Multifunctional Agroforestry Systems for Bio-amelioration of Salt-Affected Soils

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1 Introduction

Land use options that increase livelihood security and reduce vulnerability to climate and environmental change are necessary. Traditional resource management adaptations, such as agroforestry systems, may potentially provide options for rehabilitation of salt-affected soils and improvement in livelihoods through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change (Pandey et al. 2007). Reframing the challenge in another way, agroforestry systems may provide part of the answer to a challenge for sustainability on how to conserve forest ecosystems and farmland biodiversity as well as the services that they provide while simultaneously enhancing food production for an increasing population under the condition of land and water scarcity.

Worldwide, salt-affected areas are estimated to range from 340 million ha to 1.2 billion ha (FAO 2007). Millions of hectares of these salt-affected soils are suited for agricultural production but are unexploited because of salinity/sodicity and other soil and water-related problems. According to FAO, salinization of arable land will result in 30–50 % land loss in the next 25 years to year 2050 if remedial actions are not taken. In India salt-affected soils occupy about 6.73 million hectares and 3.60 million hectares is sodic soils. Indo-Gangetic plains that lie between 21°55′–32°39′N and 73°45′–88°25′E comprising of the states of Punjab, Haryana, Uttar Pradesh and part of Bihar (North), West Bengal (south) and Rajasthan (north) have about 2.7 million hectare salt-affected soils. This area is progressively expanding because of improper soil and water management and development of waterlogging and soil salinization upon introduction of irrigation in arid, semiarid and subhumid regions. Rise in the water table is inevitable upon introduction of irrigation network

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without provision of adequate drainage. Appropriate policy responses combining the agroecosystems as key assets can strengthen adaptation and help to build the resilience of communities and households to local and global changes. Trees growing in combination to agriculture as well as numerous other vegetation management regimes in salt-affected soils can be integrated to take advantage of services provided by adjacent natural, seminatural or restored ecosystems.

Increasing the livelihood security and reducing the vulnerability call for societal adaptation. Such adaptations are possible when combined with traditional resource management systems. Agroforestry as a local adaptation, therefore, is a promising area of interest for scientists, policy-makers and practitioners. This paper presented the contribution of agroforestry systems as a potential option for (1) restoring of salt-affected soils, (2) mitigating climate change, (3) enhancing the fertility status of soil, (4) producing biomass and bioenergy and (5) providing social and economic well-being of the people.

2 Origin and Distribution of Salt-Affected Soils in India

Salt-affected soils are commonly found in Indo-Gangetic plains of Uttar Pradesh, Punjab, Haryana, Rajasthan, Bihar and West Bengal. There are various reasons associated with the formation of salt-affected soils that are both natural and anthropogenic. The geological deposition of clay minerals comprises quartz, feldspars (orthoclase and plagioclase), muscovite, biotite, chloritized biotite, tourmaline, zircon and hornblende in their sand fractions (Bhargav et al. 1980). Quartz and feldspars occur distinctly in the salt fraction. However, illite, mixed-layer minerals, vermiculite and chloride are common to both the silt and clay fractions. The mixed-layer minerals vermiculites and smectite in these soils originate from biotite mica. Different workers have reported variable estimates of salt-affected soils in India. According to the latest estimation in India, salt-affected soils occupy about 6.73 million hectares of land, which is 2.1 % of the geographical area of the country (Sharma et al. 2004). Out of 584 districts in the country, 194 have salt-affected soils (Fig. 1).

3 Characteristics of Salt-Affected Soils

Salt-affected soils differ from arable soils with respect to two important properties, viz. the soluble salts and the soil reaction. Soluble salts in soils may influence the crop production through changes in the proportion of exchangeable cations, soil reaction, the physical properties and the osmotic and specific ion toxicity. The replacement of exchangeable Na^+ with Ca^{2+} requires the application of amendments which can either supply soluble calcium ions directly or induce its solubility from the soil constituents. Nutritional imbalance or specific ion toxicity also adversely

Fig. 1 State-wise extent of salt-affected soils in India (million ha). Source: Sharma et al. (2004)

affects the yields. From reclamation and management purpose, the salt-affected soils of India can be placed into *alkali/sodic* and *saline* soils.

Alkali soils contain excess of salts capable of alkaline hydrolysis such as sodium carbonate, sodium bicarbonate and sodium silicate and sufficient exchangeable sodium to impart poor physical conditions to soil and affecting growth of most plants. These soils have saturated paste pH >8.5, exchangeable sodium percentage (ESP) >15 and different levels of salinity (EC <4 dSm^{-1}). The presence of calcium carbonate concretions at about 1 m depth causes physical impedance for root proliferation (Fig. 2a, b).

Saline soils with white salt encrustation on the surface have predominantly chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+}. The soils with neutral soluble salts have saturation paste pH <8.5. The electrical conductivity of saturation extract (EC) is

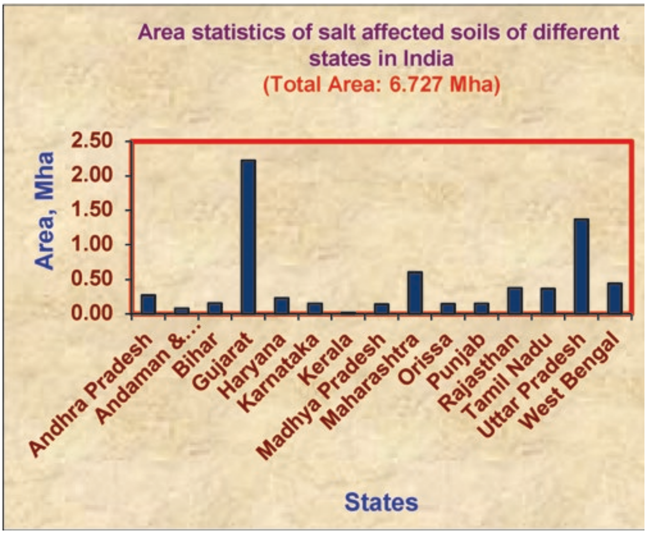

Fig. 1 (continued)

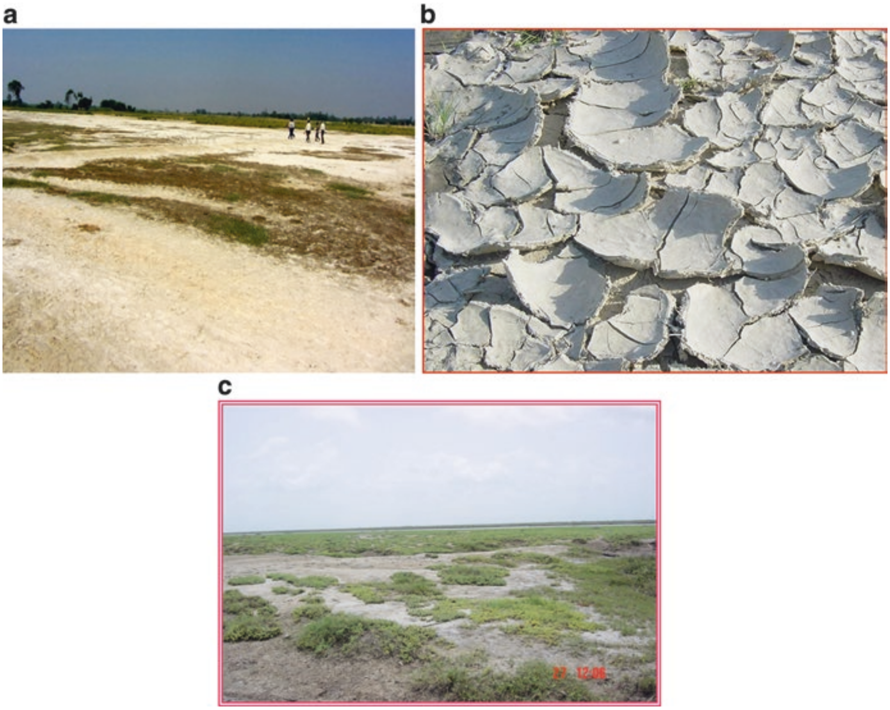

Fig. 2 Typical (**a**) alkali/sodic soil during summer (**b**) after drying and (**c**) saline soil

>4 dSm^{-1} at 25 °C. Such soils invariably have sodium absorption ratio (SAR) of the soil solution >15. The presence of excess neutral salts restricts the plant growth. The main causes of poor growth are high osmotic pressure of soil solution and complex interaction between sodium, calcium and magnesium (Fig. 2c).

4 Selection of Multifunctional Tree Species for Salt-Affected Soils

The initial establishment including germination and initial growth of tree seedlings in saline and sodic environment is a difficult task for researchers. The selection of suitable tree species for high biomass and bioenergy production in salt-affected soils depends upon the tolerance of the species to salinity and sodicity, suitability to local agro-climate and purpose of plantation. Several studies have been conducted to evaluate the performance of a large number of tree species in saline and sodic conditions in India. Yadav (1980) suggested several afforestation techniques and stressed that species like *Prosopis juliflora*, *Eucalyptus tereticornis* and *Acacia nilotica* can grow better on sodic soils. Some preliminary studies have been done to select salt-tolerant species through the pot culture experiments, in which six tree species, i.e. *Casuarina equisetifolia*, *Eucalyptus tereticornis*, *Acacia nilotica*, *Dalbergia sissoo*, *Pongamia pinnata and Araucaria cunninghamii*, were evaluated (Gupta et al. 1988). All of these species failed to grow at the above 61.4 ESP. However, the successful growth was observed at 30.6 ESP for *Acacia nilotica*, *Eucalyptus tereticornis and Casuarina equisetifolia* and at 15.2 ESP for *Dalbergia sissoo*, *Pongamia pinnata* and *Araucaria cunninghamii. Casuarina equisetifolia* showed a moderate salt tolerance. Yadav and Singh (1986) reported a 50 % reduction in the growth of *Acacia nilotica* and *Eucalyptus camaldulensis* at 5.0 dSm^{-1} salinity in clay soil, but they grew satisfactorily at ECe 10.0 dSm^{-1} in sandy soil. However, *Acacia auriculiformis* could not survive beyond ECe 2.5 dSm^{-1}.

Thirty forest tree species were evaluated at high sodicity (pH > 10.0). After 7 years of planting, only 13 out of 30 species survived. Out of these 13 surviving species, only *Prosopis juliflora*, *Tamarix articulata* and *Acacia nilotica* were found suitable for such soils. *Eucalyptus tereticornis* showed good survival and height but no meaningful biomass was observed. However, *Dalbergia sissoo*, *Pithecellobium dulce*, *Terminalia arjuna*, *Kigelia pinnata*, *Parkinsonia aculeata* and *Cordial Rothay* showed more than 70 % survival but could not attain economically suitable biomass (Dagar and Tomar 2002).

The performance of ten tree species in sodic soils having ESP 89 was evaluated at CSSRI, Regional Research Station, Lucknow. After 10 years of field study, only three species, *Prosopis juliflora*, *Acacia nilotica* and *Casuarina equisetifolia*, recorded survival rates of >90 % and attain economical biomass. *Eucalyptus tereticornis* showed good performance during the initial 4 years, but its growth rate declined thereafter. *Azadirachta indica*, *Melia azedarach* and *Dalbergia sissoo*

Table 1 Recommended tree species for the restoration of salt-affected soils

Soil parameter	Firewood/timber/fruit species (common name)
Alkali soils (pH$_2$)	
>10.0	*Acacia nilotica* (kikar), *Butea monosperma* (dhak), *Casuarina equisetifolia* (Casurina, saru), *Prosopis juliflora* (mesquite, pahari kikar), *Prosopis cineraria* (khejri, jand)
9.0–10.0	*Albizia lebbeck* (siris), *Cassia siamea* (cassia), *Eucalyptus tereticornis* (mysore gum, safeda), *Tamarix articulata* (faransh), *Terminalia arjuna* (arjun)
8.6–9.0	*Azadirachta indica* (*neem*), *Dalbergia sissoo* (sheesham, tahli), *Grevillea robusta* (*silver oak*), *Hardwickia binata* (*anjan*), *Kigelia pinnata* (balam khira), *Morus alba* (mulberry, shahtoot), *Moringa oleifera* (sonjna), *Mangifera indica* (mango), *Pyrus communis* (pear, nashpati), *Populus deltoides* (*poplar*), *Tectona grandis* (teak, saguan), *Syzygium cumini* (jamun)
Saline and waterlogged soils ECe(dSm^{-1})	
20–30	*Acacia farnesiana* (pissi babul), *Prosopis juliflora* (mesquite, pahari kikar), *Parkinsonia aculeate* (Jerusalem thorn, parkinsonia), *Tamarix aphylla* (faransh)
14–20	*Acacia nilotica* (desi kikar), *A. pennatula* (kikar), *A. tortilis* (Israeli kikar), *Callistemon lanceolatus* (bottle brush), *Casuarina glauca* (casuarinas, saru*), C. obese, C. equisetifolia, Eucalyptus camaldulensis* (river red gum, safeda), *Feronia limonia* (kainth, kabit), *Leucaena leucocephala* (subabul), *Ziziphus jujuba* (ber)
10–14	*Casuarina cunninghamiana* (casuarinas, saru), *Eucalyptus tereticornis* (mysore gum, safeda), *Terminalia arjuna* (arjun)
5–10	*Albizia caribaea*, *Dalbergia sissoo* (shisham), *Guazuma ulmifolia*, *Pongamia pinnata* (papri), *Samanea saman*
<5	*Acacia auriculiformis* (Australian kikar, akash mono), *A. deamii*, *A. catechu* (khair), *Syzygium cumini* (jamun), *Salix spp.* (*willow*, *salix*), *Tamarindus indica* (imli)

Source: Dagar and Singh (1994), Gupta Raj et al. (1995) and Singh et al. (2011)

were poor performer. On the basis of available information, a short list of consistently better performing species that could be recommended for saline and alkali soils of Indo-Gangetic plains is given in Table 1.

4.1 Multifunctional Agroforestry Systems

4.1.1 Silvipastoral System

Planting of multipurpose trees with grasses and legumes in an integrated system and their utilization through cut and carry on forage in early years followed by in situ grazing is known as silvipastoral system. From the studies conducted at CSSRI, Karnal, it was found that kallar grass (*Leptochloa fusca*), Rhodes grass (*Chloris gayana*), para grass (*Brachiaria mutica*) and Gutton panic are highly salt tolerant and high biomass producing grass species. Mesquite (*Prosopis juliflora*) and kallar grass silvipastoral practice has been found most promising for firewood and forage production and also for soil amelioration (Singh 1995a, b).

An experiment to evaluate the performance of pastoral, silvipastoral and silvicultural systems was initiated in 1995 at CSSRI, Regional Research Station, Lucknow. Grasses, trees and trees + grasses mixtures were planted in different treatment combinations. The trees have been planted in auger holes of 45 cm dia at the surface and 20 cm at the base and 120–140 cm deep. The pits were filled with a uniform mixture of original soil + 4 kg gypsum + 2 kg UTK + 10 kg FYM + 20 kg silt before planting. The trees have been planted keeping a distance of 5 m between row to row and 4 m between plants. The grass species selected were Karnal grass, Gutton panic, Rhodes grass and berseem. From the study it is concluded that establishment of a *P. juliflora* silvipastoral system with planting of *L. fusca* for 4 years followed by *T. alexandrinum* for 6 years might be a more remunerative land use system than pure pastoral or silvicultural systems (Singh et al. 2014) (Table 2). This system improved the soil to such an extent that less tolerant but more palatable fodder species such as shaftal (*Trifolium resupinatum*), berseem (*Trifolium alexandrinum*) and senji *(Melilotus parviflora*) could be grown under *Prosopis* trees after 74 months (Table 3).

Another silvipastoral model for rainwater conservation and production of fuel and forage from alkali lands has also been developed by Grewal and Abrol (1989). With this model trees such as *Acacia nilotica*, *Eucalyptus tereticornis* and *Parkinsonia aculeata* were planted on ridges, and kallar grass was established in the trenches between ridges. The system conserves rainwater during monsoon, which in turn increased the biomass of trees and intercrop of kallar grass. In addition to firewood and forage production, this system was found useful in checking run-off and soil loss (Table 4).

In addition, tree crops may be used in cattle production systems in order to provide live fences, windbreaks and shade trees and for soil and water conservation purposes.

Table 2 Performance of trees under different agroforestry systems 10 years after planting

Treatments	Survival (%)	Plant height (m)	DBH (cm)	DSH (cm)	Crown diameter (m)
Control (barren)	–	–	–	–	–
L. fusca for 4 years—*P. maximum* for 6 years	–	–	–	–	–
P. juliflora (sole)	90	4.83	6.82	12.84	8.63
A. nilotica (sole)	81	4.53	7.51	12.21	7.20
P. juliflora + *L. fusca* for *4* years—*T. alexandrium* for 6 years	95	5.21	10.10	15.57	8.87
A. nilotica + *L. fusca* for 4 years—*C. gayana* for 6 years	93	5.16	8.22	13.49	7.73
LSD($P<0.05$)	NS	NS	NS	NS	0.71

Source: Singh et al. (2014)

Table 3 Effect of *Prosopis juliflora—Leptochloa fusca* silvipastoral system on soil properties

Soil properties	Depth (cm)	Initial	After 74 months
pH$_2$	0–15	10.3	8.9
	15–30	10.3	9.4
EC$_2$ (dS m^{-1})	0–15	2.2	0.36
	15–30	1.5	0.60
Organic C (%)	0–15	0.18	0.58
	15–30	0.13	0.36
Available N (kg ha^{-1})	0–15	79	165
	15–30	73	134
Available P (kg ha^{-1})	0–15	35	30
	15–30	31	26
Available K (kg ha^{-1})	0–15	543	486
	15–30	490	478

Table 4 Rainfall, run-off, soil loss and water balance in flat (FSS) and ridge and furrow planting systems (RFS)

			Run-off (mm)		Soil loss (Mg ha^{-1})	
Year	Monsoon rainfall (mm)		FSS	RFS	FSS	RFS
1982	295.1		169.0	204.0	114.73	83.05
1983	584.6		401.3	469.6	23.86	9.39
1984	512.4		337.4	319.7	8.58	1.10
Component (mm)	1982		1983		1984	
	RFS	FSS	RFS	FSS	RFS	FSS
Rainfall	295	295	585	585	512	512
Run-off	0	169	0	401	0	337
Retention	295	126	585	184	512	175
Soil storage	88	58	132	79	216	95
Evaporation	207	69	453	105	269	80

Source: Grewal and Abrol (1989)

4.1.2 Silvi-Agriculture System

In this system the trees are grown for reasonable period of time, followed by growing agricultural crops. Prolonged occupation of alkali soils by trees results in their amelioration in terms of decreased pH and electrical conductivity and improved organic matter and fertility status. Singh (1998) grew wheat and oat in pots filled with topsoils (30 cm) collected from 24-year-old plantations of *Prosopis juliflora*, *Acacia nilotica*, *Eucalyptus tereticornis*, *Albizia lebbeck* and *Terminalia arjuna* on a highly alkali soil and a reclaimed sodic soil. The organic carbon content and nutrient status of the soil under 24-year-old plantations were much higher than that of a farm soil reclaimed through gypsum. Soil amelioration was maximum under *Prosopis* and minimum under *Eucalyptus*. Grain and straw yield of both the crops were maximum under *Prosopis* and minimum under *Eucalyptus* (Table 5).

Table 5 Grain and straw yield of crops under different tree plantations

	Wheat		Oat	
Species	Grain (g/pot)	Straw (g/pot)	Grain (g/pot)	Straw (g/pot)
Eucalyptus tereticornis	32.2	25.3	42.7	58.5
Acacia nilotica	55.7	68.8	61.6	67.5
Albizia lebbeck	45.3	43.5	52.8	66.9
Terminalia arjuna	44.0	38.5	45.8	62.8
Prosopis juliflora	61.7	87.5	87.9	111.1
Crop land	13.3	15.4	24.3	26.7
LSD ($P=0.05$)	2.8	2.0	7.0	9.4

Source: Singh (1998)

Table 6 Promising varieties of fruits for salt-affected soils

Plant types	Promising varieties
Emblica officinalis (aonla)	Chakaiya, NA-6, NA-7, NA-10
Ziziphus mauritiana (ber)	Banarasi Karka, Gola
Psidium guajava (guava)	Shweta and Allahabad Safeda
Punica granatum (Anar)	Ganesh
Morus alba (mulberry)	K-2
Syzygium cumini (jamun)	

4.1.3 Silvi-Horti-Pasture or Horti-Agricultural System

Horticultural species-based agroforestry models for alkali soils have been developed by the Narendra Dev University of Agriculture and Technology, Faizabad. In this model the growth rate of guava + eucalyptus + subabul was faster and production was higher in terms of fruit, fodder and fuelwood. Intercrops of bottle gourd, tomato, cabbage and spinach have been successfully grown in association with guava trees. The fruit species which can be cultivated successfully in alkali soils include *Carissa carandas* (karonda), *Ziziphus mauritiana* (ber)*, Emblica officinalis* (aonla)*, Syzygium cumini* (jamun) *and Psidium guajava* (guava). Aromatic and medicinal crops such as dill, isabgol, tulsi and matricaria can also be grown as intercrops between fruit trees in case if pH of soil is <9.5. The list of fruit crops suitable for developing horti-pasture system in alkali soils under different situations is given in Table 6.

4.1.4 Sequential Agroforestry System

In this system trees and arable crops are grown in sequence instead of growing them simultaneously. This practice is followed to raise fertility status of the soil, which has gone down either due to continuous cropping or where inherent fertility status of the soil is low, as in sandy desert and salt-affected soils. Short-duration, fast-growing and nitrogen-fixing trees like *Sesbania*, *Leucaena*, *Cajanus* etc. grown for 4–5 years are cut for fuelwood or forage, and the soil is used for arable farming. Rao and Gill (1990) studied this land-management system from 1985 to 1990 on a reclaimed alkali soil having surface pH 8.8. *Sesbania* was grown for 4 years followed by rice-wheat cropping system. Only P and Zn were applied to the crops at recommended rates, and the response to applied N was separately determined in plots fertilized differentially with urea-N. Grain yield of the first rice crop was 6.4 t ha^{-1} in *Sesbania* plots without adding additional nitrogen. Similarly, wheat yields averaged 2.2 t ha^{-1} even without any N application in *Sesbania* plots compared with 1.35 t ha^{-1} in the control plots. About 0.85 Mg ha^{-1} additional grains as well as 17 kg ha^{-1} of additional N ha^{-1} was derived from mineralization of organic residues. The residual effect of *Sesbania* was also noticed on the following rice crop. The total N uptake of crops in the control was 142 kg ha^{-1} and in *Sesbania* plots 222 kg ha^{-1}. The organic fertilization was 2.5 times as effective as inorganic N fertilization. Even after growing crops, without adding any N, available N status in *Sesbania* plots was similar to the plots fertilized with 120 kg N ha^{-1}.

4.2 Alley Cropping

Alley cropping, also called hedgerow intercropping, integrates the benefits of fellow period directly into the cropping period. Crops are sown in alleys between rows of trees, usually leguminous. The trees are pruned at regular intervals, at about 0.6 m aboveground level, and the pruned materials are used for mulch or animal meal. The main purpose of alley cropping is to exploit the soil improvement potential of MPTs for maintaining or even increasing crop production. But production of fodder and fuelwood has also been an objective in many alley cropping trials in India. It is a quite flexible technology that benefits crop and livestock activities and can, through a modification of tree management techniques, provide fuelwood for the household. It is a system that can be adapted to meet particular priorities of an individual farmer. *Leucaena leucocephala* and *Gliricidia sepium* have been most widely used for alley farming. Now the use of two or more species is recommended to reduce the possibility of pests and diseases completely destroying the production as psyllid pest did to *Leucaena* in a major part of the Asia and the Pacific.

4.3 Functions of Agroforestry Systems

4.3.1 Agroforestry Systems as Carbon Sinks

Land management actions that enhance the uptake of CO_2 or reduce its emissions have the potential to remove a significant amount of CO_2 from the atmosphere if the trees are harvested, accompanied by regeneration of the area, and sequestered carbon is locked through non-destructive (non-CO_2 emitting) use of such wood. The potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees and shrubs, geographic location, local climatic factors and management regimes. The growing body of literature reviewed here indicates that agroforestry systems have the potential to sequester large amounts of above- and belowground carbon compared to treeless farming systems (Singh et al. 1993). In order to exploit the mostly unrealized potential of carbon sequestration through agroforestry in both subsistence and commercial enterprises, innovative policies, based on rigorous research results, are required.

Organic carbon in soils and their mineralization can be measured as an index of reclamation of degraded soils. Carbon content in barren sodic soils as a result of plantation can be enhanced by increasing the population density per hectare as observed in *Terminalia arjuna* plantations (Jain and Singh 1998). In saline and alkali soils, mineralization rate is suppressed. The soil carbon varies with state and time depending on the productivity potential of a soil site and harvest impacts on the forest floor carbon pool (Scott et al. 1999).

4.3.2 Enhancing Soil Fertility

Trees in agroecosystems can enhance soil productivity through biological nitrogen fixation, efficient nutrient cycling and deep capture of nutrients and water from soils. Even the trees that do not fix nitrogen can enhance physical, chemical and biological properties of soils by adding significant amount of above- and belowground organic matter as well as releasing and recycling nutrients in the soil. Maintaining and enhancing the fertility of salt-affected soils to grow food grains as well as tree biomass can help meet the demand in the future. Tree species have the potential to conserve moisture and improve fertility status of the salt-affected soils in agroforestry systems. Alternate land use systems such as agroforestry, agro-horticultural, agro-pastoral and agrosilvipasture are more effective for soil organic matter restoration. The degree of improvement was linked to the total biomass production, annual litter fall and its quality, root spread and weight and the level of management practices (Singh, 1996). The highest litter fall at 10 years of tree growth stage was recorded under *Prosopis juliflora* followed by *Casuarina equisetifolia*, *Acacia nilotica*, *Terminalia arjuna* and *Pongamia pinnata*. The winter months accounted for 40–55 % of total litter fall that was composed of about 75.80 % foliage. The increase in organic carbon content of the surface soil (0–15 cm) in a span of 10 years was about fourfold under *P. juliflora* and *P. pinnata* and about threefold in other species (Singh et al. 2011,Tripathi and Singh, 2005).

4.3.3 Improving Water Quality and Water Use Efficiency

Trees with their comparatively deeper root system improve groundwater quality by taking up the excess nutrients that have been leached below the rooting zone of agricultural crops. These nutrients are then recycled back into the system through root turnover and litter fall, increasing the nutrient use efficiency of the agroecosystems. There is robust evidence that agroforestry systems have the potential for improving water use efficiency by reducing the unproductive components of the water balance (run-off, soil evaporation and drainage). Examples from India and elsewhere show that simultaneous agroforestry systems could double rainwater utilization compared to annual cropping systems, mainly due to temporal complementarily and use of run-off in arid monsoon regions. For instance, combination of crop and trees uses the soil water between the hedgerows more efficiently than the sole cropped trees or crops, as water uptake of the trees reached deeper and started earlier after the flood irrigation than of the *Sorghum* crop, whereas the crop could better utilize topsoil water. Integration of persistent perennial species with traditional agriculture also provides satisfactory drainage control to ameliorate existing outbreaks of salinity. Agroforestry in peri-urban agriculture can also be useful for utilization of sewage-contaminated wastewater from urban systems and biodrainage to prevent waterlogging in canal-irrigated areas.

4.3.4 Soil Reclamation

Various studies have been conducted to monitor the soil dynamics due to afforestation of salt-affected soils. As the tree grows, a large amount of litter is shed on the ground, which during decomposition releases several weak acids (humic and fumic) to lower down the soil pH and EC. Singh et al. (2010) and Singh et al., 2008 observed that the litter production after 10 years of tree growth by *Prosopis juliflora*, *Casuarina equisetifolia*, *Acacia nilotica*, *Terminalia arjuna* and *Pongamia pinnata* was 6.1 Mg ha^{-1}, 5.7 Mg ha^{-1}, 5.4 Mg ha^{-1}, 5.1 Mg ha^{-1} and 5.0 Mg ha^{-1}, respectively.

After 10 years of plantation, a significant improvement in the physical properties of the sodic soil was recorded in an experiment conducted at Shivri research farm at Lucknow, India. The bulk density in 0–75 mm soil layer decreased significantly over the control, whereas porosity and infiltration rate increased. The maximum reduction in bulk density was recorded under *Casuarina equisetifolia* followed by *Pithecellobium dulce*, *Acacia nilotica* and *Prosopis juliflora*; the minimum reduction was recorded under *Azadirachta indica* over the initial value. The bulk density of the surface soil (0–75 mm) under control remained unchanged, whereas under 75–150 mm soil layer, it was slightly improved (Table 7). Soil porosity under 10-year-old plantation at 0–75 mm soil layer increased from 40.7 to 54.3 %. However, under the control plot, soil porosity was almost unchanged. The highest soil porosity at 0–75 mm soil layer was recorded under *Casuarina equisetifolia* and minimum under *Azadirachta indica.* There was significant improvement in the infiltration rate under tree plantation over the control and initial values. The highest infiltration rate after 10 years of tree plantation was recorded under *Prosopis juliflora* followed by *Casuarina equisetifolia*, *Pongamia pinnata*, *Pithecellobium dulce*, *Acacia nilotica*, *Azadirachta indica*, *Terminalia arjuna*, *Prosopis alba*, *Eucalyptus tereticornis* and *Cassia siamea*.

Table 7 Ameliorative effect of different tree species on physical properties of soil 10 years after plantation

Tree species	Bulk density (Mg m^{-3})		Soil porosity (%)		Cumulative infiltration rate (mm day^{-1})
	0–75 mm	75–150 mm	0–75 mm	75–150 mm	
Terminalia arjuna	1.47	1.52	44.5	42.6	21.20
Azadirachta indica	1.48	1.56	44.1	41.1	21.70
Prosopis juliflora	1.32	1.46	50.2	44.9	26.30
Pongamia pinnata	1.36	1.57	48.6	40.7	24.30
Casuarina equisetifolia	1.21	1.42	54.3	46.4	25.80
Prosopis alba	1.37	1.61	48.3	39.2	20.00
Acacia nilotica	1.29	1.58	51.3	40.4	21.90
Eucalyptus tereticornis	1.38	1.51	48.0	43.0	19.70
Pithecellobium dulce	1.25	1.58	52.8	40.4	23.10
Cassia siamea	1.46	1.48	45.0	44.1	15.80
Natural fallow	1.50	1.57	43.4	40.7	11.80
Initial	1.57	1.60	40.7	39.6	2.10
LSD ($P \leq 0.05$)	0.08	0.11	3.26	0.76	6.34

Source: Singh et al. (2011)

Biological properties of the soil are largely affected by microorganism status in the soil and nutrients held by these organisms. Soil microorganisms are the most active fraction of soil organic matter and therefore play a central role in the fellow of plant nutrients in ecosystems. They constitute a transformation matrix for organic materials in the soil and act as a labile reservoir for plant available N and P (Jenkinson and Ladd 1981). Forest growth over 40 years has reclaimed the soil in many properties (Singh & Gill, 1992). Several soil characteristics were studied comparatively in forest as well as non-forested sodic soils of the surrounding area to observe the degree of reclamation in the degraded sodic soil. Microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) decreased significantly from the surface to a depth of 45 cm (Table 8). This decrease was about 90 % (MBC) and 65 % (MBP) from the surface soil. The mean MBC up to 0–45 cm depth was 131 μg g^{-1} in forested soil which was approximately three times greater than non-forested sodic soils. Microbial biomass carbon, nitrogen and phosphorus varied significantly between forested and barren sodic soils.

4.4 *Biomass and Bioenergy Production*

To find high biomass producing tree species for sodic soils, long-term experiment was conducted on highly sodic soils (pH > 10.0); at Shivri research farm of Central Soil Salinity Research Institute, *Prosopis juliflora* gave the maximum dry biomass

Table 8 Biological properties of forested (F) and non-forested sodic (C) soils (μg g^{-1})

Character	State	Depth (cm)			Mean	LSD_{05}
		0–15 mean ± SD	15–30 mean ± SD	30–45 mean ± SD		
MBC	F	285.33 ± 87.66	55.0 ± 33.15	33.33 ± 13.57	124.55 ± 44.79	15.0
	C	89.33 ± 6.65	32.0 ± 9.16	19.66 ± 4.61	46.99 ± 2.27	
MBN	F	53.16 ± 3.09	19.93 ± 5.96	10.2 ± 0.75	27.43 ± 2.60	4.37
	C	14.33 ± 3.76	8.26 ± 0.11	4.96 ± 0.77	9.18 ± 1.94	
MBP	F	25.76 ± 7.0	15.53 ± 4.31	10.66 ± 2.24	17.31 ± 2.38	7.0
	C	9.7 ± 3.81	5.53 ± 0.76	4.13 ± 1.17	6.45 ± 1.65	

Source: Singh and Goel (2012)

Table 9 Biomass production of different tree species in sodic soils

Species	Tree biomass (t ha^{-1})				Total energy (GJha^{-1})
	Stem	Branch	Leaf	Total	
Terminalia arjuna	23.78	10.70	7.13	41.62	933.53
Azadirachta indica	11.17	6.21	1.84	19.22	520.66
Prosopis juliflora	27.73	26.60	2.17	56.50	1267.75
Pongamia pinnata	9.05	14.45	3.10	26.60	576.85
Casuarina equisetifolia	28.60	9.15	4.35	42.10	934.11
Prosopis alba	14.70	11.10	1.95	27.75	607.13
Acacia nilotica	22.15	26.14	2.46	50.75	1206.32
Eucalyptus tereticornis	24.40	5.27	2.10	31.77	662.12
Pithecellobium dulce	23.50	6.81	1.94	32.25	696.26
Cassia siamea	14.30	5.65	1.70	21.65	466.89
LSD($P \leq 0.05$)	2.43	4.63	1.21	5.42	

Source: Singh et al. (2010)

with about 96 % biomass allocated to stem and branch wood followed by *Acacia nilotica* with 95 % biomass in wood components (Singh et al. 2010) (Table 9). This is because of their fast growth and higher yields in sodic soil. The highest portion of dry biomass in stem part was recorded with *Eucalyptus tereticornis and Pithecellobium dulce*, respectively, because of less number of branches, whereas the share of dry biomass through branches was higher in *Pongamia pinnata*, while *Terminalia arjuna* showed relatively high proportion of foliar biomass because of broad laminar morphology.

In a long term field study conducted at Shivri research farm, Lucknow, India, Singh et al. (2011) reported that the leaves had slightly higher heat of combustion, whereas it was lowest in stem (Table 9). The calorific values of stem and branches exhibited less variation, with *Acacia nilotica* having the highest heat combustion in both stem and branches, respectively. The differences in total energy production and its allocation to different plant parts led to variation between biomass yield and its allocation to stem, branch and leaves per hectare. *Prosopis juliflora* gave the highest energy harvest followed by *Acacia nilotica* and the lowest by *Azadirachta indica.*

4.5 Replacement of Cow Dung and Nutrients

As a substitute for firewood, a large quantity of cow dung is burnt as fuel in rural India. Abrol and Joshi (1984) calculated that roughly 112 and 90 Mg cow dung can be saved by raising 1 ha plantation of acacia and eucalyptus, respectively, on alkali soils (Table 10).

The cow dung thus saved can be used for upgrading fertility status of alkali soils. The nitrogen saved in the form of animal dung can meet the demand for this nutrient for about 21–26 ha by raising 1 ha of either eucalyptus or acacia plantation. They further estimated that for every ton of dung cake burnt, approximately 70 kg food grains are lost. These estimates indicate that nearly 7.84 ton food grains can be augmented by raising 1 ha of acacia for firewood and adding saved animal dung for crop production. Such benefits from extending agroforestry on salty lands will considerably increase the standard of living and purchasing power of rural work force and provide a base for economic development that will help alleviate poverty in the country. Moreover, such programmes will improve the distorted ecological balance for survival of the mankind.

4.6 Employment Generation

The role of agroforestry in providing employment, particularly in the rural areas where there is often serious unemployment and poverty, is an important consideration in assessing the development value. Abrol and Joshi (1984) estimated that roughly 216 man-days ha^{-1} are needed for initial establishment of forest on alkali soils. For raising acacia and eucalyptus for 7 years, approximately 1092 and 940 man-days are needed, respectively.

Table 10 Direct and indirect benefits from raising 1 ha forest on alkali soil (tons)

No.	Variable	Acacia	Eucalyptus
1	Increase in fuelwood production	68.00	40.00
2	Saving of animal dung cake[a]	112.00	90.00
3	Increase in food production[b]	7.84	6.30
4	Saving of soil nutrients[c]		
	(a) Nitrogen	0.40	0.32
	(b) Phosphate	0.17	0.14
	(c) Potassium	0.22	0.18

[a] 1 Mg fuelwood is estimated to replace roughly 2.24 Mg animal dung cake

[b] 1 Mg animal dung is estimated to add nearly 70 kg food grain production

[c] 1 Mg animal dung cake is estimated to supply roughly 3.5, 1.5 and 2.0 kg of N, P and K, respectively

5 Criteria for Evaluating Agroforestry Systems

The basic attributes of all agroforestry systems are:

1. Productivity (production of preferred commodities and outputs)
2. Sustainability (maintaining long-term productivity without degradation of the natural resource base on which that production is dependant)
3. Adoptability (acceptability of the system by the target clientele and the amenability of the system to adapt itself to prevailing social conditions)

It then follows that the criteria for evaluating agroforestry systems should be based on these attributes.

5.1 Productivity Evaluations

The obvious approach would be to express productivity of the different outputs in measurable, quantitative and meaningful terms. Economic yields of different species are a very common and easily understandable productivity measurement. But the noncomparable nature of different products puts a serious limit to the applicability of this approach to comparison of structurally dissimilar systems.

Calculation of the economic value of the different products gives another easily understood basis of evaluation. In a vast county like India with distinctly different agro-ecological regions, such economic calculations based on the local market value of the products are a good method of comparing systems from different areas. But the main drawback of this method is that many of the products of indigenous agroforestry systems are of a nonmonetary nature. Moreover, many of the products are consumed at the point of production; they do not enter even the local markets.

In agronomic and ecological research, scientists use land equivalent ratio (LER) as a basis of comparing the productivity of different systems. It was originally proposed as a means of comparing the performance of species in an intercropping situation with its performance when grown as a sole crop, and it is so called because it refers to the relative land requirements of intercropping versus monocropping (Mead and Willey 1980). Various modifications have been proposed to the concept (Hiebsch and McCollum 1987).

5.2 Sustainability Evaluations

Sustainability is now a major issue in all development activities concerned with land management. It is a concept that serves as a rallying theme for environmentalists and agricultural scientists and reflects the changing directions of international development efforts.

However, although much has been said and written about sustainability, it still lacks a universally accepted definition. The World Commission on Environment and Development defined sustainable development as development 'that satisfies the needs of the present without compromising the capacity of the future generations to satisfy theirs' (WCED 1987). The meaning of sustainability is dependent upon the context in which it is applied and on whether its use is based on a social, economic or ecological perspective. Nair (1990) stated that 'sustainability, like agroforestry, can be better explained by liking at the issues underlying the concept, rather than by relying on abstract definitions. In simple, production-oriented systems, sustainability can be considered as the maintenance of production over time, without degradation of the natural base on which that production is dependent'.

Since sustainability deals with the long-term productivity, the ecological, social and economic cost associated with maintaining productivity is important. Thus, sustainability evaluations will be interlinked with the other two evaluation criteria (productivity and adoptability). Therefore, the main issues related to sustainability for our discussion here are soil-related (ecological) parameters. Table 11 gives a summary of the present state of knowledge about the effect of trees on soils. It becomes imperative therefore that an evaluation procedure for agroforestry systems should evaluate the system(s) in terms of all these soil-related sustainability parameters. But we still do not have fully developed and widely adopted the criteria for measurement of all these parameters. Until these are fully developed, we will continue with anecdotal (qualitative) statements about the sustainability of agroforestry systems.

Table 11 Soil-related sustainability parameters of agroforestry

	Scientific evidence	
Factor/parameter	Direct	Indirect
Beneficial effects		
1. Organic matter addition	×	
2. Erosion control	×	
3. Improvement of physical properties		×
4. N fixation	×	
5. Improved nutrient cycling	×	
6. Synchrony in nutrient availability		×
7. Moisture availability	×	
8. Soil reclamation		×
9. Improved nutrient availability	×	
Adverse effects		
1. Moisture competition		×
2. Nutrient competition		×

5.3 Adoptability Evaluations

As in the case of productivity and sustainability evaluations of agroforestry systems, there are no widely adoptable criteria for adoptability evaluation as well. Of course, it can be argued that indigenous agroforestry systems have stood the test of time, and they need no adoptability evaluation. In such a situation, what is useful is to learn from the farmers as to why they continue to practice such indigenous systems. That information could then be used as the basis for developing adoptability criteria for new technologies.

Muller and Scherr (1990) undertook a review of agroforestry technology monitoring and evaluation in 165 projects worldwide and suggested a planning approach to the design of effective and adoptable project interventions. This approach has three steps: farmer evaluation, field evaluations and field testing. From the same study, Scherr and Muller (1990) suggest that technologies may be intensively monitored on a small number of farms, whereas a larger sample of farms may be monitored periodically but less intensively in the project area. But the lack of available methods for evaluating variables that are specific to agroforestry, particularly the effectiveness and quality of service functions, is a serious drawback that hinders evaluation procedures for assessing adoptability.

In summary, it has been realized that agroforestry systems need to be evaluated on the basis of their productivity, sustainability and adoptability. While adoptability per se is not an important consideration of evaluation of indigenous systems, all three attributes are important for the evaluation of improved systems. However, the precise criteria for such evaluations have not been fully developed yet.

6 Planting Techniques for Successful Establishment of MFTS

In addition to the effect of high sodium on physico-chemical properties of soils and nutritional problems, the tree growth in alkali soils is constrained due to inability of their roots to proliferate through the hard kankar (calcite) pan existing usually at depths below 50–75 cm from the surface. Therefore, even the earlier afforestation attempts resorted to replacement of excavated alkali soil (50 cm deep pits) with normal soil to improve upon their drainage by digging holes (90–150 cm deep) and refilling the holes with a mixture of good soil, FYM and gypsum before planting tree saplings. The method was introduced in 1895 and named 'deep thala system' of plantation. Later, Yadav and Singh (1970), Yadav (1975) and Yadav (1980) concluded that addition of gypsum (50 % GR) and FYM @ 25 kg per pit (90 × 90 cm) was comparable to replacement of the original alkali soil (pH 10.0) with normal soil for the growth of saplings and their survival. The pit planting technique suffers from the disadvantage of higher requirements of amendments, laborious pit digging operation involving more earthwork and non-perforation of roots through calcic horizon

Table 12 Effect of planting methods on tree growth in a waterlogged saline soil

	Subsurface			Ridge trench		
	Height (m)	DSH (cm)	PS (%)	Height (m)	DSH (cm)	PS (%)
Tree species	After 9 years of planting					
Acacia nilotica	6.41	44.6	50			0
Acacia tortillas	5.31	34.3	56	3.11	10.8	25
Leucaena leucocephala	6.91	36.7	50			0
Prosopis juliflora	8.06	55.9	100	6.40	42.5	100
	After 27 months of planting					
	Surface			SPFIM		
Acacia auriculiformis	1.43		13	2.42		65
Acacia nilotica	3.21		69	2.89		95
Casuarina equisetifolia	2.13		46	3.00		95
Eucalyptus amanuensis	2.24		50	3.78		95
Terminalia arjuna	1.83		81	2.00		90

Source: Tomar et al. (1994)

(hard pan). Keeping in these limitations in view, the planting technique has been improved through ‘auger-hole technique’ at CSSRI, Karnal (Sandhu and Abrol 1981). Here, 100–140 cm deep and 20–25 cm diameter auger holes are dug with a tractor-operated auger, and saplings are planted after suitably amending the dugout soil. The performance of trees planted with this method has been highly satisfactory (Table 12). This method has picked up very well with the foresters because of reduced manual labour costs and speedy operations. In addition to piercing of hard kankar layer, the advantage of this technique includes encouraging and training of deeper routing. Thus, the trees are able to probe deeper soil layers for water and nutrients to sustain their growth.

Under saline soils the tree growth is adversely affected due to reduced water availability with excessive salts along with period waterlogging and poor aeration especially during the monsoon season. To improve the aeration and reduce the water stagnation, the effect planting on high ridges and mounds showed good results. In waterlogged saline soils, the salinity is usually maximum in the surface layers and decreases with depth down to water table. Therefore, to encash the advantage of low salinity and better soil moisture resumes in subsurface layers. Tomar and Gupta (1984–1994) tried the subsurface planting of saplings (at a depth of 30 cm below the surface) and compared it with ridge planting (490 cm high). Substantially, higher salts accumulated in the ridges that resulted in poor survival and sapling growth (Table 12). The performance of trees was better when planted with subsurface method but the need for spot irrigation was the main problem. Minhas et al. (1996) observed that the planting in the sill of furrow (60 cm wide and 20 cm wide) was subsequently used for irrigating the tree saplings. Besides uniform application of irrigation water and reduction of application cost, the subsurface planting and furrow irrigation method helped increasing a low salinity zone below the sill of the furrows.

References

Abrol, I. P., & Joshi, P. K. (1984). Economic viability of reclamation of alkali lands with special reference to agriculture and forestry. In S. Kamal (Ed.), *Economics of waste land development* (pp. 19–30). New Delhi: SPWD.

Bhargav, G. P., Sharma, R. C., Pal, D. K., & Abrol, I. P. (1980). A case study of the distribution and formation of salt affected soils in Haryana State. In *International Symposium on Salt Affected Soils*, Karnal (pp. 83–91).

Dagar, J. C., & Singh, N. T. (1994). Agroforestry options in reclamation of problem soils. In P. K. Thampan (Ed.), *Trees and tree farming* (pp. 65–103). Cochin, India: Peekay Tree Crops Development Corporation.

Dagar, J. C., & Tomar, O. S. (2002). Utilization of salt affected soils and Poor quality waters for sustainable bio-saline agriculture in arid and semiarid regions of India. In *12th ISCO Conference*, Beijing, 2002.

FAO (Food and Agricultural Organization). (2007). Database http://apps.fao.org/page/collections?subset=agriculture. Accessed 22 Dec 2007.

Grewal, S. S., & Abrol, I. P. (1989). Amelioration of sodic soils by rain water conservation and karnal grass grown in interspace of trees. *Journal of Indian Society of Soil Science, 37*, 371–376.

Gupta Raj, K., Tomar, O. S., & Minhas, P. S. (1995). Managing salt affected soils and waters for afforestation (p. 23). Bull. 7/95, CSSRI, Karnal, India.

Gupta, G. N., Prasad, K. G., Mohan, S., Subramaniam, V., & Manivachakam, P. (1988). Effect of alkalinity on survival and growth of tree seedlings. *Journal of Indian Society of Soil Science, 36*, 537–542.

Hiebsch, C. K., & McCollum, R. E. (1987). Area x time equivalency ratio: A method for evaluating the productivity of intercrops. *Agronomy Journal, 79*, 15–22.

Jain, R. K., & Singh, B. (1998). Biomass production and soil amelioration in a high density *T. arjuna* plantation on sodic soils. *Biomass and Bioenergy, 15*, 187–192.

Jenkinson, D., & Ladd, J. N. (1981). Microbial biomass in soil: Measurement and turnover. In E. A. Paul & J. N. Ladd (Eds.), *Soil biochemistry* (Vol. 5, pp. 415–471). New York: Marcel Dekkar.

Mead, R., & Willey, R. W. (1980). The concept of land equivalent ratio and advantages in yield from inter-cropping. *Experimental Agriculture, 16*, 217–218.

Muller, E. U., & Scherr, S. J. (1990). Planning technical interventions in agroforestry projects. *Agroforestry Systems, 11*, 23–44.

Minhas, P. S. (1996). Saline water management for irrigation in India. *Agricultural Water Management, 30*, 1–24.

Nair, P. K. R. (1990). The prospect for agroforestry in the tropics. *Technical Paper No. 131*. World Bank, Washington DC.

Pandey, N., Prakash, C., & Pandey, D. N. (2007). Linking knowledge to action for sustainable development in India. In S. Mudrakartha (Ed.), *Empowering the poor in the era of knowledge economy* (pp. 4–10). Ahmedabad: VIKSAT.

Rao, D. L. N., Gill, H. S. (1990). Nitrogen fixation and biomass productivity by annual and perennial legumes. Annual Report on CSSRI, Karnal (pp. 112–114).

Sandhu, S. S., & Abrol, I. P. (1981). Growth responses of *Eucalyptus tereticornis* and *Acacia nilotica* to selected cultural treatments in a highly sodic soil. *Indian Journal of Agricultural Sciences, 51*, 437–443.

Scherr, S. J., & Muller, E. U. (1990). Technology impact evaluation in agroforestry projects. *Agroforestry Systems, 13*, 235–257.

Scott, N. A., Tate, K. R., Robertson, J. F., Giltrap, D. J., & Smith, C. T. (1999). Soil carbon storage in plantation forests and pastures: Land—use change implications. *Tellus, 51B*, 326–335.

Sharma, R. C., Rao, B. R. M., & Saxena, R. K. (2004). Salt affected soils in India – Current assessment. In *Proceedings of Advances in sodic land reclamation, International conference on sustainable management of sodic lands*, Lucknow, India (1–26).

Singh, G. (1995a). An agroforestry practice for the development of salt lands using *Prosopis juliflora* and *Leptochloa fusca. Agroforestry Systems, 27*, 61–75.

Singh, G. (1995b). An agroforestry practice for the development of salt lands using *Prosopis juliflora* and *Laptocloa fusca. Agroforestry systems, 29*, 61–75.

Singh, B. (1996). Influence of forest litter on reclamation of semiarid sodic soils. *Arid Soil Research and Rehabilitation, 10*, 201–211.

Singh, B. (1998). Contribution of fine roots in reclamation of semiarid sodic soils. *Arid Soil Research and Rehabilitation, 12*, 207–222.

Singh, G., & Gill, H. S. (1992). Ameliorating effect of tree species on characteristics of sodic soils at Karnal. *Indian Journal of Agricultural Science, 62*, 142–146.

Singh, B., & Goel, V. L. (2012). *Restoration of degraded land to functioning forest ecosystem* (p. 309). Lucknow: CSIR, National Botanical Research Institute.

Singh, G., Singh, N. T., & Tomar, O. S. (1993). Agroforestry in salt affected soils. Research Bulletin, CSSRI, Karnal (p. 65).

Singh, Y. P., Sharma, D. K., Singh, G., Nayak, A. K., Mishra, V. K., & Singh, R. (2008). Alternate land use management for sodic soils. Tech. Bull. No. 2/2008. Central oil Salinity Research Institute, Regional Research Station, Lucknow, India (p. 16).

Singh, Y. P., Singh, G., & Sharma, D. K. (2010). Biomass and Bio-energy production of ten multipurpose tree species planted in sodic soils of Indo-gangetic plains. *Journal of Forestry Research, 21*(10), 19–14.

Singh, Y. P., Singh, G., & Sharma, D. K. (2011). Ameliorative effect of multipurpose tree species grown on sodic soils of Indo-gangetic Alluvial Plains of India. *Arid Land Research and Management, 25*, 1–20.

Singh, Y. P., Singh, G., & Sharma, D. K. (2014). Bio-amelioration of alkali soils through agroforestry systems in central Indo-Gangetic plains of India. *Journal of Forestry Research, 25*(4), 887–896.

Tomar, O. S., Minhas, P. S., & Gupta Raj, K. (1994). Potentialities of afforestation of waterlogged saline soils. In P. Singh, P. S. Pathak, & M. M. Roy (Eds.), *Agroforestry systems for degraded lands* (Vol. 1, pp. 111–120). New Delhi: Oxford and IBH publishing Co. Pvt Ltd.

Tripathi, K. P., & Singh, B. (2005). The role of revegetation for rehabilitation of sodic soils in semi arid subtropical forest. *Restoration Ecology, 13*(1), 29–38.

World Commission for Environment and Development (WCED). (1987). *Our common future*. Oxford: Oxford University Press.

Yadav, J. S. P. (1975). Improvement of saline alkali soils through biological methods. *Indian Forester, 101*(7), 385–395.

Yadav, J. S. P. (1980). Salt affected soils and their afforestation. *Indian Forester, 106*, 259–272.

Yadav, J. S. P., & Singh, K. (1970). Tolerance of certain forest species to varying degree of salinity and alkalinity. *Indian Forester, 96*, 587–599.

Yadav, J. S. P., & Singh, K. (1986). Response of *Casuarina equisetifolia* to soil salinity and sodicity. *Journal of Indian Society of Coastal Agriculture Research, 4*, 1–8.