# Reclamation and Management Strategies under Salty Soils

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## Introduction

In order to feed the burgeoning world population, expected to reach around 9 billion by 2050, significant improvements in agricultural productivity compared to the current levels have become absolutely essential (Godfray *et al.*, 2010). Nonetheless, the attempts to increase the food production are confronted with a multitude of challenges such as relentless land degradation, fresh water scarcity and climate change impacts. Land degradation, broadly defined as the loss of soil quality and productivity, has gradually attained alarming proportions in many parts of the world in the recent decades. Unabated degradation not only diminishes the ability of land to produce food, but also poses severe threats to the precious agro-ecosystem services and functions vital to human life. According to one estimate, approximately 2 billion ha of productive soil resources have been affected by diverse forms of physical and chemical degradation. Although nature-induced degradation occurs on cultivated soils, inappropriate human activities such as land clearing, crop intensification and poor drainage management considerably hasten the rate of soil loss. The extent of the problem can be gauged by the fact that reduced soil productivity alone has led to loss of an estimated ~12-14% of the global food supply in the past five decades (Jie *et al.*, 2002). Besides soil related constraints, diminishing fresh water supplies are also adversely impacting the agricultural production in different agro-climatic regions of the world. It has been predicted that even many regions rich in water availability may witness severe fresh water shortages in the coming years. In particular, growing water scarcity could be a major threat to agricultural sustainability in the irrigated (semi) arid regions that significantly contribute to the global food output (Rosenzweig *et al.*, 2004).

Salinity, as a major form of land degradation, impairs the health and productivity of nearly 1000 million hectares (M ha) of global croplands to varying degrees (Metternicht and Zinck, 2003). In areas having limited freshwater and marginal quality groundwater, salt-induced land degradation and crop losses are often severe. Although innocuous amounts of soluble salts ($Na^+$ and $Cl^-$) are invariably found in cultivated soils, anthropogenic activities such as land clearing and intensive irrigation accentuate the salt accumulation to the levels that soils become unproductive. In severe cases, the salt-affected lands remain uncultivated and abandoned. Irrigation-induced salinity may affect new areas at an accelerated rate in the foreseable future. In India, the present estimated salt-affected area in India (6.73 M ha) may increase to 16.20 M ha by 2050 (ICAR-CSSRI, 2015). Considering the immense benefits in terms of higher crop yields and incomes to the farmers and indirect benefits such as lower greenhouse gas (GHG) emissions and increased resilience to climate variability, soil reclamation is seen as an attractive option to transform the degraded lands into a valuable asset. A recent study suggests that rehabilitating only 12% of degraded agricultural land could boost smallholders' incomes by USD 35-40 billion per year and help feed an additional 200 million people annually within 15 years. It could also increase resilience to drought and water scarcity, and reduce greenhouse gas emissions by nearly 2 Gt $CO_2$-equivalent per year (UNEP and UNCCD, 2015).

In this article, a brief overview of agricultural salinity problem and the conventional measures of salinity management in India are discussed. Taking a note of the emerging constraints that are affecting the implementation of soil reclamation projects in different parts of the country; the future research needs have been outlined.

### Characteristics and distribution of salt-affected soils

Based on the soil saturation paste values of electrical conductivity ($EC_e$), soil pH ($pH_s$) and exchangeable sodium percentage (ESP), salt-affected soils (SAS) are classified into saline ($EC_e \geq 4$ dS $m^{-1}$, $pH_s < 8.2$ and high ESP< 15) and sodic ($EC_e$< 4 dS $m^{-1}$, $pH_s$ >8.2 and ESP >15). While osmotic stress and specific ion effects suppress the plant growth under both the conditions, sodic soils also suffer from the structural and water permeability problems. In contrast to the naturally formed saline and sodic soils, presence of shallow watertable in secondary salinity affected lands is a severe hindrance to their reclamation. However, it does not imply that sub-soil waterlogging (~ 1.5-2 m below surface) is the only constraint to soil amelioration. In fact, productivity enhancement through routine measures is also increasingly becoming difficult in waterlogging free salt-affected soils (Gupta, 2016; Sharma and Singh, 2015).

All soils invariably contain soluble salts, but under specific environmental conditions and inappropriate crop management practices salt concentration exceeds the threshold limit with adverse consequences for soil health (Rengasamy, 2006). The excess soluble salts present in saline soils make them unsuitable for majority of the arable crops. Similarly, sodic soils contain excess exchangeable sodium which adversely affects the growth of most crop plants. Sodic soils also suffer from poor physical properties and low water permeability (Wicke *et al.*, 2011). Besides weathering of rocks and primary minerals as the dominant processes behind formation and accumulation of salts, other major factors which account for the development of saline soils include irrigation with saline groundwater, development of saline creeps due to excessive leaching, ingress of sea water in coastal regions, congestion of natural drainage and seepage from canals, waterlogging due to faulty irrigation practices and localized redistribution of salts (Singh, 2009).

Although exact estimates on global area under SAS are not available, various projections- ranging from 831 M ha (FAO, 2008) to 1128 M ha (Wicke *et al.* 2011) point to the widespread severity of the problem. Globally, Middle East region (189 M ha) followed by Australia (169 M ha) and North Africa (144 M ha) are worst affected by the salinity and sodicity problems. In South Asia including India, SAS occupy about 52 M ha area. Majority of the global saline/sodic soils are only slightly salt-affected (65%) followed by moderately (20%), extremely (10%), and highly salt-affected ones (5%) (Wicke *et al.*, 2011). In India, SAS occupy about 6.73 M ha. Gujarat (2.23 M ha), Uttar Pradesh (1.37 M ha), Maharashtra (0.61 M ha), West Bengal (0.44 M ha) and Rajasthan (0.38 M ha) states together account for ~75% salt-affected area in the country. In many salinity affected parts, ~25 % of the underground waters are either saline or sodic with some states like Rajasthan, where about 80% of the groundwater is of poor quality, being the worst affected (Singh, 2009).

## Technologies for management of salt-affected soils

Establishment of ICAR-Central Soil Salinity Research Institute (CSSRI) in 1969 marked a watershed in the history of salinity research. With modest beginnings, the Institute has now acquired the status of an internationally acclaimed centre of excellence for conducting basic and applied research in the reclamation and management of salt-affected soils. The technologies developed by CSSRI for the productive use of saline and sodic soils are briefly discussed under the following heads:

### *Management of sodic soils*

Gypsum-based technology has become highly popular among the farmers in sodicity affected regions. Adoption of this technology has led to reclamation of approximately 1.95 M ha of sodic soils which are now significantly contributing to national food basket and farmers' livelihoods (Sharma *et al.*, 2016). However, scarcity of good quality agricultural grade gypsum has emerged as a constraint to the soil reclamation projects in many states. Growing gypsum shortages have enhanced the interest in low-cost alternative amendments some of which such as distillery spent wash and press-mud have shown encouraging results in partly substituting the gypsum requirement. In many cases, integrated use of locally available amendments and salt tolerant varieties can give the best results to considerably lessen the dependence on gypsum (Sharma and Singh, 2015).

Many agro-forestry species (*Prosopis juliflora*, *Acacia*, *Eucalyptus* and *Populus*) and salt tolerant grasses (*Leptochloa fusca*) have also proved effective in reclaiming the deteriorated sodic soils. Certain agronomic practices such as amelioration of pits with gypsum and FYM, auger-hole method of planting and provision of irrigation further enhance the salt removal efficiency of agro-forestry trees in sodic soils (Singh *et al.*, 1988). In some cases, use of potential trees such as *Acacia* may be limited due to their less remunerative nature (Singh *et al.*, 1997). Different soil microorganisms have also been found effective in alleviating salt stress in crop plants by decreasing the salt levels and improving the water and nutrient availabilities. However, use of such microorganisms is limited due to higher costs and the lack of technical know-how. To overcome these problems, a low-cost microbial bio-formulation called 'CSR-BIO', has been developed. Application of this microbial consortium significantly improves the productivity of rice, banana and vegetables in sodic soils (Damodaran *et al.*, 2013).

### *Management of waterlogged salt-affected lands*

Sub-surface waterlogging (watertable lying within 2 m from the surface) affects the vast stretches of lands in the irrigated regions of Indo-Gangetic plains. The sub-surface drainage technology, consisting of a network of concrete or PVC pipes along with filters installed manually or mechanically at a design, spacing and depth below soil surface, has been developed to reclaim waterlogged saline lands. This system works by draining out the excess water containing soluble salts. This technology, initially developed for Haryana, has been widely adopted in Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra, Madhya Pradesh and Karnataka states. The crops grown in the reclaimed saline soils exhibit considerable increase in yield (45% in paddy, 111% in wheat and 215% in cotton) and cropping intensity (CSSRI, 2014). In spite of the socio-economic gains in terms of on-farm employment generation and higher crop yields, this technology has not gained momentum and the major constraints in its widespread use include higher initial establishment costs, operational difficulties, lack of community participation and the problems encountered in disposal of drainage effluents. Bio-drainage, based on the ability of deep rooted trees to remove excess soil water and the dissolved salts through rapid transpiration using solar energy, is a proven technology to prevent salinity build-up in canal commands. Tree species for bio-drainage (*Eucalyptus* ) give best results when planted in beginning to arrest the processes of waterlogging and salt accumulation but have limited efficiency when planted in salinized soils (Singh, 2009). In recent years, tree-based bio-drainage in combination with land modifications is being advocated as an alternative to conventional land drainage to effectively utilize waterlogged salt affected soils.

Considering the limited adoption of conventional techniques such as SSD and biodrainage in these areas, attention has been paid to harness the soil productivity through alternative measures such as land shaping, saline aquaculture and the conjunctive use of fresh and saline groundwater. Drainage solutions based on land shaping and biodrainage have proved effective in rehabilitating the waterlogged sodic lands in secondary sodicity affected areas in the Sarda Sahayak Canal command area of Uttar Pradesh (Sharma *et al.*, 2007). Simple land shaping interventions have been standardized for creating the fish ponds and raised and sunken beds in waterlogged sodic soils. Rice, water chestnut and integrated rice-fish culture are the attractive land use options for the sunken beds. Similarly, vegetables and banana can be grown on raised beds for the higher economic returns (Verma *et al.*, 2015). Multiple well points system is a new technology developed for the skimming of freshwater floating over brackish groundwater in aquifers of this region. Thousands of such wells installed in Muktsar, Faridkot and Ferozepur districts have lowered the watertable leading to 10-20% increase in crop yields. The cost of installation of a 4-well point system is about Rs. 45000 per set (Gupta and Singh, 2014). Inland saline aquaculture *i.e.*, land-based aquaculture using saline groundwater has also emerged as a viable approach in highly salinity affected areas. Despite the very high salinity of water (~25 dS $m^{-1}$), fish have been successfully cultured (CSSRI, 2013).

#### *Salt Tolerant Varieties*

Small and marginal farmers in salt-affected regions could hardly afford the costs involved in chemical amendments without government support. Similarly, they also face many problems in the installation and maintenance of SSD systems. Consistent with the need to provide these poor farmers viable and cost-effective solutions to adapt to stressful conditions, Institute has identified/developed high yielding salt tolerant varieties in rice, wheat, mustard and other crops (Table 1). These varieties exhibit tolerance to salinity and high soil pH and give significantly higher yields with the least use of chemical amendments.

**Table 1. Salt tolerant varieties developed by CSSRI, Karnal**

| Crop | Variety |
|---|---|
| Rice | CSR 36, CSR 30 (basmati type), CSR 27, CSR 23, CSR 13 and CSR 10 for inland regions; and Butnath and Sumati for coastal soils |
| Wheat | KRL 19, KRL 1-4, KRL 210, KRL 213 |
| Mustard | CS 52, CS 54, CS 56 |
| Chick pea | Karnal Chana 1 |
| Dhaincha | CSD-137, CSD-123 |

### *Alternate Land Use Systems*

In addition to salt tolerant agro-forestry trees, salt tolerant cultivars have also been identified in fruit trees, shrubs, grasses and medicinal and aromatic plants. Different fruit-based agro-forestry systems, with bael (*Aegle marmelos*), aonla (*Emblica officinallis*) and karonda (*Carissa congesta*) as tree components and cluster bean (in *Kharif*) and barley (in *Rabi*) as subsidiary components, have been found practically feasible and remunerative with the use of moderate ($EC_{IW}$ between 4.0 to 5.8 dS $m^{-1}$) to high ($EC_{IW}$ between 8.2-10.5 dS $m^{-1}$) salinity waters (Dagar *et al.*, 2008). The saline and sodic lands under long-term tree cover exhibit overall improvement in soil quality which is attributed to increase in soil organic carbon and nitrogen contents, enhanced microbial biomass, microclimate modification under tree cover and nutrient uptake from deeper layers by the tree roots (Sharma et al., 2014b). Different medicinal and aromatic plants such as isabgol *(Plantago ovata*), aloe (*Aloe barbadensis*) and kalmeg (*Andrographis paniculata*) produce high biomass under saline ($EC_{IW}$ 8.5 dS $m^{-1}$) irrigation (Tomar and Minhas, 2004).

### *Multi-enterprise agriculture model*

Keeping in view the specific requirements of small and marginal farmers in post-reclamation phase, an integrated multi-enterprise model consisting of diverse components (field and horticultural crops, fishery, cattle, poultry and beekeeping) has been developed for 2 ha area for ensuring sustainable resource use efficiency, high and regular incomes and employment generation. This model substantially reduces the production costs by synergistic recycling of resources among different components. Similar models are also being standardized for waterlogged sodic soils in Uttar Pradesh, highly saline black soils in Gujarat and coastal saline soils of West Bengal (Sharma and Chaudhari, 2012).

### *Resource Conservation Technologies*

In India, substantial increase in food production and a multitude of environmental problems co-evolved during Green Revolution of 1960s-1970s characterized by the heavy and indiscriminate use of agro-chemicals in rice and wheat crops. Many present and emerging challenges such as stagnating yields, decreasing factor productivity, fast receding water table, climate variability, deteriorating soil health, environmental pollution and secondary salinization have posed grave threats to the sustainability of rice-wheat cropping system in the Indo-Gangetic plains of India (Aggarwal *et al.*, 2004). In this backdrop, increased adoption of resource conservation technologies is imperative and CSSRI, Karnal has made important contributions in this direction by successfully demonstrating the efficacy of different technologies- zero tillage in wheat, direct seeded rice, residue incorporation and mulching, sprinkler irrigation- to optimize the resource use in rice and wheat crops for sustainable production and improvement in physico-chemical and biological properties of the soils (Sharma and Chaudhari, 2012).

## Emerging constraints and future research needs

Considerable progress has been made in the past four decades to harness the productivity of salt-affected soils. Different technological interventions have brought an overall improvement in the farmers' livelihoods and environmental quality in many parts of the country having saline/sodic soils and marginal quality waters. In spite of these achievements, many present and emerging challenges continue to plague agricultural sustainability in salt-affected environments. These problems and their sustainable solutions are briefly discussed in the following paragraphs:

### *Constraints in sub-surface drainage technology*

Waterlogged saline lands are rehabilitated by different drainage interventions. In the last few decades, sub-surface drainage (SSD) has become virtually synonymous with land drainage in India. However, over reliance on

SSD technology has led to the neglect of other potential techniques such as surface and bio-drainage which also significantly contribute to salinity management. Furthermore, constraints such as high installation and maintenance costs, poor community participation and problems in the disposal of saline drainage water have hindered the spread of SSD technology. This has resulted in slow pace of drainage improvements in about 2-3 M ha waterlogged saline area. In light of these facts, an integrated plan involving SSD, mole, vertical and bio-drainage systems has been suggested as a technically feasible and cost-effective drainage solution at the macro-scale. Results have shown that bio-drainage through salt tolerant trees having high transpiration rate could be an efficient method of watertable and salinity control in many situations (Gupta, 2016).

As SSD is often beyond the reach of an individual farmer, focus has been placed on simple land shaping techniques such as farm pond, and raised-and sunken beds to augment the productivity of coastal saline and waterlogged sodic lands by harvesting the rainwater and canal seepage water, respectively, for multipurpose use in crop and fish culture. Land modification not only alleviates the waterlogging and salinity risks, but also enhances the cropping intensity and farmers' income from the lands otherwise lying barren for decades. Salinity-affected north-western region of the country has immense potential for the commercial fish and shrimp production. Initial results reveal the prospects of integrated aquaculture (*e.g.* rice-fish-horticultural crops) in vast stretches of waterlogged saline soils in south-western parts of Punjab and Haryana.

### *Growing gypsum scarcity*

In India, gypsum is the preferred amendment to restore the productivity of even highly deteriorated sodic lands. Despite known benefits, reclamation projects in sodicity-affected states are running short of good quality agricultural-grade gypsum partly due to high costs. This has enhanced the interest in by-product gypsum (*e.g.*, phospho- and marine gypsum) and other alternative amendments. However, heavy metals present in some of these substitutes such as fly-ash and municipal solid waste compost may sometimes cause unintended side effects in the soils and plants. Considering these constraints, emphasis has increased on phytoremediation through salt tolerant agro-forestry trees and grasses with added advantages of low water use, negligible recurring costs and carbon sequestration. Salt tolerant cultivars are also available in different field and horticultural crops to obtain stable yields with reduced or no use of amendments; especially in moderately salt-affected soils (Sharma and Singh, 2015).

### *Fresh water shortages*

Many regions of the world in general and arid environments with preponderance of salt-affected soils in particular are facing severe water shortages. The anticipated increase in atmospheric temperature due to climate change would further decrease the productivity and resilience of the soils in these water scarce regions. It is worrisome to note that conventional approaches to ameliorate the saline and sodic soils (leaching and gypsum application followed by irrigation, respectively) require huge quantities of fresh water and its limited availability would necessitate the development of alternative strategies for using poor quality waters to reclaim and productively utilize them. India has 4.2% share of global water resources and supports about 16.7% of the global population. Agriculture alone accounts for about 85% water use in the country and the remainder 15% is used by the domestic and industrial sectors. Good quality water availability in desired quantities is of utmost importance for higher agricultural productivity. Besides continuous decrease in the availability of fresh water resources, many parts in India suffering from water scarcity are also usually underlain by poor quality groundwater and the maximum area under saline and brackish groundwaters occurs in the arid and semi-arid regions of Rajasthan, Punjab, Haryana, Delhi and Uttar Pradesh (Singh, 2009). Research priorities have been outlined to standardize the protocols for use of polluted waters in reclamation and significant achievements have been made with respect to ground water recharge, storage and subsequent use of rain water through land modification and other technological interventions such as *dorouv* technology to skim fresh water floating on the saline water (CSSRI, 2014).

### *Climate change impacts*

Agriculture is highly vulnerable to climate change induced shocks. Many direct and indirect effects of climate change- changes in precipitation patterns, higher atmospheric temperatures, increase in frequency of droughts, floods and storms, sea level rise, greenhouse gas emissions- would drastically limit agricultural productivity particularly in arid and semi-arid climates and coastal regions. Anticipated increase in warming and evapo-transpiration coupled with decrease in rainfall could have adverse consequences in dry (arid and semi-arid climates) regions while predicted sea level rise and the consequent increase in the process of saline water intrusion and the increased frequency of cyclonic storms would undermine the sustainability of many coastal agricultural systems. In crop plants, with most of them being non-halophytes, even a slight increase in air and leaf temperatures would mean potentially higher evapo-transpiration causing increased transpirational flow and higher accumulation of salts in aerial parts. As far as elevated $CO_2$ concentrations are concerned, it is difficult to predict the probable interaction between $CO_2$ and salinity on plant growth (Yeo, 1998). The long-term adaptation strategies to overcome these challenges are based on sustainable soil and crop management practices (resource conservation practices such as zero tillage, integrated water and nutrient management, efficient irrigation techniques and adoption of resource use efficient and stress resilient crop varieties.

### *Resodification and resalinization*

Apart from the well known menace of secondary salinity in irrigated commands and its adverse impacts on agricultural production, recent instances of resodification of gypsum-amended sodic soils and resalinization of reclaimed saline soils are a cause for concern as they could potentially offset the gains achieved in the past. Resodification refers to the reappearance of sodic patches in the previously chemical amended sodic soils. The ameliorated soils support crop production for the initial few years, but certain adverse conditions such as congestion in natural drainage, shallow water tables and seasonal fluctuations in water table, seepage from canals and subsequent water logging of fields, repeated droughts and practice of crop fallow induce the reappearance of sodic patches. These problems can be minimized to a great extent by adopting efficient irrigation and drainage techniques, balanced fertilizer use with emphasis on organic manures, cultivation of low water requiring crops and resource conservation technologies (Sharma and Singh, 2015).

## Concluding remarks

The challenge to feed the growing global population in the face of diminishing productive land and water resources has necessitated the sustainable management of vast stretches of degraded lands. Available evidence suggests that appropriate interventions can significantly enhance the productivity of salt-affected soils for producing food, fibre, fodder and fuel for the human well being. Although rapid strides have been made in the management of saline and sodic soils, changing agricultural scenario and the emerging challenges have necessitated a shift in the conventional approaches to sustain agricultural productivity in resource scarce and risk prone saline environments. Further refinements in mapping and characterization of salt-affected regions with the aid of emerging technologies such as solute transport modeling and use of air-borne geophysical sensors is the need of time. Integrated drainage solutions need to be promoted. Concerted efforts are required to develop cheap and environment-friendly alternatives to gypsum. Identification and development of multiple stress tolerant genotypes is the need of time. The tested resource conservation technologies need to be replicated in farmers' field. Vigorous efforts are required for capacity building of the farmers in salt-affected regions to enable them to effectively deal with the present and future constraints.

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