Exploitation of wastelands for fodder production and agroforestry

Gurbachan Singh

ABSTRACT

Natural resources degradation for agricultural production and environmental protection has been a matter of concern forfuture food, nutrition, environment and livelihood security. As per current estimates, 120.7 million hectare (mha) is under degraded or wastelands. These lands provide ample opportunity for growing fodder trees and grasses to bridgethe gap between demand and supply of green and dry fodder.Several species of fodder trees and grasses have been identified and their agro-techniques standardized for raising in different categories of wastelands such as affected by soil and wind erosion, salinity, acidity and mining etc. A brief account of such plants is discussed in this paper. For example, *Prosopis juliflora–Leptochloa fusca*agroforestry practice in highly sodic soil (pH >10.0) is found highly promising for fuel wood and forage production and also for bio-amelioration of high pH soils. The information in the present paper is discussed under the following sub heads: (1) nature, extent and distribution of degraded/wastelands in India, (2) suitable fodder trees, bushes and grasses, (3) agro-techniques for fodder production and agroforestry, (4) production potential and amelioration of wastelands by trees and grasses and (5) future research and policy issues.

Keywords: Agroforestry, Agro-techniques, Bio-amelioration, Fodder, Grasses, Policy, Salinity, Water erosion, Wastelands.

Introduction

Of the total 329 mha geographical area of India, nearby 120.7 mha is constituted by the degraded or wastelands. The productivity of wastelands is limited due to soil and water erosion, salinity, acidity, shallow depth and other physical and biological processes. Water and wind eroded areas cover about 85 percent of the total area under wastelands. There seems little scope for increasing area under cultivation from the present level of 142 mha. There is mismatch between demand and supply of green and dry fodder and feed resources in the country. Past efforts in increasing area under cultivated fodders largely remained unsuccessful. The so called rangelands/grasslands are no longer providing needed forage for the livestock. The opportunity lies in growing fodder trees, bushes and grasses in wastelands to augment and supplement fodder and feed requirement. In addition to forage production, establishment of silvipastoral and agroforestry practices on wastelands will provide much needed environmental services such as carbon sequestration, soil and water conservation and resilience for climate change.

Nature, extent and distribution of wastelands

Land degradation assessment undertaken by various central and state agencies lead to development of database on degraded and wastelands. But, these agencies used varying definitions of land degradation, data sources, classification systems, methodologies and scales that resulted in diverse estimates of degraded and wasteland areas. It was felt that

Table 1. Harmonized area statistics of degraded lands/wastelands of India

S. No	Type of Degradation	Arable land (in mha)	Open forest (<40%Canopy) (in mha)
1	Water erosion (>10 t/ha/yr)	73.27	9.30
2.	Wind erosion (Aeolian)**	12.40	-
	Sub total	**85.67**	**9.30**
3.	**Chemical degradation**		
	a) Exclusively salt affected soils	5.44	-
	b) Salt-affected and water eroded soils	1.20	0.10
	c) Exclusively acidic soils (pH< 5.5)	5.09	-
	d) Acidic (pH < 5.5) and water eroded soils	5.72	7.13
	Sub total	**17.45**	**7.23**
4.	**Physical degradation**		
	a) Mining and industrial waste	0.19	
	b) Water logging (permanent) (water table within 2 mts depth)*	0.88	
	Sub total	**1.07**	
	Total	**104.19**	**16.53**
	Grand total (Arable land and Open forest)	**120.72**	

Source: ICAR-NAAS, 2010

normalization of the area statistics was possible only through scientific and logical reasoning, and was decided, therefore, to bring different agencies to one platform for expressing their views to come to an acceptable and agreeable solution. In this endeavor, the National Academy of Agricultural Sciences took a pioneering step to bring all the agencies together through a series of meetings and deliberations. Accordingly, using the GIS methodology, a harmonized database of land degradation was prepared. Land degradation statistics is presented in Table 1 below.

Land degradation datasets developed (1:50,000 scale) by National Remote Sensing Centre (NRSC) have been enriched with the soil parameters generated by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). Soil parameters pertinent to land degradation like slope, erosion, parent material, soil depth, surface texture, surface stoniness, particle size, calcareousness, soil reaction (pH) and soil salinity/ sodicity were selected to enrich the land degradation datasets. The enrichment of land degradation datasets have been completed for all the states and Union Territories of India.

Extent and distribution of acid soils: Acid soils in India have been formed due to drastic weathering associated to hot humid climate and heavy rainfall. Laterization, podsolization and accumulation of undecomposed organic matter under marshy conditions contribute to soil acidity. Roughly, about 12% of acid soils are strongly acidic (pH<5.0), 48% moderately acidic (pH 5.0-5.5) and 40% mildly acidic (pH 5.5-6.5). Soil acidity is an important constraint responsible for low productivity in eastern region. Data on extent and degree of soil acidity in different states are presented in Table 2. In Eastern region, 27.44, 10.47 and 0.17 mha areas are classified under slightly, moderately and strongly acidic soils. Strongly acidic soils are mainly found in Chhatisgarh and Assam states

Table 2. Extent and degree of soil acidity in different states of eastern India

States	Strongly acid (pH<4.5)	Moderately acidic (pH 4.5 – 5.5)	Slightly acidic (pH 5.5 – 6.5)	Total
West Bengal	--	0.56	4.20	4.76
Bihar	--	0.04	2.32	2.36
Orissa	--	0.26	8.41	8.67
Chhattisgarh	0.15	6.30	4.39	1084
Assam	0.02	2.31	2.33	4.66
Eastern U.P.	--	--	0.02	0.02
Jharkhand	--	1.00	5.77	6.77
Eastern India	0.17	10.47	27.44	38.08
Total India	6.19	24.81	58.94	89.94

Source: Sharma and Sarkar (2005)

only. More than 50% of the total area of Eastern region is affected by the problem of soil acidity.

Extent and Distribution of Salt-affected Soils in India: As per recent estimates, 6.73 mha area is affected by higher concentration of salts in the root zone soil. Sodic (*alkali*) and saline soils cover 3.77 and 2.96 mha, respectively. Gujarat followed by Uttar Pradesh and Maharashtra states has maximum area under salinity and sodicity. State wise distribution of salt-affected soils is presented in Table 3.

Extent and distribution of wind and water eroded areas: Nearly 85.67mha of arable land is affected by water and wind erosionin India. Further, 9.30 mha open forest area having canopy cover of <40% is also prone to water erosion to the extent of 10 t/ha/year. Distribution of are as prone to water and wind erosion is depicted in Figure 1 and Figure 2.

Table 3. Area affected by soil salinity and alkalinity in different states

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Island	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Odisha	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

Source: CSSRI, Karnal (2007)

Suitable fodder trees, bushes and grasses

***Drought prone areas*:** The perennial shortage of quality feeds and fodders especially in dry areas, often poses a major constraint in harnessing the optimum productivity. In recent times, a changed scenario is being viewed even in the periphery of big cities, where people rear buffaloes instead of cattle and the demand of quality milk and meat is bound to increase further in times to come. With current practices, the fodder deficit in western Rajasthan during normal year is estimated to be as high as 60% of the demand, and might range from 55% in Bikaner, Jaisalmer and Barmer districts to 69% in central districts Jodhpur, Nagaur and Churu and 72% in the eastern districts Pali and Sikar. During drought years, the deficit might range from 76% in western districts to 82% in the eastern regions (Narain and Rajora, 2006).

The important top feed shrubs and trees used during drought period include: *Ailanthus excelsa, Acacia nilotica, A. catechu, A. leucophloea, A. tortilis, Balanitesroxburghii, Prosopis cineraria, P. juliflora, Azadirachta indica, Albizia lebbeck, Leucaena leucocephala, Dalbergiasissoo, Meliaazadirach, Hardwickia binata, Grewia ovate, Ficus bengalensis, F. religiosa, Anogeis suspendula, Bauhinia variegate, B. racemosa, Butea monosperma, Cordia dichotoma, Flacourtiaindica, Moringa oleifera, Dichrostachys nutans, Morus alba, Ziziphus mauritiana* and *Z. nummularia*. The leaves of most of these trees are rich in nutrients. This type of fodder becomes more relevant during drought period, when there is scarcity of fodder.

Some other trees and shrubs also have good fodder quality for sheep and goats. These include: *Acacia senegal, A. eburnea. A. jacquimontii, A. suma, Albiziaamara, Betulaalnoides, Capparishorrida, Cassia siamea, Colophospermummopane, Catoneasterbacillaris, Dalbergia latifolia, Dracaena angustifolia, Gymnosporia spinosa, Populus euphratica, Prunus cornuta, Pyruspashia, Rhododendron arboreum, Rhuscotinus, R. pariflora, Salix wallichiana, Syringaemodi, Ulmus villosa,* and *Ziziphus rugos.*

Halophytes have been used as forage in drought prone arid and semi-arid areas for millennia (Le Houe'rou, 1993). The value of certain salt-tolerant shrub and grass species have been recognized by their incorporation in pasture-improvement programmes in many salt-affected dry regions throughout the world. There have been recent advances in selecting species with high biomass and protein levels in combination with their ability to survive a wide range of environmental conditions, including salinity and drought (NAS 1990; Ulery*et al.*, 1998;Barett-Lennard, 2003;Dagar, 2006). Considerable success has been achieved in Indian Subcontinent and elsewhere in cultivating halophytic forages such as chenopods, especially *Atriplex*in areas subject to total summer drought or on badly salt-affected lands.

Ravine lands: For degraded and problematic lands, silvi-pastoral management system keeping livestock as main component is most appropriate. The grassland including in the vicinity of ravine–lands need to be protected both by live fences and social fences until the villages through village panchayats are not convinced and made partners, the success of the program is not feasible. While studying the erosion problems in Kshipra ravines, Dagar (1987, 1999) identified several suitable woody and herbaceous species for growing in ravine lands. The forage trees, which are suitable for these land include *Acacia eburnea, A. nilotica, A. leucophloea, Balanities roxburghii, Cordarothii, Azadirachta indica, Pongamia pinnata* (in river beds or bottom of ravines), *Dichrostachis cineria, Leucaena leucocephala and Prosopis juliflora*. On plateau,*Butea monosperma* also thrives well. All

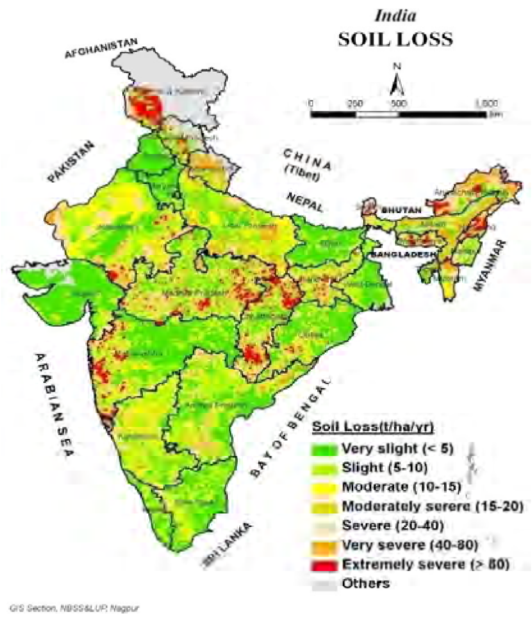

Fig. 2. Areas prone to wind erosion

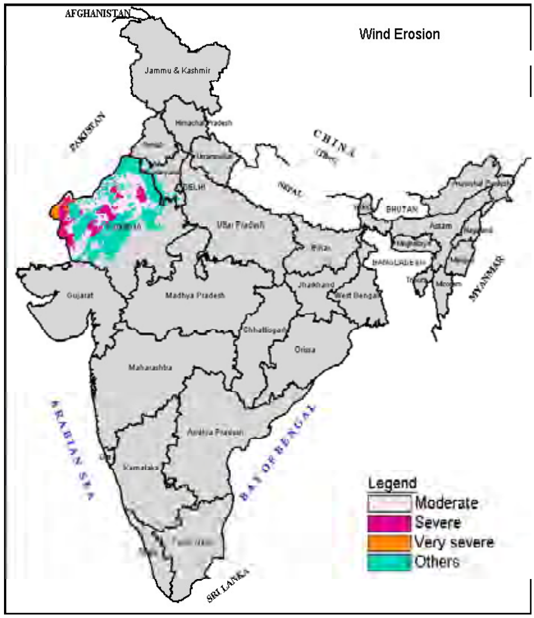

Fig. 1. Areas prone to water erosion

these trees can contribute substantially towards fodder for livestock during drought period. It was found that grasses like *Dichanthium annulatum, D. caricosum, Bothriochloa pertusa and Cynodon dactylon* had very high soil conservation and aggregation values and these are quite palatable and sustatin drought situations and can form part of silvi-pastoral system with above-mentioned trees.

Salt affected soils: The workers at the Central Soil Salinity Research Institute (CSSRI), Karnal have identified suitable grasses and other crops for growing in salt-affected soils. Relative tolerance of different crops to exchangeable sodium percent (ESP) in the soil is given in Table 4.Similarly, relative tolerance of different tree species to soil alkalinity and salinity is reported in Tables 5 and 6.

Table 4. Relative tolerance of crops and grasses to soil ESP

Tolerant ESP, 35-50	Moderately tolerant ESP, 15-35	Sensitive ESP <15
Karnal grass (*Leptochloa fusca*)	Wheat (*Triticum aestivum*)	Gram (*Cicer arietinum*)
Rhodes grass (*Chloris gayana*)	Barley (*Hordeum vulgare*)	Mash (*Phaseolus mungo*)
Para grass (*Brachiaria mutica*)	Oat (*Avena sativa*)	Chickpea (*Cicer arietinum*)
Bermuda grass (*Cynodon dactylon*)	Shaftal (*Trifolium resupinatum*)	Lentil (*Lens esculenta*)
	Lucerne (*Medicago sativa*)	Soybean (*Glycine max*)
Rice (*Oryzasativa*)	Turnip (*Brassica rapa*)	Groundnut (*Arachis hypogea*)
Dhaincha (*Seshania aculeate*)	Sunflower (*Helianthus annus*)	Sesamum (*Sesamum oriental*)
Sugarbeet (*Beta vulgaris*)	Safflower (*Carthamus tinctorius*)	Mung (*Phaseolus aureus*)
Teosinte (*Euchlaenamaxicana*)	Berseem (*Trifoliumalexandrinum*)	Pea (*Pisum sativum*)
	Linseed (*Linum usitatissimum*)	Cowpea (*Vigna unguiculata*)
	Onion (*Allium cepa*)	Maize (*Zea mays*)
	Garlic (*Allium sativum*)	Cotton (*Gossypium hirsutum*)
	Pearl millet (*Pennisetum typhoides*)	

Source: CSSRI, Karnal (2007)

Table 5. Relative Tolerance of Tree Species to Soil Alkalinity

Average pH_2 (0-120 cm)	Fuel-wood/Timber species	Fruit trees
More than 10.0	*Prosopis juliflora*(Paharikiker) *Acacia nilotica* (Kikar) *Casuarina equisetifolia* (Australian pine)	*Achrasjapota* (Chikoo)
9.0 to 10.0	*Tamarix articulata* (Frans) *Terminalia arjuna* (Arjun) *Eucalyptus tereticornis* (Safeda) *Albizzia lebbek* (Papri) *Pongamia pinnata* (SirisKaranj) *Sesbania sesban* (Dhaincha) *Emblica officinalis* (Amla)	*Zizyphus maurtiana* (Ber) *Carissa carandus* (Karaunda) *Psidium guajava* (Amrood) *Syzygium cumini* (Jamun) *Phoenix dectylifera*(Khajoor) *Aegle marmelos* (Bael)
8.2 to 9.0	*Dalbergia sisoo* (Shisham) *Morus alba* (Sehtoot) *Grevilla robusta* (Silver Oak) *Azadirachta indica* (Neem) *Tectona grandis* (Teak) *Populus deltoids* (Poplar)	*Punica granatum* (Anar) *Prunus persica* (Aru) *Pyrus communis* (Nashpati) *Vitis vinifera* (Angoor) *Mangifera indica* (Aam)

Source: Singh *et al.*, 1993

Table 6. Recommended Tree Species for Saline and Waterlogged Soils (Salinity below 0.3 m)

Salinity (ECe, dS/m)	Tree species
20 – 30	*Acacia farnesiana* (Desi babul), *Prosopis juliflora* (Mesquite, pahariKikar), *Parkinsonia aculeate* (Jerusalem thorn, Parkinsonia)
14 – 20	*Acacia nilotica* (desikikar) *Acacia tortilis* (Israeli Kikar), *Callistemon lanceolatus* (Bottle brush), *Casuarina glauca* (Casuarina, Saru), *C. Obese, C. equisetifolia, Eucalyptus camaldulensis* (River red gum, safeda)
10 – 14	*Casuarina cunninghamiana* (Casuarina, Saru), *Eucalyptus tereticornis* (Mysore gum, safeda), *Terminalia arjuna* (Arjun)
5 – 10	*Albizzia caribea, Dalbergia sissoo* (Shisham), *Guazumaulmifolia, Pongamia pinnata* (Papri), *Samanea saman*
< 5	*Acacia auriculiformis* (Australian kikar), *A. deamii, A. catechu* (Khair), *Syzgium cuminii* (Jamun), *Salix spp.* (Willow, salix), *Tamarindus indica* (Imli)

Source: CSSRI, Karnal, 2007

Under-exploited but potential fodder species

Nature has distributed plant species for use in all kind of environments for the survival of mankind. There are trees, bushes, shrubs and grasses which only thrive under harsh dry desert conditions. Similarly, some trees and shrub species like mangroves, coconuts, passion fruit, coastal *badam*, salvadora, saliconnia, etc grow best under high salinity conditions. Several species of the genus *Prosopis* like *Prosopis tamarugo* and *Prosopis juliflora* are reported to grow at salinities almost equivalent to sea water salinity. *Prosopis juliflora* is multi stress (drought, temperature, salinity, submergence) tolerant species and found growing naturally in all states of the

Table 7. A summary of uses of Opuntia

Food	Fruits and fruit peel, juice, pulp, alcoholic* beverages, jam, syrup
Forage	Stems/cladodes, fruits, seeds, cultivated as forage shrub
Energy	Biogas, ethanol, firewood
Medicine	Stems(Diarrhoea), diuretic(flowers, roots), amoebic dysentery (flowers), diabetes (stems), hyperlypidemy (stems), obeysity(fibres), anti-inflammatory(stems)
Cosmetic	Shampoo, cream, soaps, body lotions
Agronomic	Hedges and fences, mulching, soil improver, wind break, organic manure
Other	Adhesive and glues, pectin, fibres for handcrafts, paper (stems), dyes(fruits, rearing of *Dactyloptuscoccus* on clacodes, antitranspirant, ornamental

country, mostly on abandoned waste lands (Singh, 2008). About 40% of the total fuel wood requirement in the country particularly of landless rural people is met from this single tree species. It will be worthwhile to share that during the severest of the severe droughts this is the only species which provides livelihood support to human and livestock in drought prone areas like Rajasthan. Other virtues from this versatile tree include pods which contain about 10-13% proteins and 20-30% sucrose and excellent quality as furniture wood have not been fully exploited. In countries like USA, Mexico, Brazil, Argentina, South Africa, Italy, Senegal, Peru etc, the *Prosopis* trees have been commercially exploited as furniture and timber wood, human and livestock food and feed, fuel wood, fodder and other industrial uses.

Similarly, several species of Cactus or *Naghphani*are found growing naturally in dry and rainfed areas of the country. These shrubs are mostly thorny and farmers use them as bio-fence on the field boundaries to protect agricultural crops from wildlife (Singh *et al.,* 2007). Some species of Cactus like *Opuntia ficusindica* have been exploited as human food, forage, medicinal and energy crop in countries like Mexico, USA, Brazil, South Africa, Israel, Italy, Morroco etc. Mexico is the largest exporter of cactus fruit called *tuna* in the world. Both *Prosopis* and Cactus constitute one of the sustainable agroforestry systems in rangelands of US, Mexico, Brazil and several other countries. Both species are known to have highest water use efficiency per unit dry matter production, hence need exploitation for rehabilitation of rangelands / wastelands in India to create alternate food and fodder resources and drought proofing option in drought prone areas of the country. There is a need to have collaborative research and developmental programmes with international organizations to promote adoption of these agroforestry practices.

Agro-techniques for successful cultivation

Cultural practices for raising fodder based agroforestry practices have been developed for different kind of wastelands in the country. Singh *et al.,* 1988; Singh, 1995; Singh *et al.,* 1994standardised agro-techniques such as planting methods, irrigation requirements, spacing and prunning etc. for tree and grass species in salt affected soils. The results are presented in Tables 8 and 9.

Production Potential and Amelioration of Wastelands by Trees and Grasses

Grasses like *Leptochloa fusca* can be grown successfully as inter crop between *Prosopis* rows. The grasses should be introduced after one year when the trees are well established. *Leptochloa* is a halopythic forage grass which produces significant biomass even at the soil pH of 10.4. This grass has a mechanism to fix nitrogen in the soil through free living bacteria known as *Klebsillaphenomeneae.* Association of

Table 8. Comparative effect of plantation techniques on growth and production of *Prosopis juliflora* in a highly sodic soil (DSH: Diameter at stump height, DBH: Diameter at breast height)

Planting Technique	Height (m)	DSH (cm)	DBH (cm)	Biomass		Total
				Lopped	Harvested (t/ha)	
Trench (30cm wide, 30cm deep dug across the plots)	6.9	7.9	6.4	4.7	29.6	34.3
Pit (30cm wide, 30 cm in length and 30 cm deep)	7.0	8.4	6.7	6.0	30.0	36.0
Augerhole (15 cm diameter and 90 cm deep)	7.7	9.6	7.9	6.4	36.2	42.6

Source: Singh *et al.*, 1988; Singh, 1995

Table 9. Effect of tree spacing on biomass production of *Prosopis* and *Leptochloa* grass in a unified agroforestry system

Spacings	Biomass (t/ha)			
	Prosopis			*Leptochloa*
	Lopped	Harvested	Total	
2x2 m	49.1	112.2	161.3	55.6
3x3 m	31.6	55.2	86.8	68.7
4x4 m	25.0	36.1	61.1	80.7

Source: Singh *et al.*, 1994

such grasses with *Prosopis* further hastens the reclamation process. The reclaiming effects of *Prsosopis* and Leptochloa grass are illustrated in Figure 3.

Future Research and Policy Issues

I. More than 120 m ha, out of 329 m ha total geographical area of the country is degraded due to physical, chemical and biological processes. The highly degraded lands need to be rehabilitated using top feed fodder trees and grasses. Under the *Rashtriya Krishi Vikas Yojna* (RKVY) sufficient funds are provided to states for developing location specific priority programmes in agriculture. States need to utilize part of funds available in these schemes for promotion of fodder production and agroforestry in wastelands / degraded lands.

II. Agroforestry has special significance in increasing availability of green and dry fodder in the country. Several top feed fodder trees like *Hardwickia*, *Ailanthus*, fast growing Khejriand grasses need to be introduced to improve productivity and carrying capacity of rangelands/ grasslands. Rehabilitation of such lands with fast growing top feed trees and bushes and re-seeding with grasses should be considered priority policy option

III. Several agroforestry practices/models focusing on fodder production have been developed by ICAR research institutes and State Agricultural Universities for different agro- climatic regions of the country. Such practices/models need to be up-scaled by incorporating location specific adjustments

IV. There are number of multipurpose multi stress tolerant trees, bushes and shrubs

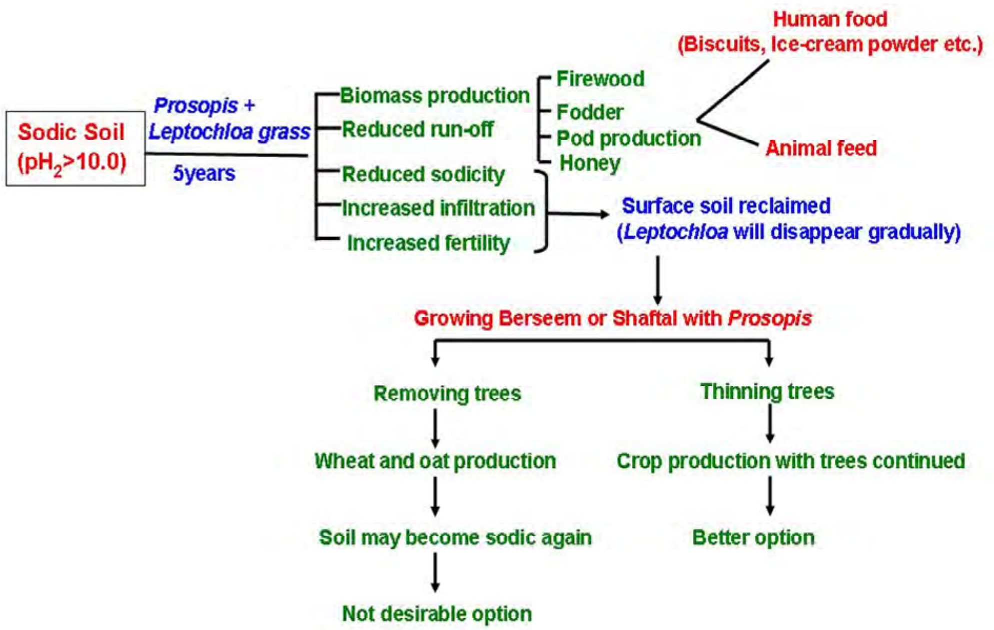

Fig 3. *Prosopis juliflora* and *Leptochloa fusca* silvipastoral model for bio-amelioration of salt lands

which naturally grow in landscapes in general and wastelands in particular like genus *Prosopis* and *Opuntia* (edible cactus). Such species have ample scope to be used as an alternate source of food and feed in dry areas/stressed environments. There is a need to improve such trees and bush species for higher productivity, produce quality, post harvest value addition, marketing and trade opportunities

V. Tree based land use systems have special role in reclamation of wastelands, detoxification of heavy metal loaded soils, use of poor quality waters including industrial effluents, lowering of water table in canal command areas showing trends of ground water rise, organic carbon build up in carbon depleted soils/carbon sequestration, increasing water infiltration rate in impeded/ caliche bed soils and moderating/negating climate change related risks. In the light of predicted climate change scenario, frequency of cold and heat waves, droughts, floods and *tsunami* is likely to increase in the near future. Therefore, emphasis on agroforestry research, development and policy need to be redoubled.

VI. Growing of fodder trees in association with crops/grasses/bushes in a unified agroforestry system helps in improving soil quality, sequestration of carbon to moderate global warming threat and other environmental and eco-system services. The farmers adopting agroforestry in their farm lands need to be compensated in monetary terms in the shape of carbon credits / other incentives. In the recent past, only a few projects in select states have been implemented to provide carbon credits to the selected stakeholders. A uniform policy need to be put in place to promote agroforestry in wastelands for food and fodder, carbon sequestration, natural resource up-gradation and other environmental services.

VII. There is an acute shortage of quality seeds, saplings/planting material of promising fodder tree and grass species. A national programme needs to be launched to promote establishment of quality seed / planting material of top feed trees and perennial grasses.

References

Barett-Lennard, E. G. 2003. *Saltland Pastures in Australia- A Practical Guide*. Dept. of Agriculture of Western Australia, South Perth WA, Australia. pp. 176.

Dagar, J. C. 1987. Studies on reclamation of Kshipra ravines. *Indian Journal of Forestry* 10: 83-89.

Dagar, J. C. 1999. Soil erosion parameters with special reference to Kshipra ravines in Madhya Pradesh. *Indian Journal of Forestry* 22: 210-221.

Dagar, J. C. 2006. Halophytic forages for salty soils in deserts. In: Pathak PS & Kundu SS (eds.). *Livestock Feeding Strategies for Dry Regions.* International Book Distributing Co., Lucknow, India. pp 193-223.

ICAR-NAAS. 2010. Degraded and wastelands of India: Status and spatial distribution. Indian Council of Agricultural Research p. 158.

Le Houe'rou, H. N. 1993. Salt-tolerant plants for the arid regions of the Middle East isoclimate zone. In: Lieth H and AI Masoom A. (eds.). *Towards the Rational use of High Salinity Tolerant Plants.* Kluwer Academic Publishers.The Netherlands. pp. 403-422.

Narain, P. and M. P. Rajora. 2006. Managing drought stress for augmenting forage productivity in arid western Rajasthan. In: Pathak PS and Kundu SS. (eds.). *Livestock Feeding Strategies for Dry Region*. International Book Dist. Co., Lucknow.pp41-56.

NAS. 1990. *Saline Agriculture – Salt Tolerant Plants for Developing Countries.* National Academy of Science, Washington, D.C. pp. 143.

Sharma, P. D. and A. K. Sarkar. 2005. Managing acid soils for enhancing productivity. NRM Division (ICAR) Publ. Krishi Anusandhan Bhavan-II, Pusa Campus, New Delhi. Technical Bulletin pp23.

Singh, G., I.P. Abrol and S.S. Cheema. 1988. Agroforestry on alkali soil: Effect of planting methods and amendments on initial growth, biomass accumulation and chemical composition of mesquite (*Prosopis juliflora*) (SW, DC) with interspace planted with and without Karnal grass (*Diplachnafusca*linn. P beauv.). *Agroforestry Systems.* 7:135-160.

Singh, G. and N.T. Singh. 1993. Mesquite for the revegetation of salt lands. Technical bulletin No. 18, CSSRI, Karnal, India, 24 pp.

Singh, G., N.T. Singh and I.P. Abrol. 1994. Agroforestry techniques for the rehabilitation of salt lands. *Land Degradation and (Rehabilitation) Development* 5:223-242.

Singh, G. 1995. An agroforestry practice for the development of salt lands using *Prosopisjuliflora* and *Leptochloafusca*. *Agroforestry Systems.* 29:61-75.

Singh, G., P.C. Sharma, S.K. Ambast, S.K. Kamra and B.K. Khosla. 2007. CSSRI: A Journey to Excellence (1969-2006). Central Soil Salinity Research Institute, Karnal, India, p. 156.

Singh, G. 2007. Opportunities for promotion of cactus (*Opunita* spp.) as livelihood source in rainfed areas. Technical bulletin 1/2007. Central Soil Salinity Research Institute, Karnal, India, p. 23.

Singh, G. 2008. Managing *Prosopis* for livelihood security in salt affected and dry areas. Technical Bulletin: CSSRI/Karnal/10/2008, Central Soil Salinity Research Institute, Karnal, India, p. 30.

Ulery A. L, J. A.Teed,M.Th. Van Genuchten and M. C. Shannon. 1998. SALTDATA: A database of plant yield response to salinity. *Agronomental Journal* 90: 556-562.