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In Salt Affected Soils

Agroforestry is a promising option

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DEPENDING on nature and properties, salt-affected soils are classified in two main groups *viz.*, saline and sodic soils. Saline soils contain sufficient neutral soluble salts, mainly chlorides and sulphates of sodium, calcium and magnesium, which adversely affect the plant growth. Increased salt concentrations in the root zone result in substantial loss of soil productivity. Use of saline groundwater for irrigation, sea water intrusion through tidal waves and localized redistribution of salts are the main causes of the formation of saline soils. Salinity is a common problem in irrigated agriculture, especially in areas of low rainfall and high evaporative demand (arid and semi-arid regions). Saline soils are however, not confined to the arid and semi-arid regions. They are also found extensively in sub-humid and humid climates, particularly in the coastal regions where the ingress of sea water through estuaries and rivers and through groundwater causes large-scale salinization. Groundwater containing carbonate and bicarbonate is one of the major contributing factors in the formation of sodic soils in many regions. The alternate wet and dry seasons and the topographic conditions appeared to be the contributing factors in the formation of vast areas of sodic soils in the Indo-Gangetic plains of India. During the wet season water containing products of alumino-silicate weathering accumulated in the low lying areas. In the ensuing dry season, as a result of evaporation, the soil solution is concentrated resulting in some precipitation of the divalent cations, causing an increase in the proportion of sodium ions in the soil solution and on the exchange complex with simultaneous increase in pH. This process when repeated over the years results in the formation of sodic soils.

Traditional approaches for the amelioration of saline soils include leaching the salts below the root zone and drainage to lower the water table. The practical utility of these approaches is limited as fresh water is increasingly becoming scarce and surface and sub-surface drainage technologies are not only technically demanding but also costly and time consuming. Sodic soils are reclaimed through the application of chemical amendments such as gypsum and organic manures. In view of the limited availability and competing demands for gypsum and organic manures, it is imperative to explore the alternative strategies for the sustainable management of salt affected soils. Among the available options, greening the vast tracts of degraded salty environments through perennial vegetation seems to be an environmental friendly strategy

Crop production in saline and sodic soils is neither feasible nor economically profitable. This is due to the specific soil and water related constraints of these soils. Saline soils have excessive amounts of soluble salts which adversely affect the growth of most crop plants. Similarly, the high exchangeable sodium present in sodic soils is injurious to most crop plants. Traditionally, leaching with good quality water is recommended to make the saline soils suitable for crop production. Sodic soil reclamation requires the removal of toxic exchangeable sodium by calcium ions in the root zone. This is mainly achieved by gypsum application. However, the efficacy of both the management practices is limited by the scarcity of good quality water and gradually diminishing gypsum supply. This scenario has necessitated the development of alternative technologies for the sustainable management of these resource poor and challenging environments. The article highlights the agroforestry techniques developed by the CSSRI, Karnal which can enable the economic exploitation of such marginal lands.

Table 1. Tree and shrub species suitable for saline soils

Tolerance (ECe dS m-1)	Trees and shrubs
High(>25)	*Tamarix articulata, Prosopis juliflora, Acacia nilotica, Salvodora persica and Salvodora oleiodes*
Moderate(10-25)	*Acacia nilotica, Acacia tortilis, Acacia pennatula, Callistemon lanceolatus, Casuarina equisetifolia, Casuarina glauca, Casuarina obesa, Casuarina cunninghamiana, Eucalyptus camaldulensis, Leucaena leucocephala, and Pithecellobium dulce*
Sensitive(< 10)	*Acacia auriculiformis, Albizzia caribea, Caesalpinia eriostachys, Crescentia alata, Eucalyptus tereticornis, Guazuma ulmifolia, Haematoxylon brasiletto, Leucaena shannonii, Samanea saman, Senna atomaria, Syzygium cuminii, Tamarindus indica, Terminalia arjuna*

Table 2. Relative tolerance of tree species for soil sodicity

pH_2	Fuelwood/fodder/timber species	Fruit species
>10	*Prosopis juliflora, Acacia nilotica, Tamarix articulata*	Not recommended
9.6-10.0	*Eucalyptus tereticornis, Pithecellobium dulce, Prosopis alba, Prosopis cineraria, Casuarina equisetifolia*1, Salvadora persica, Salvadora oleoides, Capparis decidua, Terminalis arjuna*	*Carissa congesta, Psidium guajava, Zizyphus mauritiana, Emblica officinalis*
9.1-9.5	*Cordia rothii, Albizia lebbeck, Cassia siamea, Pongamia pinnata, Sesbania sesban, Parkinsonia aculeata, Dalbergia sissoo, Kigelia pinnata, Butea monosperma*	*Punica granatum*2, Phoenix dactylifera, Achrus japota*1, Tamarindus indica*1, Syzygium cuminii, Feronia limonia*
8.2-9.0	*Grevillia robusta, Azadirachta indica, Melia azedarach, Leucaena lencocephata, Hardwickea binnata, Moringa loiefera, Populus deltoids, Tectona grandis*	*Grewia subinaequalis, Aegle marmelos*2, Prunus persica, Manigifera indica, Morus alba, Ficus spp., Sapindus laurifolium, Vitis vinifera*

*1 (frost sensitive), *2 Does not stand water stagnation, may be raised on bunds.

which could provide a lasting solution to the problem in question. Amelioration of salt affected soils with the agroforestry trees will reduce the pressure on the productive lands to fulfill the food needs of the growing population and environmental concerns. The article summarizes the role of different agroforestry systems in the amelioration and sustained use of saline and sodic soils.

Agroforestry Systems for Salt Affected Soils

Although a number of agroforestry systems have been developed for arable lands, they cannot be recommended for salty environments. Decades of work at CSSRI, Karnal has identified tree-based agroforestry systems for these challenging environments.

Fruit-based Agroforestry Systems

The Institute has successfully demonstrated the practical feasibility of using dryland saline resources through bael (*Aegle marmelos*), *aonla* (*Emblica officinallis*) and karonda (*Carissa congesta*) based agrihorticulture system. Moderate (EC_{IW} between 4.0 to 5.8 dS/m) to high (EC_{IW} between 8.2-10.5 dS/m) saline waters were used for the irrigation. Cluster bean (in *kharif*) and barley (in *rabi*) were grown as intercrops between the tree rows. During the initial four years, there was very good survival of all the three fruit species. Coupled with this, the yields of intercrops were fairly good indicating the compatibility of fruit species with crop components and the probable absence of allelopathic interactions.

Silvipastoral Models

High sodic soils can be productively utilized by the adoption of silvipastoral models developed by the institute. The *Prosopis juliflora-Leptochloa fusca* silvipastoral model *in* a highly sodic soil (pH_2> 10.0) is a success story. This is an excellent system for fuelwood and forage production and for the amelioration of high pH soils. When followed for little more than four years, the tree and grass cover reclaims sodic soils to such an extent that normal agriculture crops such as *Trifolium alexandrinum* and T. *resupinatum* can be grown successfully. A similar model consisting of *Acacia nilotica/ Dalbergia sissoo/Prosopis juliflora* with Halfa grass (*Desmostachya bipinnata*) was also developed. This system greatly improves soil physical, chemical and biological characteristics. There is increased soil carbon content and total nitrogen and reduction in soil pH under the combined tree-grass system as compared to the sole grass cover.

Planting Techniques for Sodic Soils

Pit method: In this technique, pits of about 1 x 1 x 1 m are dug with the help of spades and the salty soil is replaced by the normal one. Alternatively, if normal soil is not available one should add organic manures and amendments such as gypsum or pyrite and tree saplings should be transplanted.

Ridge-trench method: Ridges of about 45cm height are made and seedlings are planted on top. Based on soil tests, suitable soil amendments, FYM and fertilizers are added to improve the soil fertility. This practice has limited popularity because irrigation is a problem with this method. However, it gives a good result in waterlogged conditions provided salt concentration is not high.

Auger-hole method: A tractor-mounted auger is used to make auger holes of 15-cm diameter by piercing the hard kankar layer at 150-180 cm depth. Auger holes are refilled with original soil, 3 kg gypsum, 8 kg FYM, 10 g $ZnSO_4$, and termiticides to control the

Auger-hole method for the afforestation of sodic soils

Jamun (*Syzygium cumini*) plantation in a sodic soil by auger-hole technology

termites. As the kankar layer, which creates hindrance in the development of plant roots, is broken in the process of making holes the plant roots grow at a faster rate towards deeper soil layers where sufficient moisture is usually available in alkali soils.

Pit auger-hole method: Although the auger-hole method has been found to yield good results, feeder roots are confined to the diameter of the auger hole in upper soil layer. Consequently, plants may face nutritional problems during later stages of growth. To overcome this problem, a pit and auger-hole method was designed. In this technique tractor mounted auger is used to make holes of dimensions 20-25 cm diameter and 1.2-1.8 m deep. This technique recognizes that in trees, owing to their deep root systems, management of the root zone by modifying the soil environment to greater soil depths using a limited quantity of amendments would be vital. It was seen that original soil mixed up with 3-5 kg gypsum (50% of gypsum requirement in the auger-hole) and 8-10 kg FYM in each auger-hole would be most suitable.

Pit-auger hole and furrow method: This planting method is similar to the previous method except that a furrow is made running across the slope. Furrows (20 cm deep and 50-60 cm wide at top) are first made at specified intervals cutting across the slope and are then used to make pit-holes. Furrows can be made by tractor-driven furrow maker. The additional advantage of this method is in providing sufficient moisture to the plants in furrows by preventing erosion losses. This is important in such soils, which often show moisture deficiency. This system seems to be reliable and may be the best method of planting for alkali soils, particularly black cotton alkali soils.

Planting Techniques for Saline Soils

Pit method: Pits of 45 x 45 x 45cm size are dug and tree seedlings are planted, as in normal soil. Since saline soils contain a major salt accumulation in the upper 30cm layer, seedlings are badly affected if planted at the surface.

Sub-surface planting method: Auger holes of 15cm diameter and 45cm deep are prepared. Seedlings are planted at a depth of 15cm to minimize the adverse effects of high salinity. Sub-surface planting provides a less hostile saline environment for the roots as compared with surface planting.

Ridge-trench method: Ridges of about 40cm height are made and seedlings are planted on top of them. This method facilitates good aeration and salt leaching in waterlogged saline soils. Field observations, however, have indicated that ridges are generally unstable in the presence of excess salts and it is difficult to irrigate saplings by a flood method to simultaneously affect salt leaching. In the absence of leaching, salinity increases in the ridges which in turn causes plant mortality. The method may prove useful in the waterlogged areas only when soil salinity is low.

Subsurface planting and furrow irrigation system: For agro-forestry in saline, waterlogged soils the Institute has developed a special technique called subsurface planting and furrow irrigation system. In this technique furrows (15-20 cm deep and 50- 60 cm wide) are created at 3-5 m intervals with a tractor drawn furrow maker. Auger-holes (0.2 m diameter and 1.2 m deep) are dug at the sill of these furrows spaced at 2-3 m intervals. These are re-filled with the mixture of original soil plus 8 kg of farmyard manure, 30 g super-phosphate, 15 g zinc sulphate and 15 g of iron sulphate. Six months old tree saplings are transplanted during rainy season (July-August) at sites where auger-holes are dug. The irrigation with saline water is given in furrows only. The irrigation may be provided for initial three years (4-6 times in a year) and thereafter, plantations may be irrigated once during the winter only. Salt storage in soil profile may increase during irrigation period but the added salts get distributed in soil profile as a consequence of seasonal rainfall during monsoon and some episodic events.

Soil amendments: The practice of adding soil amendments to alkali soils for the purpose of raising tree plantation has been found to be useful. Normally, gypsum is used in the filling mixture as it is a cheap source of calcium and is easily available. However, the quantity of gypsum used will depend on the extent of alkalinity and volume of soil intended to be improved. For afforestation of alkali soils, soil amendment should not be applied on the entire land surface but instead should be confined to the planting pits.

Transplanting: If root coiling is observed in saplings, the bottom 1-2 cm of the root system should be removed by cutting off the base of polythene bag. This will prevent from continued coiling and deformation of root system after planting. Normally, the rainy season is preferred for better establishment of saplings, because irrigation requirement of the saplings is lowest and rain water is usually sufficient to meet it. In areas subjected to waterlogging, planting should be carried out after cessation of rains.

Spacing: To ensure good initial growth of saplings, it is essential to provide optimum spacing. Since salt-affected soils are also poor in fertility, initial spacing can be closer than in normal soils, to compensate for mortality of saplings during early growth.

Irrigation: Among the improved cultural practices, irrigation of saplings is imperative during the early growth stage, particularly if the normal occurrence of monsoon rain fails. Irrigation should be on a need basis for the establishment of plantations essential for higher survival and rapid early growth. Subsequently, the tolerance of tree species to salinity/alkalinity increases with time. Most alkali lands are endowed with good quality ground water, but in some places the ground waters are also alkaline. In case of RSC waters, application of amendments is useful in counteracting the harmful effects. Conversely, excess moisture is also harmful and causes aeration problems. In such situations, earthen beds help in the establishment of saplings, and excess water should be led to drains as early as possible.

Weeding and hoeing: Since alkali soils are very poor in fertility, weeds do not grow much, at least in the initial stage after planting; any weed growth can be checked by mechanical weeding. However, to improve the soil aeration, hoeing is considered an important factor for alkali soils. This operation will also check the crust formation.

Nutrient management: Since salt-affected soils generally lack organic matter, nitrogen, available zinc and calcium, application of nitrogenous fertilizers, gypsum and zinc sulphate is essential at the time of transplanting. However, application of nitrogenous fertilizer may be avoided in the case of nitrogen-fixing trees. Application of nitrogen (100 g urea/plant) in split doses at the onset of two monsoon seasons helps improve plant growth. To prevent the termite attack, termiticides such as chlorpyrifos should be applied.

Pruning and Training: During initial years, the growing trees should be formatively pruned to obtain upright growth. Drastic pruning should be avoided as it may have an adverse effect on plant growth and survival. Bushy and spreading trees need more pruning than erect trees such as *Eucalyptus*, *Casuarina* and *Populus* etc. Pruning should be done during the dormant season.

Future prospects: Successful agro-techniques have been developed for raising salt-tolerant tree plantations on saline and sodic soils and considerable areas have recently been rehabilitated using these techniques in the north-western states of Haryana, Uttar Pradesh, Punjab, Rajasthan and Gujarat. However, farmers do not easily accept the idea of growing trees alone owing to the long time lag involved in getting returns from trees compared to crop cultivation. This situation highlights the need to develop viable agroforestry systems consisting of commercial species such as fruit trees, flower crops, medicinal and aromatic plants, arable crops and grasses. Agroforestry ranks high among the significant initiatives in improving land management that have occurred the world over during the past few decades.

SUMMARY

Due to the global efforts in research and development in recent past, the age-old forms of agro-forestry are becoming an integrated approach for addressing many of the world's most serious land-management challenges. Development of diversified, climate resilient and farmer centric agroforestry systems has tremendous potential to significantly improve the sustainability of agro-ecosystems in salt-affected areas bringing tangible socio-economic and environmental benefits to the society and nation.

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Maintaining soil organic carbon

Soil organic carbon (SOC) is a strong determinant of soil quality and agronomic productivity, especially in arid and semiarid tropics. The critical carbon (C) input required for maintaining SOC at the existing level was worked out for two agroecological settings using data from long-term experiments with chemical, organic and combined input use. The critical organic C input for maintaining SOC was 2.47 Mg/ha/year for Inceptisols under rice–lentil cropping system at Varanasi in the northern plain hot semi-arid ecosystem, and 1.12 Mg/ha/year for Alfisols under groundnut monocropping at Anantapur in the Deccan plateau hot arid ecosystem.