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Status of rice cultivation under Indian saline lowlands

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Abstract
Abiotic stress, especially Salinity is one of the major restraints for attaining self-sufficiency in the food grain production. The Saline soils affect the crop growth both directly and indirectly by interfering with plant metabolism resulting in reduction in yield potential of various crops. As the gross cultivable lands in Indian condition are limited, extending the crop production in these problematic soils is mandatory to meet out the food requirements of the growing population. Reclamation and management of the salt affected soils by application of various organic and inorganic amendments and developing the salt-tolerant cultivars are the ways to combat with the saline environments. This article was aimed at reviewing the various innate plant mechanisms to evade salinity, effects of various soil amendments on crop growth on Saline condition and the utilization of available saline-resistant cultivars of Rice *(Oryza sativa)* under coastal saline conditions of Indian lowlands. As an initial step of the study, the present study reviewed all the published information available on Salinity researches and critically examined the present status, knowledge gaps and future perspectives leading to a sustainable Rice production that are pertinent to the present situation of crop cultivation.

Keywords: desalinization, reclamation, rice, salinity, salt tolerance, sustainable production

Introduction
The salt affected soils are assessed to spread over to an extent of over 6.73 million ha in India with the conditions of Gujarat and Uttar Pradesh having more area under saline tract of 2.23 m ha and 1.37 m ha respectively. Maharashtra and West Bengal follows with 0.61m ha and 0.44 m ha of Salt affected areas (D. K. Sharma *et al*., 2015) [42]. These states altogether accounts for more than two third of the total land area affected by salinity in the country. The usage of poor-quality water has contributed much for the development of saline lands in these states (Singh, 2009) [46]. The area under Saline condition is estimated to triple (20 m ha) in India by 2050 (Sharma *et al.* 2014) [43]. The coastal area is spread over more than 7000 km covering a wide range of climatic and topographical conditions. Coastal areas account for more than 66% of the total rice growing tract in the country. Groundwater contaminated by intruded sea water further worsened the soil physical and chemical status by increasing the accumulated salt levels.
Even though Rice is moderately tolerant to salinity, the yield loss reaches to the extent of 50% when the Salinity level reaches 6.9dSm^{-1} (Van Genuchten and Gupta, 1993) [52]. However, the damage level may vary based on the crop stage affected and the nature of salt present in the soil (Lutts *et al.* 1995; Khan *et al.* 1997) [22, 27]. By adopting proper management and reclamation measures, the yield can be improved by 35 to 50 m tones annually (Lal *et al.* 2003) [24].

Salinity
Abiotic stress includes cold, heat, salinity, drought, effect of heavy metals present in soil, etc., which are the major issues that retard the effective crop cultivation worldwide (Pareek *et al.* 2010) [36]. Among these stresses, the yield loss due to the presence of excess soluble and exchangeable salts (salinity) in the soil colloidal complexes retards crop growth to the greater extent than any other factors. Salinity includes all the salt related problems in the soil especially due to presence of excess sodium which accumulated naturally from soil forming material and by the continuous application of poor-quality water and basic residue fertilizers (Flowers and Flowers, 2005) [13]. More than 444 m ha of land area are affected by Salinity globally (FAO, 2008) [11] which is more than that of India's total geographic area (328.74 m ha). The following are the criteria to classify the nature of different salt affected soils:

Reaction of the soil measured by pH, conductance of the salt solution Salinity measured by means of its Electrical conductivity (ECe) and the Exchangeable Sodium Percentage (ESP).
The salinity can be classified into Saline, Alkaline and Saline-alkaline based on the nature of salt present in the soil solution and on the colloidal complex. Sulphates and chlorides of calcium, sodium and magnesium are the predominant salts present in Saline soils. Whereas, the Alkaline soil has a pH value greater than 8.5 with the accumulation of the carbonates and bicarbonates of sodium salts. The Saline-alkaline soil develops with the accumulation of salts similar to Saline soils (US Salinity Laboratory, 1954) [51]. Mishra (1995) [30] observed that saline environment are more suitable for growing Rice than any other cultivated crop species because the continuous flooding of paddy field enables the excess soluble present in soil solution to be leached down below the root zone of the crop. Hence, the injury level is reduced in Rice crop in comparison with any other salt-tolerant crops like barley, etc. The sodicity classifications based on the chemical nature of the soil are given in Table 01.

Table 1: Sodicity classification based on chemical properties (US Salinity Laboratory, 1954) [51]

Sodicity type	pH	Electrical conductivity (ECe) (dSm-1)	Exchangeable sodium percentage (ESP) (%)	Sodium absorption ratio (SAR)*	Typical soil physical condition
Normal soil	<8.5	<4	<15	<13	Flocculated
Saline soil	<8.5	>4	<15	<13	Flocculated
Alkaline soil	>8.5	<4	>15	>13	Dispersed
Saline-Alkaline soil	>8.5	>4	>15	>13	Flocculated

*SAR of soil water extract

Coastal lowlands under saline conditions
The coastal saline tract can be classified into: East coast coastal soils along the Bay of Bengal Sea coast and the West coast coastal soils along the Arabian Sea Coast. These soils occur as strips of 5 to 100 km land masses as reported by Yadav, 1979 [57]. In these areas Salinity results due to the intrusion of saline sea water into the shallow groundwater tables which are the main source of irrigation lifted by open wells or borewells dug to few hundred meters (Sabareshwari *et al.* 2018) [41]. Hence, this groundwater contains more of water-soluble cation in the order of $Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$ which in excess amount affect the crop growth and yield to a greater extent which is referred as mineral toxicity. The salt in water reaches the top soil through capillary raise and deposits as white patches over the upper soil horizons (Prasenjit Ray *et al.* 2014) [38].
The effect of saline soils and saline irrigation water on crops is not only limited in affecting the quality and quantity of the grains but also the choice of the crop being raised in those stress environments (Dhanushkodi *et al.* 2012) [8]. Among the salt affected coastal areas, 15% of area suffers from extreme limitations towards crop growth (Wicke *et al.* 2011) [55].

Rice under salinity
Plants can be grouped into two types based on their level of tolerance to varying salt concentrations: Glycophytes which tolerate salt levels only to a very few concentrations and the other extreme being Halophytes which includes plants that tolerate high concentration of salts (Maas, 1998) [28]. Rice is placed under the category of Glycophytes with some degree of tolerance to salinity during crop growth stages of tillering and towards maturity but are sensitive during early seedling stage and at peak flowering (Zeng *et al.* 2001) [60]. The level of tolerance determines the yield potential of crop as reported by (Momayezi *et al.* 2009) [31]. Salinity interferes with growth, accumulation of photosynthetase and other essential plant metabolism. Generally Osmotic and ionic stresses are observed on Rice plant under salt stress. Osmotic stress occurs when the salt concentration around the root zone increases beyond the threshold level. Ionic stress results in necrosis of leaves when their concentration is increased over optimum level in the older leaves of the rice plant (Munns *et al.* 2008) [32]. Growth and yield differences among different varieties of rice depend on the salt concentration and the tolerance level of the particular plant (Eynard *et al.* 2005) [9].

Crop nutrient uptake status
Salinity results in the complete to partial closure of stomata which increases plant canopy temperature and retarded shoot growth (Rajendran *et al.* 2009) [40]. This was regarded as 'Osmotic phase' by Munns and Tester (2008) [32]. The plants are severely stunted. The concentration of Ca, Mg and Na are increased and the concentration of K is decreased owing to salinity. Singaravel *et al.* (2006) [45] reported that the organic matter content in the soil is decreased to a considerable extent in coastal saline lowlands. The N uptake is drastically reduced with the increase in NaCl concentration (Bilkis *et al.* 2016) [4]. The salt toxicity coupled with nutrient starvation affects every stage of crop growth for varying degrees.

Mechanism of salt tolerance in rice
The genus *Oryza* has a broad genetic base ranging from complete susceptibility to moderate tolerance to salinity such as Pokkali variety grown on the coastal areas of Kerala. The salt affected plants make the osmotic adjustment by retention more quantities of Osmolytes. K^{+}, Ca^{2+}, Cl^{-} and other inorganic salts are accumulated for this purpose (Jian *et al.* 2010) [20]. In order to maintain the favorable osmotic balance, plants exclude the entry of excess salts into the plant system (Salt exclusion) or compartment these salts in cell vacuoles of older leaves (Salt compartmentation). Further, retention of excess salts in upper roots and basal portion of stem can also helps in evading salt stress (Munns, 2002) [33].

Sustainable use of salt affected areas
Bio-saline agriculture i.e., the use of tolerant tree, shrub and herb sp. Prove to be more economical in saline belts. There are only two possible ways to extend the crop cultivation under salinity. One is to reduce the salinity and bringing back the salt affected soils to normal (neutrality) condition and the other is to develop salt tolerant cultivars which can give good yield despite the excess salts. ICAR- Central Soil Salinity Research Institute, Karnal, Haryana (1969) have been created to undertake research activities related to Soil salinity management in Agriculture.

Salt tolerant cultivars

Rice being moderately tolerant to salt stress can be grown under saline conditions with proper management practices (Hassan *et al.* 2001) [18]. Genomic approach by locating the QTLs for salt tolerance and high throughput genotyping has confirmed the existence of major locus for salt tolerance called *Saltol* in the chromosome 1 of Pokkali and SKC1 of Nona Bokra which provides Na^+/K^+ homeostasis balance under salinity (Thomson *et al*, 2010; Platten *et al*, 2013) [37, 50].

Reclamation and management of saline soil

Salinity and water-logging can be best managed by providing suitable surface or sub-surface drainage system (Gupta, 2002) [16]. Local condition, availability of suitable amendments and the crop variety grown during reclamation period also play a major role in deciding the effective management practice to be adopted. Saline soil can be used for regular cultivation by removing the excess salts through flooding and leaching down the soluble salts by providing better drainage options. In the long run, application of farm yard manure (FYM), inclusion of rice in the cropping system and continued irrigation with good quality water has given attractive results (Kaur *et al.* 2000) [21]. PVC or concrete lined sub surface drainage with filters placed at regular intervals helps in effectively leaching down the excess salts as reported by Singh, 2009 [46]. The sub-surface drainage system was initially developed in Haryana. Following the success stories, it was further extended to other states covering more than 1,10,000 ha of saline areas all over India. Soil desalinization can also be achieved by cutting back thee above ground parts of cultivated crops and leaving behind the stubbles with intact roots to leach away excess salt along with irrigated water (Swallow and O'Sullivan 2019) [47]. Another method called Scrapping which is to scrap away the salt patches left over the soil surface (Abdel-Fattah 2018) [1]. But it seems to have no practical utility under field conditions. The soil texture, nature of salt, and the volume of soil to be leached decides the volume of water to be used for leaching purpose (Biswas and Biswas 2014) [5]. Novel techniques such as *Biomimicry* that is to mimic vascular plant's capillary action to allow deep percolation have also developed (Swallow and O'Sullivan 2019) [47].

Reclamation and management of alkaline and saline-alkali soils

Organic amendments such as compost and well-decomposed FYM as well as salt tolerant cultivars can be helpful in providing a better soil structure and aggregation properties for reclaiming sodic salts (Davis *et al.* 2014) [7]. Reclamation activities involves the removal of excess sodium ions from the soil colloids by using divalent cations preferably Ca^{2+} to improve soil flocculation. The removed Na^+ ions have to be leached down below the root zone of the crop along with irrigation water (Mahmoodabadi *et al.* 2013) [29]. Gypsum is the economical and most commonly applied reclamation material for Saline-Sodic soils which can improve both the physical and chemical properties of soil by maintaining a high Ca/Na ratio (Yaduvanshi *et al.* 2008) [58]. Organic amendments on their part can increase the dissolution of $CaCO_3$ by the increased activity of Carbonic acid near the upper soil profile which in turn Ca^{2+} ions replace Na^+ ions at the exchange site (Yaduvanshi, 2017) [59]. Thus, Organic matter plays a very crucial role in the reclamation of every problematic soil especially saline and saline-alkali soil by favorably altering the soil physical, chemical and biological properties as reported by Tejada *et al.* 2006 [49]. Gupta *et al.* 2016 [15] reported that the combined application of Organic matter and Gypsum have improved the soil characters such as reduced bulk density, decreased electrical conductivity and exchangeable sodium percentage (ESP).

Leaching

Leaching is an inevitable process in the reclamation of Salt affected soils and its efficiency depends on the depth of available ground water and the nature of salt present in the soil (Kuligod *et al.* 2000) [23]. During the process of leaching, the water-soluble salts are dissolved and carried down much away from the reach of crop rootzone. Aich *et al*. (1996) [2] reported that the yield potential of rice crop is increased by leaching when compared to the control plots (unleached soils).

Role of various amendments in ameliorating salt stress

Various amendments of diverse nature like pressmud, farm yard manure, green and green leaf manuring, Gypsum, etc., can be used for improving the soil fertility and productivity status by favorably manipulating the bulk density and other chemical status of the soil.

Gypsum

Gypsum can be applied directly on the soils which are low in carbonate content as Gypsum contains more of calcium ($CaSO_4.2H_2O$) ions. On the other hand, sodic soils rich in calcium, Sulphuric acid can be used instead (Horney *et al.* 2005) [19]. The sulphuric acid reacts with the excess of Calcium ions in the soil, thus forming Calcium sulphate (Gypsum) insitu. Due to cheaper cost and ready availability, Gypsum has emerged as the most suitable chemical amendement for Alkali soils (Wang *et al.* 2016) [54]. Haq *et al.* (2001) [17] reported that the combined application of Gypsum, farm yard manure and pressmud gave the highest level if rice yield under coastal-saline condition.

Amendments of organic origin

Organic amendments improve every aspects of soil health *viz*., physical, chemical and biological properties under saline condition (Le Guillou *et al.* 2011) [25]. There is wide evidence that the organic amendments reduce the toxic effects of saline soil in many cultivated crop species (Leithy *et al.* 2010; Raafat and Thawrat, 2011) [26, 39]. Adding organic matter improves the soil stability, aggregate formation and enables better leaching and lowering down the pH to normal (Tejada *et al.* 2006) [49]. Further soil microbial biomass level is increased tremendously upon the addition of organic matter which in turn increases nutrient availability and mobility (Kaur *et al.* 2000) [21]. Including organic amendments and the conjuctive use of salt affected and fresh water if found to be beneficial in many saline tracts (Sharma *et al.* 2014a) [43].

Green manuring

Inclusion of green manuring in the cropping system is important to improve soil quality and sustainability of the cropping system. Apart from lowering the salt level, it adds nutrient content to the soil (Fabunmi *et al.* 2012) [10]. Green manures such as *Crotalaria juncea, Sesbania sp*. etc., and green leaf maures like *Azadiracta indica, Pongamia glabra* when ploughed into the soil, will improve the OM content, bulk density, soil porosity and water holding capacity (Wiesmeier *et al.* 2015) [56]. Mythili *et al*. (2001) [34] reported that the inclusion of *Sesbania aculeata* in sandy loam and sandy soils is found to increase the availability and uptake of Zn and S. The application of 6.25 t/ha of Green and green leaf manuring along with the recommended dose of NPK fertilizers and Gypsum has resulted in the significantly higher yield of 17 - 24% than unmanaged conditions (Nagarajan *et al.* 2000) [35]. Vanathi and Mohamed Amanullah (2007) [53] recorded the higher yield of rice under coastal saline conditions with the application of *Calotropis gigantea* at 6.25 t ha^{-1}. Among the salt tolerant crops, *Sesbania aculeata* grows well under saline conditions and can be used as an effective element in reclamation of these problematic soils (Baig *et al*. 2005b) [3].

Farm yard manure

Every aspects of soil health can be improved by the application of farm yard manure (Wong *et al.* 2009). Farm yard manure is an effective, cheap and easily available amendment for the remediation of Saline soils (Tejada *et al.* 2009) [48]. Farm yard manure at the rate of 12.5 t/ha is found to saturate hydraulic conductivity and reduce bulk density to the desired level (Fares *et al*. 2008) [12]. Farm yard manure plays a very crucial role in stability of the soil aggregates (Chagant *et al.* 2015) [6] by the way of binding soil colloids with organic polymers. The addition of farm yard manure provides a better balance between the soil micro and macropores as reported by Shi *et al*. (2016) [44]. The faster infiltration of water into the soil profiles provides faster leach of excess salts and prevents soil erosion (Grigg *et al.* 2006) [14].

Conclusion

Salinity problems persist from the days when agriculture was really started. Though there was many researches and significant contributions made by Central Soil Salinity Research Institute, Karnal, Haryana and several other research institutes including State Agricultural Universities all around the world, the problem of Salinity remains unsolved. There were many evidences for reducing the severity of salinity by the combined use of organic and inorganic amendments for improved productivity and sustainable land use system under problematic conditions. But there is a huge void pertaining to the use of salt tolerant cultivars and other amendments which involves higher costs under rainfed situations. In this context, near future efforts have to diverted for exploring new technologies which can suitably modify the crop growing environment and for the identification of genetically superior plant types which are economical, efficient and more sustainable.

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