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Characteristics of Coastal Saline Soil and their Management: A Review

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A B S T R A C T

The salinity is mainly due to the presence of saline ground water at shallow depths and frequent flooding and sea water intrusion in low-lying areas. The intrusion of seawater into aquifers can occur directly, but also occurs a number of complex geochemical processes such as mixing between aquifers, mobilization of salt water, water-rock interactions and anthropogenic pollution. NaCl and Na_2SO_4 are the dominant salts with an abundance of dissolved cations in the order Na> Mg> Ca> K. The salt reaches the soil surface through capillary rise during dry season and makes the soil saline and unproductive for agriculture. Salinity ranges 0.5 dSm^{-1} in monsoon and 50 dS m^{-1} summer. A better understanding of the nature, properties and constraints associated with different coastal soil groups is needed to implement better management practices to increase the productivity and quality of saline soil.

Introduction

In India, the total area under salt-affected soils is 7.3 million hectare (Mha). Low productivity of this ecosystem is attributed to the unfavorable agro-climatic conditions. Coastal soils are encountered with various abiotic stresses viz., salinity, acidity, waterlogging and sandy texture. Most of the coastal areas have problematic soils, such as saline, alkaline, acid sulphate, marshy and waterlogged soils, situated in low-lying areas, mainly along the deltas. Coastal salinity is the main factor responsible for poor yield of crops growing an area of about 3.1 million hectares.

Direct sea water intrusion, intrusion through estuaries and the upward movement of salt from shallow water table are the major causes of salinity in salt-affected soils. Ingression of salt water in fields during monsoon season and its subsequent recession during winter and summer leaves the salt residues behind, which keeps accumulating on the surface due to upward movement and evapotranspiration. A very peculiar situation of coexistence of salinity and acidity is normally observed in these soils.

Salinity causes severe constraints to crop production in these soils. Salinity causes soil structural changes and alters soil physical processes affecting water and air movement and available water capacity (Oster and Jaywardane 1998). This further affects the osmotic and matric potential and microbial activities (Reitz and Haynes, 2003; Sardinha *et al.*, 2003). This ultimately reduces the rate of organic matter decomposition and release of nutrients and thereby affect the plant growth. Soil microbial community structure, their activities and enzyme activities are adversely influenced by the salinity (Reitz and Haynes 2003; Vijayakumar *et al.,* 2013). Velayutham *et al.,* (1999) revealed that saline soil resource and their potentials for different Agro-ecological Sub Regions (AESR) of India. It shows total 10.78 million hectare area under this ecosystem (including the islands) in India, which was the first scientific approach for delineation of the coastal soils. Extent and distribution of coastal area in India is presented in table 1 and Soil salinity classes and crop growth is presented in table 2.

Major coastal soils and their formation

Coastal soils are rich in salts, mainly due to the presence of saline ground water table at shallow depth and frequent brackish water inundation in the low lying areas. The ground water influenced by sea and brackish water estuaries reaches the soil surface through capillary rise during dry season, evaporates from the soil leaving salts behind, finally making the soil saline and unproductive for agricultural crops. The soil salinity thus shows high temporal and spatial variation depending on the elevation, soil texture, climate (evapo-transpiration, precipitation, wind velocity, relative humidity etc.), drainage and other related factors. The salt-laden sands blown by sea winds are also greatly responsible for formation of coastal salt-affected soils. Development of acid sulphate soils in coastal areas is the result of the drainage of soils that are rich in pyrites (FeS_2) which on oxidation produce sulphuric acid in presence of excess sulphate ions in soil. Pyrites accumulate in waterlogged soils that are rich in both soil organic matter (SOM) and dissolved sulphates.

Characteristics of coastal saline soils and their formation

In coastal saline soil, the salinity status widely fluctuates from ECe 0.5dSm^{-1} in monsoon to 50 dSm^{-1} in summer/drymonth. Mostly NaCl followed by Na_2SO_4 are the dominant soluble salts, with abundance of soluble cations in the order of Na > Mg > Ca > K. Chloride is the predominant anion, and bicarbonate is found in traces. In India, the soils are, in general, free of sodicity except in a few pockets in the South and Westcoast. Saline soil can be classified as the soils having pH less than 8.5, ESP less than 15, and preponderance of chlorides and sulfates of sodium, calcium and magnesium. Properties of soils at different coastal places of the east coast is presented in table 3.

Bandyopadhyay *et al.,* (1987) observed that coastal saline soils are characterized by clay loam with varied presence of silt and sand. The electrical conductivity ranges from 0.5 to 9.2dSm^{-1} with sodium as dominating caution in the salts. Biswas *et al.,* (1990) observed that coastal saline soils generally have highly saline shallow under groundwater table with gradual upward movement of saline water during summer months and subsequent evaporation of the water that contributes to soil salinity during dry periods. Salinity is one of the major obstacles to crop yield in deltas, estuaries and coastal fringes in the humid tropics. It is a serious impediment to growth of irrigated rice (Ponnamperuma, 1972). The salinity of the soil varies with the season. It reaches the maximum between January and May and decreases there after with the on set of monsoon (Bandyopadhyay and Bandyopadhyay, 1984). This cyclic salt accumulation and intermittent flood make these regions predominant in rice cultivation. Rajput and Polara (2012) reported presence of high salinity (EC 1.09 to 17.8 dS m^{-1}) in the coastal soils of Bhavnagar district of Gujarat, however, on the contrary to results of the present investigation, they observed higher soil pH (neutral to alkaline i.e. 7.0 to 8.9). Mahajan *et al.,* (2015), stated that, the coastal saline soils of Goa were found low, low to medium and medium to high with respect to soil available N, P and K, respectively. The soils were sufficient with respect to DTPA-extractable micronutrients – Fe, Mn, Zn and Cu and hot water soluble B.

The main obstacle to intensification of crop production in the coastal areas is seasonally high content of salts in the root zone of the soil. The salts enter in land through rivers and channels, especially during the later part of the dry (winter) season, when the down stream flow of fresh water becomes very low. During this period, the salinity of the river water increases. The salts enter the soil by flooding with saline river water or by seepage from the rivers, and the salts become concentrated at the surface through evaporation. The saline river water may also cause an increase in salinity of the ground water and make it unsuitable for irrigation. Coastal salines oils, the problem is further complicated by inundation through back wash from sea, tidal waters, wind borne salts and underground intrusion of sea water in sub soils.

Constraints in coastal saline soil

The major constraints are as follows

- More accumulation of soluble salts and alkalinity in soil,
- Pre-dominance of acid sulphate soils,
- Toxicity and deficiency of nutrients in soils,
- Intrusion of seawater into underground aquifers,
- Shallow depth to underground water table rich in salts,
- Periodic inundation of soil surface by the tidal water vis-à-vis climatic disaster and their influence on soil properties,
- Fines oil texture and poor in filter ability of soil in many areas,
- Eutrophication, hypoxia and nutrient imbalance,
- Erosion and sedimentation of soil, and
- High population density (Table 4).

Management approaches to improve quality and productivity of coastal soils

Saline soils can successfully be cultivated by removing excessive soluble salts through reclamation techniques. Reclamation of saline soils depends on the local conditions, available resources and the kind of crops that can be grown during reclamation. Reclamation can be accomplished in the long run by continued irrigation and cropping, inclusion of rice in cropping system together with incorporation of large quantities of organic manure (Gupta and Abrol, 1990). Reclamation of saline soils is by reducing the soil salinity to acceptable levels. In saline soils, maintenance of crop productivity at optimum level requires consideration of salt distribution within root zones that is influenced by the water extraction pattern of the crop, the method of water application, soil profile modifications, mulching, rainwater leaching and adoption of an appropriate crop rotation involving salt tolerant cultivars (U.S. Salinity Laboratory, 1954).

Leaching the soil

Leaching is the removal of soluble salts beyond the root zone, especially in shallow rooted crops. Salinity level of salt-affected coastal soils can be reduced by leaching the soils with good quality water. This can be a better option to reclaim the cyclone affected soils of the coastal area also. The amount of water used for reclamation of saline soils depends on degree of soil salinity, quality of irrigation water, the soil depth to be reclaimed and the water application techniques. The process of leaching was successful in the depth of 0-10 cm by means of maximum leaching of salts by Mahendran (2007). In the low-lying coastal areas where water table remains shallow for most part of the year and the quality of ground water is poor, installation of sub-soil drainage system is more useful.

Drainage

Drainage is the primary method of controlling soil salinity. The system should permit a small fraction of the irrigation water (about 10 to 20 percent, the drainage or leaching fraction) to be drained and discharged out of the irrigation project. In irrigated areas where salinity is stable, the salt concentration of the drainage water is normally 5 to 10 times higher than that of the irrigation water. Salt export matches salt import and salt will not accumulate.

Table.1 Extent and distribution of coastal area in India

States/Union territories	Area (km^2)
West Bengal	14,152
Orissa	7,900
Andhra Pradesh	35,500
Tamil Nadu	7,424
Kerala	7,719
Karnataka	7,424
Maharashtra	10,000
Goa	220
Gujarat	17,465
Lakshadweep	26
Pondicherry and Karaikal	3
Total	**1,07,833**

Velayutham *et al.,* (1998)

Table.2 Soil salinity classes and crop growth

Soil Salinity Class	Conductivity of the Saturation Extract (dS/m)	Effect on Crop Plants
Non saline	0 - 2	Salinity effects negligible
Slightly saline	2 - 4	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	Yields of many crops are restricted
Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only a few very tolerant crops yield satisfactorily

Table.3 Properties of soils at different coastal places of the east coast

State/U.T.	Soil texture	pH	EC (dS m^{-1})	Dominant salt
West Bengal	Silty clay-Silty clay loam	3.5-7.0	4.0-35	NaCl, Na_2SO_4
Orissa	Clay loam-Clay	5.0-7.5	2.0-50	NaCl
Andhra Pradesh	Sandy loam-Clay loam	6.0-8.8	0.5-17	NaCl, Na_2SO_4
Pondicherry	Sandy loam-Loam	6.6-8.5	1.0-50	NaCl, Na_2SO_4
Tamil Nadu	Sandy loam-Loam	6.0-8.2	2.0-10	NaCl, Na_2SO_4
Andaman & Nicobar Islands	Loam-Sandy loam	3.0-7.0	4.0-25	NaCl, Na_2SO_4

Bandyopadhyay (1994)

Table.4 Saline tolerant varieties

Crop	Variety
Rice	Saline Soil: CSR-49, CSR 36, CSR 30 (basmati type), CSR 27, CSR 23, CSR 13 and CSR 10. Coastal saline soil: Butnath (CSRC(S)5-2-2-5) and Sumati- CSRC, Gangavathi sona-05-01
Wheat	KRL 213, KRL 210, KRL 19 and KRL 1-4
Indian Mustard	CS 56, CS 54 and CS 52
Chick pea (gram)	Karnal Chana 1
Dhaincha (sesbania)	CSD 137 and CSD-123

The other management technologies are,

1. Selection of tolerant varieties
2. Use of organic matter
3. Use of mulch
4. Foliar application of fertilizers
5. Fertilizer management
6. Integrated nutrient management
7. Phytoremediation
8. Green manures & green leaf manure
9. Strip cropping (Manjunath, 2016, Naik, 2014 and Quadir, 2005)

Selection of tolerant varieties

Avoidance of summer fallow

Most of the coastal areas suffer from excess water in monsoon season with attendant problem of prolonged deep water submergence having adverse effect on crop growth. Whereas in winter and summer months, the capillary rise of the saline ground water impel the farmers to take only one rice crop in a year during the monsoon season. Introduction of second rice crop during the fallow periods, if good quality water for irrigation is available, can reduce the salinity level and increase the cropping intensity.

The high salinity is due to the high evaporation rate from soil during winter and summer months, if ground water is at shallow depth and rich in salt content. In coastal areas, the availability of good quality irrigation water is one of the major problems. However, if sufficient irrigation water of good quality is not available, a crop like chilli, barley, linseed, sugar beet can be grown whose crop canopy will reduce evaporation and thus there will be reduction in soil salinity.

Application of soil amendments

Field experiments conducted at Coastal Saline Research Centre, Tamil Nadu Agricultural University, Ramanathapuram, Tamil Nadu revealed that application of agro-industrial wastes significantly improves oil organic carbon, pH, EC and soil bacteria, fungus and actinomycetes population and enhanced the soil fertility status (macro and micro nutrients) and improved the crop productivity of finger millet. Application of press mud @1 2.5 tha^{-1} recorded better growth and yield of fingermillet followed by composted coirpith @ 12.5 t ha^{-1} (Rangaraj *et al.*, 2007). Application of lime and alkaline fly ash in proper combination to the coastal acid sulphate soils is effective for amelioration to some extent. Rice husk biochar could be used as a substitute for liming materials to improve the quality of acid sulphate soils. Increase in the pH of acid sulphate soil due to application of rice husk biochar is well documented. Amending coastal sandy soils with polyacrylamide @ 100-120 mg kg^{-1} is useful for increasing the aggregation of soil, which in turn increases the water holding capacity of coastal sandy soil. This plays important role in highly permeable coastal sandy soils during dry summer months.

Addition of organic material either in the form of FYM, compost or green manure reduces the adverse effects of salinity on rice crop. Dhaincha (*Sesbania cannabina*), Shevari (*Sesbania aegyptica*) and leaves of bhend (*Thespesia populanea*) are found to be useful in increasing the yield of rice crop (Kadrekar *et al.*, 1981). Linear response was observed with increasing doses of FYM upto 15 t/ha along with recommended dose of fertilizers (Chavan *et al.*, 1990).

Mulching appears ultimately as the most efficient method in reclaiming these coastal saline soils (Aidara, 2017). Beye (1973) applied the mulching method to reclaim saline acid soil in the coastal area of southwestern Senegal and obtained up to 50% reduction of salinity in the topsoil (around 30 cm) after four years despite low rainfall during the trial period. But the lack of soil characterization makes these results really transient, limiting their large-scale application. Accordingly, Grigg *et al.,* (2006) suggested further research in order to ascertain the long-time efficiency of the mulching technique.

Growing of suitable crops

In coastal areas, rice is the most preferable crop which is highly salt tolerant and can be grown under submerged condition. Rice cultivation promotes the leaching of salts from coastal saline soils. Adoption of rice crop in acid sulphate soils of coastal areas increases the pH of soil and thus reduces the iron and aluminium toxicity. Selection of suitable rice variety depending upon the salinity level and depth of water regime is highly appreciable. A large number of promising rice varieties have been developed/identified by Central Soil Salinity Research Institute, Karnal, Haryana and its regional research station at Canning, West Bengal for various waterlogging and salinity levels in kharif season. Other than rice, chilli, guava and sapota have been identified as salt tolerant vegetable and fruit crops for coastal saline soils. Growing of cashew in the coastal belt with proper irrigation and management practices may be beneficial.

Nutrient management

Most of the coastal soils are deficient in nitrogen due to heavy loss through volatilization, leaching and run-off. Phosphorus deficiency is also a common phenomenon in coastal acid sulphate or acid saline soils. Use of nitrogenous fertilizers is very much essential to obtain higher yield of crop in coastal saline soils. Application of rock phosphate as phosphorus source is highly beneficial for coastal acid saline soils. Long term fertilizer experiment showed significant response of rice crop due to application of nitrogenous fertilizers on coastal saline soils under rice-fallow cropping system. Integrated use of chemical fertilizers and farmyard manure (FYM) @15 t ha^{-1} is also a recommended practice for better use of fertilizer nutrients in coastal soils.

For effective utilization of land resources and betterment of livelihood of the local people in coastal areas, paddy-cum-fish culture can be adopted in lowland areas of coastal regions without much affecting the productivity of the soils. This may facilitate additional income generation to the farmers struggling for survival in the coastal regions and also uplift their socio-economic condition (Prasenjit Ray *et al.,* 2014).

Phytoremediation

Phytoremediation, also known as vegetative bioremediation, is an approach for saline soil remediation through the cultivation of salt-accumulating or salt-tolerant plants and is perceived as a sustainable and cost-effective technique (Qadir and Oster, 2004; Jesus*et al.*, 2015; Jing *et al.*, 2019). The successful growth of salt-tolerant plants in salt-affected areas (Imadi *et al.*, 2016) and the various remediation mechanisms employed by plants (Munns and Gilliham, 2015) have been reported in previous studies. Basically, the two main mechanisms involved are based on either the exclusion of salt by the roots or the control of salt concentration and distribution (Hanin*et al.,* 2016).

The plant species used for phytoremediation are mainly halophyte, hyperaccumulator, salt-tolerant, or transgenic plants. *Tamarix chinensis* has been reported to successfully reduce the salt concentration in saline soils and increase the abundance of soil nutrients (Cao *et al.,* 2014; Zhang *et al.,* 2016). *Lycium chinense* is also classified as a halophyte (Zhao *et al.,* 2002) and can grow in highly saline soil (Yuan *et al.,* 2015). *Gossypium hirsutum*, commonly known as upland cotton, is classified as a salt-tolerant plant, although the levels of salt tolerance differ among cultivars (QadirM and ShamsM. 1997; Gossett *et al.,* 1994).

Although using these plants for the purpose of phytoremediation in coastal saline soils has been reported, a comprehensive comparison of remediation efficacies and its underlying mechanisms across plant species, particularly in long-term treatments, has not been performed.

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