International Journal of Plant and Environment
Vol. 2, No. 1-2 (2016), 29-35

Rehabilitation of Sodic Waste Land through Agro-Forestry System

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Publication Info

Article history:
Received : 05.10.2015
Accepted : 31.03.2016
DOI : 10.18811/ijpen.v2i1-2.6615

Key words:
Agro-forestry
Biological reclamation
Exchangeable sodium percentage
Medicinal and aromatic plants
Phytoremediation
Rehabilitation
Revegetation
Sodic soil

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Abstract

Sodic soils are widely distributed in arid and semi arid regions of the world and suffer from high values of pH, exchangeable sodium percentage (ESP), sodium absorption ratio (SAR) and low fertility. In north India, Uttar Pradesh, which is a major contributor to the national food grain stock, due to its large arable land, is occupying about 1.6 Mha of this type of sodic waste land. To alleviate the pressure of fulfilling the demand of wood, timber, fodder and food for the enormous population of human and cattle, the vast sodic soil area has to be rehabilitated by planting trees or adopting agro-forestry system. In this context, an attempt has been made to rehabilitate sodic waste land through the establishment of green cover, with diverse plant communities at Distant Research Centre of CSIR-National Botanical Research Institute, Lucknow during last few decades. A rehabilitated forest ecosystem was developed consisting of a number of herbs, shrubs and trees. *Derris indica*, *Dalbergia sisso*, *Azadirachta indica*, *Cassia siamea*, *Terminalia arjuna*, *Syzigium cumini* were the dominant species in this rehabilitated forest, resulting in significant amelioration process, influenced greatly by diversity of species and their productivity. A combined effect of both biomass productivity and species diversity contributed about 92% towards amelioration. There was reduction in soil pH and ESP and an increase in organic C and N contents showing that sodicity has receded in the forest soil. To meet the increasing demand of medicinal, aromatic, dye, gum, fibre, fodder yielding plants in the present scenario, the shade loving plants of these categories can be grown successfully in between the rows of economic trees like teak, poplar, Eucalyptus etc. Such agro-forestry models have been tried with various inter-crops like *Curcuma longa*, *Rauvolfia serpentina*, *Zingiber officinale*, *Desmodium gangeticum* and *Asparagus racemosus* etc. The findings of such studies are very useful for fulfilling the demand of economic plants by utilizing the waste land and free spaces of trees cultivated in such lands.

1. Introduction

Waste lands in India have been estimated to the extent of about 175 m ha by Ministry of Agriculture, Govt. of India. Generally, four main causes of farmland degradation are observed viz. deforestation, over-cultivation, unskilled irrigation and overgrazing. The state wise distribution of the total non-forest waste lands in India has been documented as; Gujarat 38%, U.P. 29%, Rajasthan 13%, Tamil Nadu 12%, Andhra Pradesh 3%, Haryana 1%, Maharashtra 1% and others 3%. Most of the waste land available in U.P. is salt affected, consisting of about 80% sodic soils. Of this, UP alone constitutes about 1.23 m ha sodic soils. The districts worst hit by the ravages of salt infestation include Kanpur, Allahabad. Mainpuri, Rae Bareilly, Etah, Farrukhabad, Aligarh, Etawah, Sultanpur, Fatehpur, Hardoi, Pratapgarh, Jaunpur, Moradabad, Azamgarh and Faizabad.

2. Sodic Soil: Properties and Constraints

Sodic soils exhibit unique structural problems as a result of certain physical processes (slaking, swelling, and dispersion of clay) and specific conditions (surface crusting and hardsetting) (Shainberg and Letey, 1984; Sumner, 1993; Qadir and Schubert, 2002). These soils are compact and heavy with a high bulk density and silty clay loam texture and, suffer with a varying level of degradation in structural, chemical, nutritional, hydrological and biological properties. A cemented bed of calcium carbonate gravels and iron granules of 30-50 cm thick commonly persists in subsoil at 30-40 cm depth from surface. A high pH (9-10), high exchangeable sodium percent (ESP>60) and imbalance ionic equilibrium of soil solution leading to abnormal nutrient unavailability do not support the plant growth.These problems can affect water and air movement, plant-available water-holding capacity, root penetration, seedling emergence, runoff and erosion, as well as tillage and sowing operations (Oster and Jayawardane, 1998). In addition, changes in the proportions of soil solution and exchangeable ions lead to osmotic and ion-specific effects together with imbalances in plant nutrition, which may range from deficiencies of several nutrients to high levels of Na^+ (Naidu and Rengasamy, 1993; Grattan and Grieve, 1999; Mengel and Kirkby, 2001). The high Na:Ca and low C:N cannot sustain the vegetation. As a consequence, only sparse grasses occur as natural vegetation. Deficiency of some micronutrients (Zn, Fe, Cu, Mn) and toxicity of other elements (Na, B, Mo) further aggravate the situation for a stress growth of whatever plants exist on such land. Poor water permeability (hydraulic conductivity and infiltration rate) due to interlocked pore spaces as well as compactness impedes in root development of plants. In water-logging condition, root respiration is inhibited under oxygen stress. A wide range of microorganism population and diversity does not exist in sodic soil due to hostile conditions, which retards the rate of organic matter decomposition and nutrient mineralization, leading to poor nutrient availability to the growing plants. Such physical and chemical changes have a bearing on the activity of plant roots as well as on soil microbes, and ultimately on crop growth and yield.

3. Role of Agro Forestry in Rehabilitation of Sodic Waste Land

The use of sodic waste land for crop production is expected to increase in the near future, which could aggravate sodicity problems through mismanagement. Despite the implications associated with the amelioration and management of sodic waste land, the fact remains that these soils are a valuable resource that cannot be neglected (Qadir *et al*., 2006). Consequently, if the challenges of global food security are to be met, it is imperative to find ways to improve these soils to ensure that they are able to support highly productive land-use systems. To meet various diverse needs of ever-increasing human and animal population, we need to be rehabilitating all such type of degraded lands.

Khan (2003) reported that sodic soil can be permanently rehabilitated by the adoption agroforestry system, to supplement the requirements of fuel wood, fodder and timber to the farmer's and to maintain friendly eco-system in the area. He initiated his work from 1989 by planting ten tree spp. on arable land and reported that after twelve years of planting initial soil pH and EC of experimental field which was 10.5 and 0.730 mmhos/cm, respectively in the year 1989 dropped up to 8.26 and 0.21 mmhos/cm, respectively during the year 2001. It may be attributed due to leaching of harmful salt through roots of plants and by the decomposition of litters on the upper surface of the soil. Similar effect of tree species on soil pH and EC were reported by Singh (1995); Singh *et al*. (1998).

Over the past few years, several different approaches, involving chemical amendments, tillage operations, crop-assisted interventions, water-related approaches, and electrical currents, have been used to ameliorate sodic soils. Of these, chemical amendments have been used most extensively (Oster *et al*., 1999). A number of tillage options, such as deep plowing and subsoiling, have also been used to break up the shallow, dense, sodic clay pans and/or natric horizons that occur within 0.4 m of the soil's surface (Rasmussen *et al*., 1972; Abdelgawad *et al*., 2004). However, from last few decades, the crop-based approach, phytoremediation, has shown promise as an effective low-cost amelioration intervention (Robbins, 1986; Ilyas *et al*., 1993; Ghaly, 2002), as it is much cheaper than chemical amelioration, the costs of which are prohibitively high for resource-poor farmers in many developing countries (Qadir and Oster, 2004).

There have been some constraints with chemical amelioration of sodic soils in several developing countries because of:

(1) Low quality of amendments containing a large fraction of impurities; (2) Restricted availability of amendments when actually needed by the farmers for amelioration; and/or (3) Increased costs due to competing demands for amendments in the industrial sector and substantial reductions in or termination of government subsidies for agricultural use of the amendments.

With the last factor having overriding importance, chemical amelioration has become prohibitively expensive for subsistence farmers since the early 1980s. In parallel, scientific research and farmers' feedback have demonstrated that sodic and salinesodic soils can be ameliorated through a plant-assisted approach, phytoremediation (Kumar and Abrol, 1984; Robbins, 1986; Mishra, 2002; Qadir *et al*., 2002).

Typical plant-based amelioration strategies for contaminated soils, such as those containing elevated levels of metals and metalloids, work through the cultivation of specific plant species capable of hyper accumulating target ionic species in their shoots, thereby removing them from the soil (Baker *et al*., 1994; Salt *et al*., 1998; McGrath *et al*., 2002). In contrast, phytoremediation of such type of degraded soils like sodic soil is achieved by the ability of plant roots to increase the dissolution rate of calcite, thereby resulting in enhanced levels of Ca^{2+} in soil solution to effectively replace Na^{+} on the cation exchange complex (Oster *et al*., 1999). The salinity levels in soil solution during phytoremediation maintain adequate soil structure and aggregate stability that facilitate water movement through the soil profile and enhance the amelioration process (Oster *et al*., 1999).

4. Mechanisms of Amelioration of Sodic Soil through Plants

Phytoremediation of sodic soil (***Phyto***$_{Sodic}$) assists in enhancing the dissolution rate of calcite through processes at the soil-root interface resulting in increased levels of Ca^{2+} in soil solution. It is a function of the following factors:

$$\boldsymbol{Phyto}_{Sodic} = \boldsymbol{R}Pco_2 + \boldsymbol{R}_H^{+} + \boldsymbol{R}_{Phy} + \boldsymbol{S}_{Na}^{+}$$

Where: $\boldsymbol{R}P_{CO2}$ refers to increased partial pressure of CO_2 within the root zone; $\boldsymbol{R}H^+$ is enhanced proton (H^+) released in the root zone in case of certain crops that include legumes; ***R***Phy addresses physical effects of roots in improving soil aggregation and hydraulic properties of the root zone; and $\boldsymbol{S}Na^+$ represents Na^+ content of shoot, which is removed through harvest of the aerial plant portion. The collective effects of these factors ultimately lead to soil amelioration, provided drainage is present and adequate leaching occurs (Qadir *et al*., 2007).

Many species of forest and fruit trees, shrubs, forbs, grasses and medicinal plants have been identified and evaluated for growing in problematic areas. Vast tracts of arid and semi-arid areas remain barren due to this degraded land. With use of appropriate planting techniques and salt-tolerant species these could be brought under viable vegetation cover. Auger-hole technique for sodic soils, furrow technique of tree plantation, and ridge plantation in waterlogged fields are found quite appropriate. By applying appropriate planting and management techniques (e.g. sub-surface planting and furrow irrigation), various species of forest and fruit trees, forage grasses, medicinal and aromatic and other high value crops have been found equally remunerative. Tree-based technologies have additional environmental benefits including huge amount of carbon sequestration, biological reclamation and mitigating climate change.

5. Plant Species for Phytoremediation

An appropriate selection of plant species capable of producing adequate biomass is vital during phytoremediation. Such selection is generally based on the ability of the species to withstand elevated levels of soil sodicity (Gupta and Abrol, 1990) while also providing a saleable product or one that can be used on-farm (Qadir and Oster, 2002). The salt resistance of a crop is not an exact value because it depends on several soil, crop, and climatic factors. It reflects the capability of a crop to endure the effects of excess root zone salinity. Considerable variation exists among crops to resist ambient levels of salinity and sodicity. Such inter- and intra crop diversity can be exploited to identify local crops that are better adaptable to sodic soil conditions (Shannon, 1997; Maas and Grattan, 1999).

6. Choice of tree species selection

Planting site matched tree species with appropriate tree planting technique in salt affected soils exerts bio ameliorative effects, in addition to providing forest cover, fuel wood, fodder, timber and preventing soil and water loss through runoff besides improving the microclimate of that area. Since saline and alkaline soils differ from each other, methods of working the soils will also be different. The following should be kept in mind while selecting species:

- Adaptiveness of the species to local environment - Species should have the capacity to tolerate variable salt concentrations, fire, frost, occasional flooding and other extreme climatic hazards.
- Species should be drought resistant as the high salt contents in soil solution also cause physiological drought.
- Species should have low water and nutrient requirements and must be devoid of allelopathic potentialities.
- Species should be perennial, cheap enough to establish and easy to manage and also should have the capacity to improve soil physical, chemical and biological properties through root activity, litter fall etc.
- Species should possess a high photosynthetic efficiency and greater biomass production efficiency. It should be fast growing and should have the capacity to re-sprout quickly after pruning and pollarding, so that farmer can quickly realize the returns through short rotation forestry.
- Species should be capable of producing a prolific root system to facilitate drainage from waterlogged saline soils.
- Species should have multi-utility value (MPTS) such as firewood, liquid fuel, food, high palatable fodder with nutrient value and minimum anti-quality factors, fiber, edible or non- edible oils, medicinal product, paper pulp and ability to fix atmospheric Nitrogen etc.

A number of tree plantations have been grown on sodic soils. These include: *T. arjuna* (Roxb. ex DC.), *P. juliflora* (Sw.) DC. (Bhojvaid and Timmer, 1998), *D. sissoo* Roxb. ex DC., *A. nilotica* (L.) Willd. ex Delile (Kaur *et al*., 2002), *Parkinsonia aculeata* L. and *P. cineraria* (L.) Druce (Qureshi and Barrett-Lennard, 1998), *Sesbania* *sesban* (L.) Merr. and *Tamarix dioica* Roxb. ex Roth. (Singh, 1989), and *Leucaena leucocephala* (Lam.) de Wit (Qureshi *et al*., 1993), among others. In Australia, Farrington and Salama (1996) recommended revegetation by trees to be the best long-term option for controlling dry land salinity. In addition, efforts are needed to assess other crops such as high-value medicinal and aromatic species that could have the potential for adequate growth on sodic and saline-sodic soils.

7. Inclusion of Medicinal and Aromatic Plants as Inter Crop with Trees

There is also a great scope of cultivation of medicinal and aromatic plants on marginal soils/ waste lands without disturbing the food priorities for the increasing population of the country. Due to ever-increasing population, we have optimum pressure on arable lands for cultivation of food crops; therefore, utilization of degraded waste lands including salt affected soils is a viable option for cultivation of medicinal and aromatic plants (MAPs). A large number of species of medicinal and aromatic plants belonging to this category have been screened for their adaptability and feasibility for large-scale cultivation on alkaline soils, extensively occurring in the Gangetic alluvial plains of Uttar Pradesh (Singh, 1997). Recent studies have shown that several medicinal and aromatic plant species have the ability to tolerate ambient levels of salinity in soil and irrigation water as well as to produce adequate biomass of economic value.

Many MAPs are well adapted to partial shading, moist soil, high relative humidity and mild temperatures (Vyas and Nein, 1999), allowing them to be intercropped with timber and fuel wood plantations, fruit trees and plantation crops. Some well known medicinal plants that have been successfully intercropped with fuel wood trees (e.g., *Acacia auriculiformis*, *Albizia lebbeck*, *Eucalyptus tereticornis*, *Gmelina arborea* and *Leucaeana leucocephala*) in India, include *safed musli* (*Chlorophytum borivilianum*), rauvolfia (*Rauvolfia serpentina*), turmeric (*Curcuma longa*), wild turmeric (*C. aromatica*) and ginger (*Zingiber officinale*) (Chadhar and Sharma, 1996; Mishra and Pandey, 1998; Prajapati *et al*., 2003). The trees may also be benefitted from the inputs and management given to the intercrops. Short stature and short cycle MAPs and culinary herbs are particularly suited for short-term intercropping during the juvenile phase of trees (Rao *et al.,* 2004).

Studies have been conducted in India since mid-1980s on the feasibility and economic aspects of intercropping aromatic plants with timber trees. Experiments at different sites in India demonstrated that aromatic *Mentha* spp. (*M. arvensis*, *M. piper-ita*, *M. citrata* var. *citrata*, *M. spicata*, *M. cardi-aca* and *M. gracilis*) and *Cymbopogon* spp. [lemon grass (*C. flexuosus*); Java citronella (*C. winterianus*); and palmarosa (*C. martinii*)] can be grown intercropped with *Populus deltoides* or *Eucalyptus* spp. for three to five years after planting the trees. Some of the above aromatic species and *Pelargonium* sp. (geranium) can also be intercropped with another essential-oil-yielding tree *Eucalyptus citriodora* (lemon- or citron-scented gum) (Singh *et al*., 1998). Tree growth was generally little affected or improved probably due to the inputs given to the intercrops. Essential oil profiles of citronella and palmarosa grown in open and partial shade were not significantly different, even the oil of menthol mint (*M. arvensis*) produced under shade was richer in menthol (Singh *et al*., 2002). This implies the need to consider the effect of intercropping on oil quality of some aromatic plants. These intercropping systems gave two to four times greater economic returns than sole cropping of the components. These studies indicate that aromatic plants can be profitably grown in association with linearly growing fuel and timber trees such as *L. leucocephala*, *Casuarina* spp. and *Grevillea robusta.*

Aromatic grasses such as vetiver (*Vetiveria zizanioides*), lemongrass and citronella (*Cymbopogon nardus*) can be grown on field bunds and soil conservation bunds in croplands. Vetiver has extensively been tested and is being promoted for planting in contour strips or as a live hedge barrier and to stabilize terrace risers on sloping lands in a number of countries, for example, in India, Fiji, Haiti and Indonesia (NRC, 1993).

8. Influence of Trees on Salt Affected Soils

The cultivation of these plants on degraded lands like sodic waste land requires special agronomic management such as planting methods, amendment use, irrigation, spacing and lopping schedules are discussed, for starting the cultivation. The plants have varying degree of tolerance to such soils and the cropping systems shall be adopted accordingly. Therefore, concerted efforts are required for R&D work on these crops for their cultivation in waste lands to release the ever increasing pressure on normal soils.

In semiarid alkali soils, soil pH and ESP under *Tamarix articulata* was reduced to maximum, followed by *Prosopis juliflora* and *Acacia nilotica*. Organic carbon in the surface layer also increased under *Tamarix* *articulata* by 0.23% (Dager *et al.*, 2001).

In Central Dry Zone of Karnataka *Prosopis juliflora* plantation reclaimed the sodic soils by significantly reducing the pH, ECe, saturated extract sodium, ESP and SAR of soil, but increased the CEC, available N, P_2O_5 and K_2O status of the soil, which clearly indicated its effectiveness in amelioration of salt affected soils (Basavaraja *et al.*, 2007).

In some studies, rehabilitation of degraded sodic lands through afforestation and cropping also showed that the soil reaction (pH and EC) increased towards deeper soil profiles. This might be due to superficial ameliorative effect of trees and crops. It has been observed that the pioneer algal flora, habituated on halosere (saline-sodic barren land) after tree plantations, secretes some organic substances that act as buffer to lower the pH. There might be some other explanations behind decreasing trend of soil-pH and EC through phytoremediation as:

- In areas having good tree cover, most of the moisture is lost through transpiration rather than through evaporation from the soil surface. Thus, deposition of salts in the upper layers of the soil is minimized because the shade of the vegetation retards soil moisture evaporation and thus reduces the upward movement of ground water containing salt to the soil surface (Gill and Abrol, 1990).
- Revegetation using deep-rooted perennials is seen as a method of reversing the salinity problem. The deep and sturdy root systems of tree open up the soil and improve water permeability and facilitate leaching of salts (desodification). Fine roots have contributed significantly in the reclamation of soil structure, pH and water permeability (Garg, 2000; Mishra *et al.*, 2002).
- Exudation of organic acids by tree roots neutralizes the alkalinity of soils. The decrease of bicarbonate levels in soils under tree cover is due to increased litter fall, organic carbon content and root activities. Usually organic residue addition from the leaf litter and root dyeing over the years promote microbial flora and fauna in soil and thus helped in generation of high fluxes of carbon dioxide. In addition to this, complementary effects of other decomposition products like soluble organic acids, amino acids, sugars etc. and root exudates favored the dissolution and translocation of bicarbonates in soils (Garg and Jain, 1992).
- Under alkali tolerant trees, decreasing trend for exchangeable Na is attributed to the removal of Na by tolerant trees or leaching from the surface soil through the roots of trees acting as a bio-drain. The relative changes in chemical properties of sodic soils may be attributed to the depletion of exchangeable Na in the soil, perhaps due to the biological production of carbonic acid (H_2Co_3) by tree roots causing solubilization of the native $CaCo_3$ present in such soils (Garg and Jain, 1996; Mongia *et al.*, 1997).

Afforestation on degraded land not only accumulates biomass in various plants and developed phytodiversity, even stimulates the outogenic succession and alters the structure and stability of communities. Soil pH and EC decreased significantly from degraded to rehabilitated lands. The accumulation of litter by different tree species and crop residues, increase in resource heterogeneity which promotes the enrichment of the soil fauna and the activation of the processes of nutrient cycling. Consequently, it improves soil quality and provides microclimatic conditions allowing the increase in microbial population of other stress susceptible species.

This article revealed that tree species composition and crop diversification plays an important role to restore all the aspects (physico-chemical, biological, biochemical and molecular) of degraded sodic lands, in which agroforestry approach has ameliorated the soil more efficiently.

Acknowledgements

The authors are grateful to Director, CSIR-National Botanical Research India, Lucknow for providing necessary facilities and cooperation.

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