected by light to moderate degree and 42.9 million ha by strong to extreme degree of land degradation. Over exploitation of land, water and vegetation resources due to increased population of human as well as livestock are as the prime contributors to accentuate land degradation. Arid zones cover 18.8 per cent area world over where Africa, accounts for 46.1 per cent, followed by Asia (35.5%) (UNEP, 1997). About 19.4 per cent of arid zones are spread over in Australia, North America (Mexico and Southern part of USA) and South America where Europe has only < 0.5 per cent arid zone.

The arid zones of USA, middle east, central Asia and Australia meet out their domestic energy need through petroleum products and natural gas, whereas woody vegetation are the main sources of fuel, fodder, small timber and fencing material in Indian arid regions (Tewari et. el., 1998). Forest trees and perennial vegetation have definite and positive role to play in controlling desertification (Baumer and Ben Satem 1985). It is heartening to note that tree cover in arid region of India registered an increase of 16% from 1984-85 to 1993-94 (Anonymous, 1987, 1994), perhaps

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positive indicators of successful restorative forestry and agroforestry efforts being carried out in different landforms of Indian arid tropics.

ABOUT THE INDIAN ARID TROPICS

The arid tropics or hot arid regions of India lies between 24°-29° N latitude and 70°-76° longitude covering an area 3170 million ha in the states, Rajasthan, Gujrat, Punjab, Haryana, Andhra Pradesh, Karanataka and Maharastra (Table 1). The arid regions of Rajasthan, Gujrat, Punjab and Haryana together constitute great Indian desert, better known as *Thar. Thus, Thar* accounts for nearly 90 per cent of total hot arid region of India (Tewari *et. al.,* 1999) and represents typical arid to hyper arid environment, where as arid areas of Andhra Pradesh, Karnataka and Maharastra located in peninsular India and have relatively better climatic regime as compared to *Thar.*

Physiography

Thar is spread over in twelve districts of western Rajasthan, Kutchh and Saurashtra region of Gujrat, and western parts of Haryana and Punjab states. Major part of it occurs between Aravalli ranges on the east and south-east and *Thal* desert of Pakistan (*Thal* desert is the western extension of *Thar*, with changed name) which is spread upto Sulaiman-Kirthar ranges in extreme west. Thar extends for 640 km from north-west to south-east with an average width of 300 km from east to west. The desert in the east of Jaisalmer, form a elevated plateau, 150-325 m above mean sea level with numerous out crops of rock emerging out of the desert. North, east and south of Kutchh region in Gujrat is surrounded by level marshy land called Rann of Kutchh, separating it from the main land. The arid areas of peninsular India are mostly sandy plains with small rocky-gravelly hilly terrain. Five major land forms viz., (1) sand dunes and sheet deposit, (2) dune free area, sandy plains, (3) shallow soil areas, (4) rocky-gravelly terrain and (5) saline runs and brackish water areas are recognized (Sharma and Tewari, 2004).

Climate and Soils

The entire stretch from the Sahara to Thar appears to be meteorologically homogenous. The production and life support system in this part of hot Indian arid zone are constrained by climatic limitations such as, low annual precipitation (100-300 mm/year); very high summer temperatures touching a maximum of 48° to 50°C and short cool and dry winters; high wind speed (30-40 km/hr); high evapo-transpiration; and low humidity (aridity index 0.045 - 0.19). Frosts are common in winter season in hyper arid areas (4 to 7 days in a season) and often in other parts (1 to 3 days in a season). Peninsular Indian, arid regions receive 400 and 500 mm rainfall; 38°C mean maximum summer temperature; mild winter temperatures of 15-19°C. Arid areas of Andhra Pradesh, Karmataka and Maharastra have relatively high humidity. On an average, three droughts in a decade are common in hot arid zone of India, but human and livestock population worst affected when droughts occur successively for two to three years.

Sand dunes are dominant land forms covering more than 64 per cent area. In general, soils contain 1.8-4.5% clay, 0.4-1.3% silt, 63.7-87.3% fine sand and41.3-30.3% coarse sand. These are poor in organic matter (0.04-0.12%) low in nitrogen (0.20-0.07%) and low to medium in phosphorus (0.05 - 0.10%) with 7 to 15 cm/hr infiltration ratio. Soils are highly erodible. In Kutchh area, the soils are moderate to highly saline in nature. In IGNP (formerly RaJasthan canal) command areas, and in many other parts there is also problem of water logging of soil and moderate to highly salinity. The red

soils, common in the arid areas of peninsular India, are derived from granite, which are highly variable in depth and exhibit a well developed profile character. The percentage of clay increases markedly from the tops soil to sub-surface soil. Often murrum layer, which is gravelly disintegrated rock is found beneath the red soils.

The Population and Livelihood Resources

The population of Thar desert registered an increase of 490 per cent from 1901 to 1991 touching 22.0 millions now with a population density of more than 100 people per km^2 , which is much higher as compared to 6-8 persons/km other arid zones of world. The population of arid zones of Andhra Pradesh, Karnataka and Maharashtra is about 2 million. In spite of erratic and unevenly distributed rainfall, agricultural is the mainstay of arid region with livestock based mixed farming system having the average land holding of 4 to 6 ha. The number of livestock in Thar is estimated to be 30.0 million in year 2000, which includes cattle, sheep, goats, camels and buffaloes. On an average, a household has 2.28 cows, 0.62 buffaloes, 6.48 sheep, 6.50 goats and 0.49 camel with young stocks. Other sources of livelihood are occupations like carpentry, black smithy, oil pressing, pottery making, tanning, leather work, dyeing, gold smithy, etc.

Vegetation

Hot Indian arid regions has a wealth of 682 species belonging to 352 genera and 87 families of flowering plants (Bhandari 1978; Kumar, 1998) of these 9 families, 37 genera and 63 species are introduced, the majority of these species are woody ones. Phytogeographically, 37% of the plant species represent African element, 20.0% oriental element, 14% species being tropical, 10.3% cosmopoliton, and 9.3% Australian. Nearly 9.4% species are endemic to the Indian hot arid regions.

Classified broadly under "Tropical Thorn Forest" (Champion and Seth, 1968), the vegetation of hot Indian arid zone has been categorized into six major formations by Satyanarayan (1964) viz., mixed xeromorphic thorn forest, mixed xeromorphic woodlands, mixed xeromorphic riverine thorn forest, lithophytic scrub desert, psammophytic scrub desert and halophytic scrub desert.

TREES FOR LIVE SUPPORT: A UNIQUE FEATURE

A typical image of a desert without vegetation long stratches of sand and inaccessible terrain is not the characteristic of Indian *Thar,* excepting few areas in extreme western fringes. Sparsely distributed trees with underneath growth of arable crops (especially during *kharif* season) and/or grasses and other herbaceous flora in long stretches interspersed with distantly distributed settlements and *"Dhansi"* (a small settlement pattern of *Thar,* away from the village but near by their crop fields) are real features of the region (Tewari *et. al.,* 1999). In fact, Thar is one of the most vegetated desert with rich bio-diversity of about 682 species, out of which 131 are known for their economic uses.

Farmers in hot Indian arid regions raise crops and animals in association with tree since ages, an unique form of combined protective-productive farming called "Agroforestry", which are based on sound principles of ecology, productivity and sustainability. Most of trees are drought resistant, yet able to provide multiple production like, fuel, fodder, fruits, etc., when the crops fail due to frequent droughts in the region. Besides livelihood, trees also provide services of climate moderation under inhospitable

environment. These extensive agroforestry system of hot arid regions of India are living systems, evolved through interaction of environmental, biological, social, economic and cultural factors, and have adapted to specific site and climates by intimate coexistence of plants, animals and human beings, functioning integral elements of these systems. Agri-silvicultural, silvi-pastoral, horti-pastoral and agri-silivi-pastoral systems are most common forms of agroforestry systems of hot arid regions of the country (Tewari et al., 1999). Woody components (i.e., trees or shrubs) in these agroforestry systems supply considerable amount of subsidy for sustainable operation of specific system in form of fuel wood, fodder, minor timber, fruits and many other edibles. The pattern of integration of native woody species with arable crops/ grasses are given in Table 2. Over exploitation of already sparse woody vegetation in hot arid regions is largely the outcome of continuing pressure of ever-increasing human and livestock population, which is threatening of sustainability of these time tested systems.

CONCEPT OF FORESTRY IN INDIAN HOT ARID REGIONS

In general, native tree species of hot Indian arid regions are very few and are slow growing, with weak natural regeneration of trees due to inhospitable climate (Tewari et al., 1993). Realizing importance of plantation forestry for arid regions, R & D efforts began soon after independence in the frontiers of arid zone forestry and agroforestry in India. Introduction of fast growing species from iso-climatic regions of the world was given priority and more than 200 tree species were screened and identified for this purpose (Tewari and Harsh, 1998).

In fact, forestry in arid region involves management of trees for conservation, improve environment and for limited production purpose like wood for fuel, poles and fencing material; leaves for livestock fodder; and pod/seeds for many a times for the use in human diet. The role of trees to conserve the fragile ecosystems of hot arid regions has been well recognized (Mann and Muthana, 1984). The trees also provided so many services to mankind, which make them an intricate part of man-livestock-agriculture continuum, the lifeline of hot arid regions (Saxena, 1997).

CHOICE OF SPECIES, THEIR PLANTATION AND MANAGEMENT IN ARID LANDFORMS

Each of these five described landforms has unique features and problems in arid environment therefore, native plant communities on these landforms are found in severe stages of degradation (Kaul and Gangul, 1964). Due to very slow growth of native plant species, it was throught necessary to introduce the species of relatively higher growth rate, which are also tolerant to drought, frost and salinity (Tewari, 1997). Efforts in this direction were initiated in early 1960s (Bhimaya *et.al.,* 1964; Kaushik et al., 1969; Mann and Muthana, 1984) and continued (Tewari *et.al.,* 1989; Tewari and Harsh, 1998). Till date over 500 accessions of 200 tree species from iso-climatic regions of the world have been evaluated through long term screening trials to asses their adaptability and growth performance on different landforms.

Sand Dunes

More than 64 per cent of the area hot arid regions is covered by drifting or semi-stabilized sand dunes, sometime upto 100 m in height. Singh (1977) has identified seven types of Sand dunes on the basis of their shape. There are parabolic, coalesced parabolic, longitudinal, transverse, burchan, obstacles and shrub

coppice. Some of them are highly active and menace to inhabitants and infrastructure. Some of the dunes are semi-stabilized but their crests and flanks remain active because of cultivation on them and mismanagement. CAZRI, Jodhpur has successfully developed the technological package for their stabilization (Harsh and Tewari, 1993); which includes:

- Protection against biotic interference.
- Treating the affected dunes by eracting micro-wind breaks opposite to the wind direction in parallel strips or checker board
- Plantation of appropriate species on treated dunes.

Important features of tree species that perform well on sand dunes (Table 3) are drought resistant at seedling and maturity. By adopting CAZRI developed technology, forest department ofRajasthan have been stabilized more than 400,000 ha of sand dunes in arid western Rajasthan, the many a times *Cenchrus ciliaris, C. setigerous* and *Lasiurus sindicus* grasses are introduced on spaces between the tree species after 2 or 3 years of initial field out - planting of tree seedlings. This provides vegetation cover on blank spaces, which further helps in better stabilization of active surface of sand dunes and also provide fodder for livestock.

Sandy Plains

Sandy plains are characterized by deep sandy soils with varying depth (70-150 cm), below which a Kankar pan is some times found. These are spread over in entire hot arid regions and cover more than 30 per cent of land area. Majority of agricultural activities in hot arid regions are practised on this landform. For planting out tree seedlings 50 x 50 x 50 cm pit is excavated and a saucer shape basin of one meter diameter around the pit is made so that more rain water could be available to growing seedlings.

This type of landform occur throughout the hot arid zone in rainfall gradient of 150 mm to 350 mm. Suitable species for such landform must have good drought tolerance ability during first two to three years growth (Table 4). Some of these species are being used successfully in intensive agroforestry systems of hot arid regions (Hocking, 1993).

Shallow Soil Areas

Such sites are generally found in eastern and south-eastern part of arid western Rajasthan and Kutchh area. These soils have 30-45 cm depth followed by a layer a calcarious nodules and/or 'Kankar pan'. In such sites, planting is done in 60 x 60 x 60 cm pits by breaking hard pan using crowbar to facilitate root growth and avoid root coiling due to presence of had pan.

These shallow soil areas are also found in many pockets of Gujart, Punjab and Haryana. Recommended tree species for shallow soil areas are limited. MPTs which are found to grow satisfactory are as under:

Category (< 250 mm rainfall zone)	Category II (> 250 mm rainfall zone)
Acacia salicina (I)	*Azadrachta indica (N)*
Hardwickia binata (O)	*Dichrostachys nutans (I)*
Prosopis juliflora (I)	*Hardwickia binata (O)*
Prosopis alba (I)	*Prosopis juliflora (I)*
Grewia tenax (N)	*Acacia nilotica (N)*

Ziziphus nummularia (N)	*Acacia senegal* (N)
Cordia rothii (I)	*Ziziphus mauritiana* (I)
Capparis decidna (N)	*Holoptelia intagrifolia* (O)
Acacia jequemontii (N)	*Eucalyptus conaldnlemis* (I)
A. leucophloea (N)	*Pongamina pinnata* (N)

N = Native; I = Introduced from isoclimatic regions; O = Introduced from other drier regions

Rocky-Gravelly Terrain

Such areas are scattered in pockets through out the hot arid regions with exception in the east of Jaisalmer, where a large tract of lowly elevated plateau 150-325 m above mean sea level exists with numerous rocky masses cropping out of the desert sand. Such areas consist of bares rock out crops, which form small hills, however at the foot hills, shallow soils have finer particles integrated with rock fragments. Staggered counter trenches with a cross-section of 60 x 40 cm to minimize water erosion are recommended for such sites. Pits of 60 x 60 x 60 cm re-filled with good soil brought from other sites with 5 kg FYM are used to out planting the seedlings of desired species. Choice of tree species is very limited for rocky-gravelly sites. *Acacia Senegal, Prosopis juliflora, P. chilensis* and *Wrightia tinctoria* perform better on such sites, however, species like *Ziziphus nummularia, Capparis deciauas* and *Grewia tenax* could also be planted successfully.

Salt Affected Soils

About 3.0 million ha area in hot arid regions of India is affected by salinity and brakish water problems. In such areas, upper layers of soils often contain silt and clay. These lands are recognized by the presence of a white or greyshwhite efflorescence of salts on the surface during summer and may be categorized as saline or alkali soils depending upon salt constituents (Yadav and Singh, 2000).

Alkali soils contain carbonates and bi-carbonates of sodium with more than 1.5% exchangeable sodium percentage (ESP). The high pH may be 8.5-10.5 through out soil profile and calcarious layer 'Kankar pan' is generally confronted at about 75 cm to 1.0 m depth. Poor water transmission which lead to water stagnation and reduce aeration inhibit tree growth in alkali soils. On the contrary saline soils contain excess neutral soluble salts of chlorides and sulphates of sodium, calcium and magnesium. Such soils have low ESP and pH, and good physical condition but plants are affected due to high osmotic pressure and toxic effects of specific ions. The promising multipurpose tree species (MPTs) for salty lands are as under:

Alkali soils	Saline soils	Bio-drainage species
Prosopis juliflora (I)	*Prosopis juliflora* (I)	*Eucalyptus camaldulensis* (I)
P. alba (I)	*Prosopis chilensis* (I)	*E. teriticornis* (I)
Terminalic arjuna (N)	*Azadirachta indica* (N)	*Acacia auriculiformis* (I)
Dalbergia sissoo (N)	*Pitheclobium dulce* (I)	*Syzigium cumini* (N)
Pongamia pinnata (N)	*Acacia nilotica* (N)	*Albizia lebbek* (N)

Acacia nilotica (I)	*Acacia torlilis* (I)	*Dalbergia sissoo* (N)
=	*Salvador a per sica* (N)	=
=	*Tamarix specie* (N)	=

N = Native; I = Introduced from iso-climatic regions

PLANTATION TECHNIQUES FOR ALKALI SOILS: A CASE STUDY

Planting technique for alkali soil involves digging pits of 30 cm diameter and 100-140 cm depth with the help of tractor mounted post-hold anger (Singh 1998). The pits are refilled with a mixture of 3 kg gypsum and 8 kg FYM before planting out 5 months old seedlings of selected species. A dose of 5 g zinc sulphate and 10 g BHC powder are also mixed in the filling mixture. Four irrigations are given after planting out the seedlings at weekly intervals during first month. By this technique > 80 per cent survival of out-planted species is obtained in highly alkaline soils, where nothing else, could be produced. The growth and biomass production of tested species at the stage of 28 months (Table 5 & 6) of growth in the highly alkaline soil were in order of: *Prosopis juliflora* > *Acacia nilotica* > *P. alba* > *Terminalia arjuna* > *Pongamia pinnata* > *Dalberhia sissoo*. If soil pH is more than 9.7, the choice of species become limited to *P. juliflora, A. nilotica* and *P. alba.*

Comparative growth performance of 10 years old *P. juliflora* and *A. nilotica* plantation in highly alkaline soil reveal that both the species perform well in such soils (Table 6), However, over all survival was better in case of P. juliflora. The amount of amendment used is determined by volume of soil extracted from the augerhole and the chemical status of the soil. Gypsum, FYM, molasses, sulphuric acid and even rice husk have been mixed with alkali soil before re-filling the pits after outplanting the tree seedlings. When P. juliflora is used as test species, the best growth was obtained when 3 kg of gypsum and 8 kg of FYM per pit were used.

EFFICIENT AGROFORESTRY MODEL TO RECLAIM ALKALI SOILS

A silvi-pastoral model comprising P. juliflora with Leptachloa fusca grass has been developed by Central Soil Salinity Research Institute (CSRI), Carnal, for reclaiming alkali soils (Table 7). *P. juliflora* and *Leptachloa fusca* are grown for about five years without fertilizers and soil amendments. The maximum Leptochloa grass yield was obtained in 4 x 4 m spacing. Maximum fuelwood is also obtained under same spacing.

Spacing (m)	Biomass			
	Lopped (t/ha)	Harvested(t/ha)	Total (t/ha)	Leptachloa grass (t/ha)
2x2	49.1	112.2	161.3	55.6
3x3	31.6	55.2	86.8	68.7
4x4	25.0	36.1	61.1	80.9

This silvi-pastoral system improved the soil to such an extent (Table 7) that it was possible to plough under the *Leptochloa* grass after 4/2 years and grow less tolerant, but more palatable fodder like *Trifolium resupinatum, Trifolium alexandrium* and *Melilotus parviflora.*

PLANTATION TECHNIQUE FOR SALINE SOILS

In such lands, planting is done on the raised bunds. The width of bunds is 1 m at the base and 75 cm at the top. If the terrain is flat at the planting site, the site is ploughed two three times using a tractor and then bunds are constructed. Forty five cm pits are dug out at the top of bunds in centre, 4 kg of FYM is mixed in excavated soil for each pit before back-filling. If the salinity level is quite high the quantity of FYM is often doubled. Many a times good soil is brought from nearby areas for back-filling the pit for out planting the seedlings. If the better quality water is available, the plantations are irrigated as and when possible, at least for first three years, which is highly beneficial. *P. juliflora* and *P. chilensis* can be raised in the soils having electrical conductivity as high as 15 dS/m. *Salvadora persica* and *Tamarix* species can be raised even in soils having electrical conductivity > 15 dS/m but, *Azadirachta indica* perform well in the soils having electrical conductivity < 10 dS/m.

SUSTAINABLE FORESTRY AND AGROFORESTRY IN ARID REGIONS:

Most of the land in arid regions of India has been under cultivation since last three decades regardless of its marginality. In many cases the farmer can hardly get back his seed from the field he cultivates. Irrational utilization of resources under unbalanced man/resource ratio on the one hand and their fragile natural on the other, have given rise to a deterioration of resources and environment. Therefore protective - productive system integrated trees, grasses and crops are required to be adopted. Sand dune stabilization around cultivated plains and silivipastoral system on village community lands, with proper management practices are the examples of combined protective-productivity system. Such systems become much more important in critical areas, where these act as buffer strips to protect fringes of good lands from encroachment (Eren, 1995). Farm boundary plantation of MPTs, plantation along roads, railway lines and canal, home gardens are some of the examples of indirectly integrated systems. Integrated land use system with direct and indirect systems could be remedy to reverse the ruthless exploitation of woody biomass in one hand, which will be helpful in restoring the much required tree cover on the other.

The restorative forestry and agroforestry can not be considered as the user of "residual land" in arid land situation of western Rajasthan, where even more than 70% of sand dunes are owned by farmers. Land tenure giving security to land owners would encourage long term investment by the farmers (Faroda, 1997). For sustainable growth of forestry sector the national and provincial rules of tree tenure, and their relationship with land tenure is critical. In any kind of plantation forestry programme, component of tree tenure (i.e., right to own or inherit the trees, the right to use and dispose trees and their products), if included and followed in true spirit in larger interest of rural manses, the tree cover could be improved substantially under inhospitable environmental condition of hot arid regions. Moreover, traditional agroforestry practised in entire arid western Rajasthan and other north-western parts of country must be recognized as agroforest landuse. Till date such agroforests are classified as agriculture land use in revenue records. This will give a new dimension to recognize trees on agricultural fields hot in arid eco- systems of in regions of the country.

EPILOGUE

The hot arid regions of India in economically and environmentally

disadvantaged part of the country with unique problems. These, ecosystems are highly fragile and large liabilities causing severe impediments in development programmes. Despite of hostile climatic and edaphic conditions, Indian hot arid zone are fairly well vegetated and tree species diversity perhaps much higher in comparison of hot arid zones of other parts of world. More over, the tree species which have been introduced successfully in hot arid regions of the country from iso-climatic region of the world or from other drier parts were evaluated on the basis of information available on climatic homologues, potential ' inherent elasticity and genetic variability could be very useful for plantation programmes. In this part of the country, rural folk need tree produce daily, however, in the economic balance of tree use, the cost of tree products is closely related to their availability.

In hot arid regions, trees are instruments with ecological investment strategy. Matter and energy are immobilized in long-lived woody structures and this accumulated production is harvested at longer intervals. The majority of tree species which are found in hot Indian arid zones, are multipurpose and have ability to satisfy the expectations of rural folk regardless in the production of their needs of fuel, fodder, timber, food (fruits/pods/seeds) and other tree products like, gum and medicines, etc. Plantation forestry in different arid land forms thus assumes much significance for desertification control and ecosystem services.

Though, combined productive- protective agroforestry systems are not a well defined part of land use system, however, in true sense entire hot arid zone represents the vegetation complex in the form of agroforestry. The tree components play a vital role in both productivity, sustainability and livelihoods. Environmentally beneficial trees have ability to utilize incoming solar radiation through out the year; the capacity to enrich microsites by recycling litter to the topsoil, which can then be utilized by shallow rooted species; and a capacity to modify the microclimate, which can bring about favourable effect on the soil, and associated plant and animals species.

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Table 1. *Distribution of arid regions in different states of India.*

State (s)	Area (Million hectares)	Percent of Total
Rajasthan	19.61	61.0
Gujrat	6.22	19.6
Punjab & Haryana	2.73	9.0
Andhra Pradash	2.15	7.0
Karnataka	0.86	3.0
Maharastra	0.13	0.4
Total	**31.70**	**11.8% of India**

Table 2. *Woody component and associated crop/grass species in extensive agroforestry systems of the hot Indian arid zone*

Habitats	Annual Rainfall (mm)	Tree/Shrub species association	Associated of crops/grass
Sand dunes, interdunes	110-150	*Calligonum-Haloxylon-Leptadenia*	Pearl millet, Clusterbean, Lasiurus sindicas
Rocy, gravelly padiments	150-200	*Ziziphus-Capparis*	Pearl millet, Green gram, Moth bean, Clusterbean/ *Cymbopogon jwarancousa, Aristida sp., Cenchrus ciliaris*
Sand, gravelly pediments	200-250	*Calolropis-Calligonum-Clerodendrum*	Pearl millet, Green gram, Moth bean. Sesame, *Cenchrus ciliaris*
Alluvial plains, soils, often-with "K-ankar pans" at 80-150 cm soil depth	250-300	*Prosopis-Zizphus-Capparis*	Pearl millet, Clusterbean, Green gram, Moth bean, Sesame, *Cenchrus ciliaris* with *C. setigerus*
Alluvial plains but soils are moderately saline	250-300	*Salvandora-Prospis-Capparis*	Clusterbean, Pearl millet. Sesame Capparis and Wheat (irrigated areas) with *Cenchrus setigerus, Sprobolus sp.*
Sandy plains (rainfed)	275-325	*Prosopis-Tecomella*	Pearl millet, Clusterbean, Green gram, Moth besm/Cenchrus ciliaris with *C. setigerus*
Alluvial plains (rainfed)	300-350	*Prosopis*	Pearl millet, Clusterbean, Green gram, Moth beai *Cenchrus ciliaris*
Alluvial plains (irrigated)	300-350	*Prosopis-Acacia*	Sorghum, Cumin, Pearl millet, Mustard, Wheat

Table 3. *Tree species for sand dune stabilization and their growth rate and utility*

Species	Origin*	Growth Rate		Utilization Age (yrs)	Uses(S)**
		Early	Late		
Acacia iortilis	I	7	10	8-35	F(7), Fd(4), T(5), G(4)
A.Senegal	N	3	6	5-20	F(3), Fd(5), Ft(6),G(8)
A. bivenosa	I	7	7	5-12	F(2), Fd(I)
Colophospermum mopane	I	8	7	5-20	F(8), Fd(9)
Dichrostachus nutans	I	5	6	3-25	F(2), Fd(7)
Prosopis alba	I	6	7	8-40	F(7), Fd(8), T(6)
P. chilensis	1	6	8	5-40	F(7), Fd(7), T(4)
P. cineraria	2	5	1	5-80	F(8), Fd(8), Ft(8), G(5)
P.pallida	I	5	8	5-45	F(7), Fd(7), T(7)
P.juliflora	I	8	9	8-50	F(8), Fd(5), T(6)
Hardwickia binata	O	3	7	15-45	F(4),Fd(9), T(8)
Z nummularia	N	7	6	4-20	F(3), Fd(9), Ft(5)
Z rotundifolia	N	5	7	6-25	F(4), Fd(9), Ft(6)

* N = Nalive; I = Introduce from isocltmatic regions; O = Introduced from other drier region

** F = Fuel; Fd = Fodder; Ft = Fruits; T = Timber; G = Gum

Higher the number (range 1 to 10), better it is in growth and higher is the quality for that use, respectively, relative to others.

Table 4. *Tree species for sandy plains*

Species	Origin	Annual Rainfall Requirement (mm)		Growth Rate		Drough Resistance		Main use
		Min	Max	Early	Late	Young tree	Mature tree	
Prosopis cineraria	N	75	700	2	5	8	10	Mp
Capparis deciduas	N	100	1000	3	6	9	10	Ft
Tamarix aphyla	I	100	400	3	6	8	10	F,Fd
Acacia tortilis	I	100	700	10	10	7	10	MP
A. salicina	I	125	550	5	8	8	8	T
Ziziphus numularia	N	125	1000	5	7	9	10	MP
Z. rotundifolia	N	125	1000	5	8	8	10	MP
Z. maruritiana	N	150	2000	4	6	7	9	MP
Prosopis juliflora	I	150	700	8	9	10	10	F,Fd
P. chilensis	I	150	700	6	8	10	10	F,Fd
F. pallida	I	150	750	5	8	9	9	MP
Acacia Senegal	N	200	600	3	6	8	10	MP
Dischrostachys nutaus	I	200	700	5	6	7	9	Fd
Acacia holosericea	I	200	1500	5	8	8	8	F,Fd
Grelvia tenx	N	200	800	4	7	5	7	Fd
Eucalyptus camaldulensis	I	250	2000	4	8	7	8	F,PW
Hardwickia binata	O	250	1500	3	7	7	8	MP
Acacia albida	I	300	1500	2	6	8	10	Ft
Albizia lebbek	N	300	2250	7	9	8	8	MP
Azadirachta indica	N	300	1100	5	8	7	8	MP
Cassia siamea	N	300	700	5	9	6	7	MP
Ailanthus exeelsa	N	350	800	4	8	7	8	Fd,T
Emblica offiainalis	N	350	2500	3	6	6	8	Ft

N = Native; I = Introduced from isioclimatic region; O = Introduced from other drier region; MP = Multipurpose; Ft = Fruits; F

Fuel; Fd == Fodder; T = Timber

Table 5. *Effect of soil pH levels on growth of MPTS 28 months after planting*

Tree species	pH levels											
	8.7			9.3			9.7			10		
	Height (m)	Cd (cm)	Biomass (kg/tree)	Height (m)	Cd (cm)	Biomass (kg/tree)	Height (m)	Cd (cm)	Biomass (kg/tree)	Height (m)	Cd (cm)	Biomass (kg/tree)
Prosopis alba	3.7	4.3	9.5	3.3	3.8	29	3.4	4.1	3.2	3.4	3.9	2.6
P. juliflora	4.1	3.4	3.9	6.2	6.5	15.9	5.4	6	13.9	6.1	7	28.1
Terminalia arjuna	4.7	7	10.1	3.7	6.8	9.6	3.8	6.9	8.3	3.1	4.7	1.6
Dalbergia sissoo	5.1	7.2	17.1	3.5	5.6	5.4	2.8	4	3	1.9	2.6	0.4
Pongania pinnata	5.4	4.2	4.9	3.2	4.1	2.6	2.3	3.3	1.2	1.9	2.9	0.9
Acacia nilotica	3	6.2	26.1	5.3	6.2	36	4.4	5.7	20.6	4.8	5.7	8.6

Source: Singh (1996)

Table 6. Relative performance of *P. juliflora* and *A. nilotica* on alkali soils

Parameter	*P. juliflora*	*A. nilotica*
Plantation age (yrs)	10	10
Survival (per cent)	88	71
Height 11.7-13.8	10.7-11.9	
Range (m)	12.9	11.6
Mean(m)		
Depth		
Range (cm)	13.7-19.6	14.0-16.9
Mean (cm)	15.9	15.4
Bole weight		
Range (kg/plant)	69.0-142.0	61.0-101.0
Mean (kg/plant)	112.6	85.4
Branch + Leaves weight		
Range (kg/plant)	28.0-76.0	32.0-64.0
Mean (kg/plant)	43.2	43.8

Source: Modified from Singh et. al (1994)

Table 7. Effect of *Prosopis juliflora* - *Leptochloa fusca* system on certain characteristics of alkali soils

Soil character	Original	After 6 years	
		P. juliflora	P. juliflora + grass
pH	10.3	9.3	8.9
EC (dS/m)	2.2	0.46	0.36
Organic carbon (%)	0.18	0.43	0.58
Available N (kg/ha)	79	133	165
Available P (kg/ha)	35	36	30
Available K (kg/ha)	543	555	486

Source : Singh (1998)

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