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Agroforestry practices for physiological amelioration of salt affected soils

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ABSTRACT

Agroforestry is a sustainable land use system act as an alternative form of biological reclamation in salt affected soils apart from sustainable production, continuous income, and regular employment along with food and nutrition security. In general, salt affected soils get ameliorated by tree species; however, following factors such as nature and type of tree species planted, growth habit, quantity and quality of litter production, planting density, nitrogen fixation, and different management practices are influenced. In the present study, various studies pertaining to soil reclamation in the salt affected soils are reviewed. Overall result showed that trees grown with crops, horticultural crops, pastures resulted in improvement of physical and chemical properties of soil under various agroforestry systems. For instance, reduction of soil pH, electrical conductivity, and exchangeable sodium percentage minimization of salt deposition in the upper layers of the soil, improvement of water permeability and water holding capacity, improvement of infiltration rate and hydraulic conductivity with soil fertility, enhancement of cation exchange capacity, and other features are characteristics of soil as influenced by tree species, as well as through agroforestry practices. Various multipurpose tree species such as *Acacia auriculiformis*, *Acacia nilotica*, *Albizia lebbeck*, *Terminalia arjuna*, *Casuarina equisetifolia*, *Prosopis cineraria*, *Prosopis juliflora*; and fruit trees such as *Zizyphus jujuba*, *Emblica officinalis*, *Syzygium cumini*, and *Tamarindus indica* ameliorated the different salt affected soils in different agroforestry systems *viz.,* agrisilvicultural system, silvipastoral system, multipurpose wood lot, and agrihorisilvicultural system. Thus, agroforestry system provides an alternative for restoring soil health and amelioration of salt affected soils for further yield improvement. Therefore, these species are suggested for reclamation of salt affected soil through agroforestry systems.

KEY WORDS: Agroforestry, alkali soil, multipurpose tree species, sodic soil, soil amelioration

INTRODUCTION

Total geographic area of the country is 329 million hectare, out of which, 6.74 million hectares of land are affected by salts. Gujarat, Uttar Pradesh, Madhya Pradesh, West Bengal, Maharashtra, Rajasthan, and Tamil Nadu cover the maximum salt affected lands (Biswas and Biswas, 2014). In the era of climate change with depleting soil fertility and reducing ground water table with the increasing pressure on land resources lead to different types of degradation including salinization, which is the process of increasing salt in soil profiles. One of salt affected group of soils belonging to small and marginal farmers is alkali soils, which is unproductive because of high pH and per cent exchangeable Na^+, which adversely affect physico-chemical and biological properties of these soils (Oster *et al.*, 1996; Oster *et al.*, 1999; Qadir *et al.*, 1996; Qadir *et al.*, 1997; Qadir *et al.*, 2001). The presence of hard kankar (calcite) pan at a depth of about 90 cm of the soil profile is a major problem for planting of deep rooted plants (Garg *et al.*, 1996; Jain and Singh, 1998; Singh *et al.*, 1989). Tree growth in alkali soils is constrained mainly by the inability of roots to penetrate this calcite pan. Judicious use of these lands can substantially contribute to increasing demand for food, fodder, fuel, and timber in India. Planting of trees and grasses on alkali soils provide an alternative to control further deterioration of these soils and to maintain soil health (Thorrold *et al.*, 1997; Singh *et al.*, 2008). Another group is saline soil, which also influences the growth, development and production of crops, fruit and tree species.

SALT AFFECTED SOILS NATURE

Soils having excess salt content (>critical level) negatively affects the growth, development and production of most of the crop plants (Richards, 1954). Salts primarily originate as a result of weathering of rocks. In the arid and semi-arid tropics, high temperature, low rainfall with high evaporation rate left out the salts at the soil surface. In the low rainfall areas, the deposited salts at the surface are sometimes blown by wind over years and get deposited on soil surface at other place producing salt affected soils elsewhere. The ground water containing high amount of salts increases the salt content of soils. Faulty irrigation with injudicious uses of inorganic fertilizers in the farms increases the surface salt content in the soil.

Salt affected soils are broadly classified into alkali and saline soils on the basis of nature, amount of soluble salts affecting the physico-chemical characteristics, color, process of formation, and plant response. Alkali soils have exchangeable sodium percentage (ESP), sodium absorption ratio (SAR), and pH more than 15, 13, and 8.2, respectively. The high alkali status resulted in scorching and leaf burning of crop or yellowing of leaves. In extreme condition, the land remains barren with very less or no vegetation (Biswas and Biswas, 2014; Richards, 1954).

Saline soils are characterized by low ESP and pH < 8.2. These soils support patchy growth of crops and show visible signs of salt injury like tip burn or chlorosis of leaves. Increased ESP or pH in the soil causes physical properties of soil that negatively affects on the plant growth. For instance, restriction in entry of air and water in the soil resulted in poor root growth or causing temporary water logging, formation of surface crust, which inhibit seedling emergence, and the compaction of topsoil and subsoil leads to poor plant growth. Similarly, excess soil salinity also causes plant growth, where increased level of soil salinity decreases water availability to plants, retards the absorption of essential plant nutrients, and some time, it may act as toxic to the plants (Biswas and Biswas, 2014; Bhargava 1989).

CHARACTERISTICS AND ROLE OF AGROFORESTRY FOR AMELIORATION OF SALT AFFECTED SOILS

Agroforestry a sustainable land use system consists of trees, agricultural crops, and grasses with/without animals as various components and act as an alternative form of biological reclamation of salt affected soils along with continuous income generation, employment and food and nutrition security. Agroforestry is generally practiced with the objective to better utilization of resources, to minimize the environmental degradation, to improve the soil organic matter content through leaf litter and plant debris, and to maximize the more efficient nutrient cycling within system. Moreover, more proficient utilization of nutrients and biological nitrogen fixation and solubilization of relatively unavailable nutrients are added advantages of agroforestry. In general, the salt affected soils get ameliorated by trees depends upon the nature and type of tree species, growth habit, quantity and quality of litter produced, planting density, age of plantation, ability to fix N, and management practices. Trees grown with agricultural crops in salt affected soils improve the physical properties of soil. For instance, tree minimizes the salt deposition in the upper layers of the soil, it prevents salt accumulation on the surface layer, it improves water permeability and it facilitate leaching of salts, it decreases the bicarbonate levels, it reduces soil pH and electrical conductivity (EC), it increases water holding capacity, as well as infiltration rate and hydraulic conductivity with soil fertility. Similarly, enhancing cation exchange capacity (CEC) reducing ESP and improvement in desodification process all along the profile depth can be taken place through tree planning in salt affected soils. Tree species has different ability to overcome the problem of alkalinity. However, Tomar and Gupta categorized tree species into high tolerant, tolerant, moderately tolerant, and sensitive, which are publicized in Table 1 (Tomar and Gupta, 1986).

Again Tomar and Gupta also classified trees into tolerant, moderately tolerant, moderately sensitive, and sensitive categories based on ability of tree species to withstand the various level of soil salinity with different examples given in Table 2 (Tomar and Gupta, 1986).

AGROFORESTRY SYSTEMS FOR AMELIORATION OF SALT AFFECTED SOILS

Successful cultivation of cultivable salt affected wastelands necessitates suitable reclamation and management strategies. Of different methodologies to ameliorate the salt affected lands, planting trees in the form of agroforestry are a low cost viable option. Location specific agroforestry models have been developed for better results in terms of production and reclamation. As per review, amongst the various agroforestry systems, agrisilvicultural system, silvipastoral system, multipurpose woodlots, and agrihortisilvicultural system are suitable for reclamation of salt affected soils. Hence, in this paper emphasis is given for these four agroforestry systems.

Table 1: Example of tree species as per tree classification (Tomar and Gupta, 1986) based on nature of tolerate/sensitive to different soils with varying pH

High tolerant (plant able to perform best in soil with pH>10.0)	Tolerant (plant able to perform best in soil with pH 9.5-10.0)	Moderately tolerant (plant able to perform best in soil with pH 9.0-9.5)	Sensitive (plant able to perform best in soil with pH<9.0)
Prosopis juliflora,	*Acacia catechu,*	*Acacia auriculiformis,*	*Bauhinia variegata,*
Acacia nilotica,	*Albizia lebbeck*	*Albizia procera,*	*Bombax ceiba,*
Tamarix articulata,	*Butea monosperma,*	*Azadirachta indica,*	*Cedrela toona,*
Casuarina equisetifolia	*Cordia rothii,*	*Bambusa* spp.,	*Ficus virens,*
	Eucalyptus tereticornis,	*Cassia siamea,*	*Hardwickia binata,*
	Pithecellobium dulce,	*Dalbergia sissoo,*	*Populus deltoids,*
	Pongamia pinnata,	*Grevillea robusta,*	*Tectona grandis,*
	Tamarindus indica,	*Kigelia pinnata,*	*Thespesia populnea*
	Terminalia arjuna	*Leucaena leucocephala,*	
		Melia azedarach,	
		Moringa oleifera,	
		Morus alba,	
		Sesbania sesban	

Table 2: Example of tree species in different tree classification (Tomar and Gupta, 1986) on the basis of degree of tolerate to sensitive to soil with varying EC

Tolerant (EC 25-35 dS/m)	Moderately tolerant (EC 15-25 dS/m)	Moderately sensitive (EC 10-15 dS/m)	Sensitive (EC 7-10 dS/m)
Acacia farnesiana,	*Acacia pennatula,*	*Acacia auriculiformis,*	*Acacia deamii,*
Parkinsonia aculeata,	*Acacia tortilis,*	*Albizia caribaea,*	*Albizia guachapele,*
Pithecellobium dulce,	*Acacia nilotica,*	*Casuarina cunninghamiana,*	*Alelia herbertsmithite,*
Prosopis juliflora,	*Casuarina equisetifolia,*	*Eucalyptus tereticornis,*	*Caesalpinia eriostachya,*
Tamarix articulata,	*Casuarina obesa,*	*Leucaena shannoni,*	*Caesalpinia velutina,*
Tamarix troupii	*Casuarina glauca,*	*Pongamia pinnata,*	*Haematoxylon brasiletto,*
	Callistemon lanceolatus,	*Samanea saman,*	*Salix* spp,
	Eucalyptus camaldulensis,	*Terminalia arjuna*	*Syzygium cumini,*
	Leucaena leucocephala		*Syzygium fruticosum,*
			Tamarindus indica

EC: Electrical conductivity

AGRISILVICULTURAL SYSTEM FOR SALT AFFECTED SOIL AMELIORATION

Multipurpose trees (MPTs) are raised first for some periods then agricultural crops are raised in the inter space available. Extended growth of trees on alkali soils ameliorates by decreasing the pH and EC along with increasing organic matter and fertility. Trees such as *Eucalyptus tereticornis, Acacia nilotica, Albizia lebbeck, Terminalia arjuna, Prosopis juliflora* are selected on the basis of ability species tolerant to sodicity; however, agricultural crops are grown as intercrops on the basis of local need (Biswas and Biswas, 2014). Singh studied the change in the various soil properties through tree crop combination in partially reclaimed lands, where there was decrease in soil pH and EC with enriched soil organic carbon, available N, P, and K through growing agricultural crops of berseem, rice, wheat, and mustard under *Populus deltoides*, *E. tereticornis*, and *A. nilotica*-based agrisilvicultural system at 5 years age (Singh, 2011) [Table 3]. Devaranavadgi *et al.* reported that all the tree (seven) species significantly reduced pH, EC, and increased organic carbon of the saline soil. The lowest soil pH (7.53) and EC (0.24 dS/m) were recorded in *A. nilotica* followed by *Dalbergia sissoo*, whereas organic carbon content was significantly high in *Leucaena leucocephala* (6.15 g/kg) followed by *A. nilotica* (5.98 g/kg). This may be attributed to different ability of tree species to produce leaf litter and thereby cause the reduction in pH and EC (Devaranavadgi *et al.*, 2005).

SILVIPASTORAL SYSTEM FOR SALT AFFECTED SOIL AMELIORATION

Promising salt tolerant MPTs along with grasses are adopted in the agroforestry system to reclaim the alkali soils. Most suited tree species for reclamation of alkali soils are *P. juliflora*, *A. nilotica*, *Casuarina equisetifolia*, *T. arjuna*, *Tamarix articulata*, and *Pongamia pinnata*. Similarly, the following grass species are also used to improve the status of alkali soil: *Leptochloa fusca*, *Chloris gayana*, *Brachiaria mutica*, and *Sporobolus* spp. One of the studies carried out by Singh showed that *P. juliflora* with *L. fusca* under silvipastoral system reduced the soil pH and EC and improved the soil nutrients *viz.*, organic carbon (%), available NPK at soil depth of 0-15 cm and 15-30 cm at 74 months after planting (Singh, 2011) [Table 4]. Singh *et al*. recorded that Prosopis-based silvipastoral system proved more effective in reducing soil pH, displacing Na^+ from the exchange complex, increasing organic carbon, and available NPK. This system also improved the physical properties of soil such as bulk density, porosity, soil moisture, and infiltration rate over sole tree plantation (Singh *et al*., 2014).

MULTIPURPOSE WOOD LOTS FOR SALT AFFECTED SOIL AMELIORATION

In this system, salt tolerant MPTs are raised in block plantation with less spacing for the purpose of production of fuel wood, fodder, and other non-timber forest produces. Growing MPTs ameliorate alkali soils at a faster rate due to build up of organic matter and the recycling of important nutrients. Singh and others identified tree species for amelioration of salt affected soils. In addition to biomass production, trees growth on salt affected soils helps in their amelioration by improving physical, chemical, and biological properties of soils. Ameliorating effects of 20-year-old tree plantations showed that organic carbon increased by 3-5 times and pH decreased from 10.3 to lowest of 8.03 (Singh *et al*., 1993) [Table 5]. *P. juliflora* is one of the promising MPTs for reclamation of saline-sodic lands, which reduced the ECe and ESP considerably and increased organic carbon (%) over land without trees (Biswas and Biswas, 2014). Dager *et al*. recorded that tree species such as *T. articulata* followed by *P. juliflora* and *A. nilotica* reduced the soil pH and ESP. Organic carbon in the surface layer also increased under *T. articulata* by 0.23% (Dagar *et al*., 2001). Basavaraja *et al*. studied the performance of *P. juliflora* toward reclamation of salt affected soils at central dry zone of Karnataka for 10 years. They have recorded that trees of *P. juliflora* improved the soil properties in land with salt affected soils, where tree significantly decreased the soil pH, ECe, saturated extract sodium, ESP, and SAR. However, CEC and available NPK level increased in the plantation area (Basavaraja *et al*., 2007). Singh *et al*. also studied the ameliorative effectiveness of 10 MPTs for the period of 10 years. It was noted that tree plantations of MPTs reduced the soil pH, EC, ESP of sodic soils, and improved the organic carbon in the soil (Singh *et al*., 2008) and details are given at Table 6. Khan and Shukla got the result by the plantation of MPTs, soil pH, and EC were decreased up to 8.2 and 0.2 mmhos/cm, from initial values of 10.5 and 0.736 mmhos/cm, respectively, after 11 years of experimentation. The soil organic carbon, available phosphorus and available potash were increased. Among the tree species tested, *A. nilotica*, *Albizia procera*, *L. leucocephala*, *Azadirachta indica*, and *Eucalyptus hybrid* found most suitable tree species for rehabilitation of alkali soils (Khan and Shukla, 2003).

Table 3: Influence of different tree-crop combinations on soil properties

Land use systems	Soil pH	Organic carbon (%)	Available nitrogen (kg/ha)
Crop based system	−0.45	+0.07	+10
Eucalyptus based	−0.67	+0.12	+21
Acacia based	−0.63	+0.20	+31
Populus based	−0.80	+0.17	+25

− and +indicate the decrease and increase in values over the initial values

Table 4: Effect of *Prosopis juliflora-Leptochloa fusca* silvipastoral system on physical and chemical properties in land with alkali soil (Singh *et al*., 2014)

Soil property	Depth (cm)	Initial	At 74 months of planting
pH	0-15	10.3	8.9
	15-30	10.3	9.4
EC	0-15	2.2	0.36
	15-30	1.5	0.60
Organic carbon (%)	0-15	0.18	0.58
	15-30	0.13	0.36
Available nitrogen (kg/ha)	0-15	79	165
	15-30	73	134
Available phosphorus (kg/ha)	0-15	35	30
	15-30	31	26
Available potassium (kg/ha)	0-15	543	486
	15-30	490	478

EC: Electrical conductivity

Table 5: Ameliorative effects of tree plantation on alkali soils (Singh *et al*., 1993)

Tree species	Before planting		After 20 years of plantation	
	pH	OC (%)	pH	OC (%)
Eucalyptus tereticornis	10.3	0.12	9.18	0.33
Acacia nilotica	10.3	0.12	9.03	0.55
Albizia lebbeck	10.3	0.12	8.67	0.47
Terminalia arjuna	10.3	0.12	8.15	0.58
Prosopis juliflora	10.3	0.12	8.03	0.58

OC: Organic carbon

Table 6: Ameliorative effects of tree plantations (after 10 years) on sodic soil

Tree species	pH	EC (dS/m)	OC (g/kg)	ESP
Initial	10.6	1.43	0.8	85-92
Terminalia arjuna	9.8	0.39	3.5	60
Azadirachta indica	9.8	0.33	2.7	56
Prosopis juliflora	9.5	0.30	4.3	51
Pongamia pinnata	9.7	0.61	4.0	54
Casuarina equisetifolia	10.0	1.26	3.6	71
Prosopis alba	9.9	0.63	3.3	64
Acacia nilotica	9.7	0.77	3.5	56
Eucalyptus tereticornis	9.8	0.86	2.4	62
Pithecellobium dulce	9.9	0.70	2.7	65
Cassia siamea	10.0	0.69	2.6	71

OC: Organic carbon, EC: Electrical conductivity, ESP: Exchangeable sodium percentage

AGRI-HORTI-SILVICULTURAL SYSTEM FOR SALT AFFECTED SOIL AMELIORATION

Salt tolerant horticultural fruit trees or small trees along with agricultural crops are practiced for production of various products, as well as to reclamation the soil. Fruit species are generally sensitive to salt stress; however, some of the species *viz., Zizyphus mauritiana*, *Punica granatum*, *Syzygium cumini*, *Emblica officinalis*, and *Tamarindus indica* showed good performance on saline soils (Singh *et al*., 2004). Tomar *et al.* also reported the soil amelioration in terms of reduction in soil pH, improvement in organic matter and available nitrogen contents under agrihorticultual system. Moreover, agricultural crops such as Egyptian clover, wheat, onion, and garlic cultivated under *Carissa carandus*, *P. granatum*, *E. officinalis*, *Psidium guajava*, *Syzygium cumini*, and *Z. mauritiana* also improves the soil properties of alkali soils (Tomar *et al*., 2004).

CONCLUSION

On the basis of the present study, it is concluded that agroforestry is one of the options for amelioration of salt affected soil through biological way. Several tree species, pastures, agricultural crops, and horticultural crops/trees adopted in different agroforestry systems such as agrisilvicultural system, silvipastoral system, multipurpose wood lot, and agrihorisilvicultural system described in the paper are well suited for reclamation of salt affected soils. These trees or plants physiologically ameliorating the salt affected soil particularly saline and alkali soils by reducing soil pH, EC, and ESP and by increasing CEC organic carbon; and available nutrient such as nitrogen, phosphorus, and potassium status of soil. Therefore, it is suggested to grow these MPT species in agroforestry systems to ameliorate the salt affected soil over a period of time to get the multiple benefits.

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