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SALINITY STRESS AND SUSTAINABLE AGRICULTURE- A REVIEW

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ABSTRACT

Soil Salinity is being recognized as a major threat to the agriculture and food production in the arid and semi-arid soils. Accumulation of sodium, magnesium and calcium salts enhances the alkalinity of the soils making the crop production difficult. Plant system has developed certain adaptation strategies for tolerating the toxicity of the salts in the soil. The present review focuses on the probable sources of soil salinity, induction of toxicity mechanisms of salinity stress tolerance in crop plants along with the strategies needed to be adapted to make agriculture a sustainable one.

Key words: Crop plants, Osmolytes, Salinity, Salinization, Sustainability, Tolerance mechanisms.

The growth and productivity of the crop plants depend on a wide variety of environmental factors such as light, water, temperature, nutrients in the soil etc. Whenever, the survival of plants is limited by these factors, than they are considered to be under stress. The most common abiotic stress factors influencing the plant productivity are salinity, drought, alkalinity, UV radiation, low and high temperatures, dust, nutrients, flood etc. Among which, salinity of the soil is a major stress factor which affects the plant growth and productivity in the semi-arid regions (Win, 2011).

Soil salinity became an aspect of serious concern to global agriculture throughout the human history (Lobell *et al.,* 2007). Due to the extensive utilization of land, the problem became more prevalent all over the world (Egamberdieva *et al.,* 2008; Meloni *et al.,*2008). Every soil possesses certain water-soluble salts, which will be absorbed by the plants as plant nutrients. However, over accumulation of these salts will make the soil saline, and will suppress the plant growth. Salinization of soils is more prevalent in arid and semi arid regions. Salts are personified in the soil as ions, which will migrate upward in the soil depending on the external climatic conditions (Zhang *et al.,* 2012). When there is dearth in the precipitation, leaching of ions from the soil profile will not takes place leading to accumulation of salts resulting in soil salinization. This will not only effects plant growth and productivity, but also affects economic welfare, environmental health and agricultural production (Rengasamy, s2006). According to FAO Land and Nutrition Management Service (2008), over 6% of the world's land is affected by the salinity, which accounts for more than 800 million hectares of land in 100 countries with the general perception focused on arid and semi-arid regions.

Salinization is the result of two processes; 1. Primary salinization and 2. Secondary salinization. Primary salinization is the development of salinity due to natural processes such as the deposition of sand stones, alluviam in the arid and semi-arid lands, intrusion of oceans into the coastal areas followed by evapo-transpiration and high tidal intrusion of sea water into rivers. Certain ocean salts like Sodium chloride (NaCl) will be carried by the wind during cyclones and deposited by rainfall. Secondary process is the resultant of soil salinization by human beings as a consequence of irrigation using improper methods such as poor quality of water usage, deforestration, contamination of river waters with industrial chemicals and overgrazing by domestic animals (Omami *et al.,* 2006). Deforestration and land clearing are the major reasons for the salinization and alkalization of the soils as an

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outcome of soil migration in both the upper and lower layers (Said-Al and Omer, 2011). Anthropogenic salinization occurs in arid and semi-arid areas mainly due to water logging brought about by improper irrigation (Ponnamperuma, 1984). The severity of secondary salinization arises due to poor irrigation practices such as the type of system and timing and the amount of irrigation water like the usage of inadequate quantities of irrigation water to leach salts that accumulate in the root zone due to evaporation (Homaee *et al.*, 2002). The performance of crop plants in salinized soils is not only affected by the salinity levels but also by the soil characteristics (Burger and Èelková 2003).

Types of salts active in soil salinization: Salts of several cations such as sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) are found to induce salinity to soil, however, sodium is the most dominant salt causing deterioration of the physical structure of the soils. Sodicity is the result of secondary salinization in clay soils, where leaching occurs through human induced processes which washes soluble salts into the subsoil and leaves sodium bound to the negative charges of the clay due to an increase in its concentration (Sangeeta *et al.*, 2011). The common anions are chloride (Cl^-), sulphate (SO_4^{2-}) and carbonate (HCO_3^-). Both Na^+ and Cl^- are toxic to plants (Hasegawa *et al.*, 2000). Historically soils were classified as saline, sodic or salinesodic based on the total concentration of salt and the ratio of Na^+ to Ca^{2+} and Mg^{2+} in the saturated extract of the soil (Dubey, 1997).

Nitrogen fertilizers and nitrate leaching: Nitrogen fertilizers such as urea and ammonium nitrate have a high leaching potential and mobility. During the past few years excessive use of the ammonia and urea fertilizers resulted in leaching of soils below the root zone, contaminating groundwater. Fertilizers misused for higher yield is an important cause of nitrate contamination. Other agents such as animal manure, domestic waste water and *in situ* organic matter deposition in soils are exacerbating the risk. Crop management and nitrogen fertilization techniques are important in reduction of nitrogen losses since annual crop's nitrogen uptake efficiency is < 50% and about 30–50% of applied nitrogen fertilizer is leached into groundwater (Ventura *et al.*, 2008).

Interactive effect of nitrogen fertilizers and salinization: Nutrient deficiency limits plant growth under low salinity, which results in increased salt tolerance. In moderate or high saline conditions, increased concentration of salts hinders the growth. In most of the saline soils, application of fertilizers enhanced the soil salinity, which inturn increased the yield and productivity of cotton, millet, rice, corn and wheat. Plants will reduce their tolerance to salt when nitrogen is applied to extreme saline soils. This might be the reason for similitude behavior of both halophytes and glycophytes in high and mild saline soil conditions coupled with deficiency of nitrogen. However, biomass of some plants like cotton and corn were found to be increased when nitrogen is applied in less saline conditions. High concentrations of salt ions, usually Na and Cl affect the activity of nutrients in the soil, resulting in a nutritional disorder in plants. Nutrient status in plant tissues may be associated with the interactive effect of salinity and nutrients on the plant growth. Nutrient uptake and accumulation by plants was affected under saline conditions due to the competition among various salt species which also further affected by composition of soil (Khorsandi and Anagholi, 2009). Na^+ induces deficiency of K^+ during salinity stress although plants selectively absorb potassium over sodium.

Impact of soil salinization in India: In India increasing soil salinity and its damaging effects on agricultural soils severely affecting the agriculture yield, which has become not only an environmental concern but also an economical issue. Year after year increased salinization of agricultural land is reported in the sub-continent due to accumulation of salts in the soil. Among the 9.38 million hectares of salinized soils in India, 3.88 million hectares are alkali soils and 5.5 million hectares are salinized due to the climatic and environmental factors (Jaleel *et al.*, 2008). Soil salinization increases in proportion due to lack of rainfall and irregular farming practices. In Indian sub-continent, average rainfall is approximately 1100mm, out of which 46% of rain water merges into various water bodies. 32 % water gets evaporated and only 22% water from the rainfall recharges the ground aquifers and the soil. Even though this water resource is huge in nature it distributes across India seasonally and spatially due to vagaries of monsoon, resulting in floods or drought. Floods result in the runoff of the water excessively, through rivers into Bay of Bengal or Arabian Sea, leading to a process of natural salinization due to the wash of soil top layers and accumulation of salts mostly in the coastal areas of the sub-continent (Hemapriya *et al*, 2010).

Arid and semi-arid regions of India and the remaining world are more vulnerable to salinity risk, which is found to be a serious threat to the agriculture effecting both growth as well as the yield. Legume grains have very less defiance to the salinity stress since their levels of tolerance are less to salinity and more over their symbiotic nitrogen fixation is sensitive when higher salinity rates predominates the area (Ramana *et al.,* 2012). Rhizobial infection and root nodule development are particularly sensitive to salinity. Even though soil salinization does not affect the rhizobial activity in colonization but will reduce the efficacy of the fully grown nodules which are developed prior to the saline conditions. Apart from these ill effects, saline conditions hamper the growth of newly initiated nodules (Rao *et al.,* 2002). Studies on cereals indicates that salinity stress decreased relative water content, chlorophyll content, carotenoids, biomass and grain yield. (Sai Ram *et al.,* 2002).

Agriculture in arid and semi-arid conditions also enhanced the salinity of the soils. Indian farmers are depending on the ground water for their agriculture needs resulting in the decrease of permanent water table levels leading to the accumulation of salts at the root zone. Enhanced salinity and sodicity of the soils will have adverse effect on the physical structure of the soil which inturn resulting in decreased aeration and water transfer. However, farmers are attempting to resolve this problem by irrigating their farm lands either with a potpourri of canal water and ground water or alternate irrigation (Dutta *et al.,* 2002)

Effect of Soil Salinization

Agriculture: One of the main factors exacerbating the rate of salinization in most of the irrigated soils is the poor drainage system and availability of ample irrigation water (Town *et al.,* 2008). During the general process of water absorption by plants or due to evaporation, salts in the water will remain in the soil, contributing to the soil salinization. This process along with the improper irrigation management is increasing the risk of soil salinization day by day. One of the prominent methods to prevent this is to pass surplus amount of water through the root zone in order to leach the salts from soil (Maas *et al.,* 1999). However, some of these salts are essential to plants as plant nutrients and some salts such as nitrates act as pollutants if leached into groundwater in excess. Osmotic effect is the first outcome of salinization of the soil requiring an additional energy input of plants to absorb water, which means that the soil need to be moist in order to supply similitude amount of water to plant. More energy is exerted by the plant due to osmotic effect caused by soil salinization whereas not essential under normal conditions (Romero *et al.,* 2001). This energy can otherwise be used for the purpose of flowering, fruiting or growth. When threshold tolerance exceeds, plant's growth is affected resulting in its death due to excess salt concentration (Sohan *et al.,* 1999).

Yield of crop plants: Salinization severely affects the agricultural productivity of crop plants. The salinization of agricultural lands at massive scale causes severe economic loss at the global level. The annual global income losses due to salinization of agricultural land were $11.4 billion in irrigated land and $1.2 billion in non-irrigated areas (Zhu *et al.,* 2005). Nutritional imbalance coupled with excessive salt in the leaves will affect the photosynthetic system causing chlorosis and death of plant in saline soils (Munns and Tester, 2008). One of the limiting factors for plant survival in saline soils is leaf senescence (Parvaiz and Satyavati, 2008). In saline soils, plant density is an important factor which affects the salinity in crop plants. However, optimum plant density determination is highly difficult since levels of salinity and stress tolerance of several crop plants varies. This strategy may work in reducing the impact of salinity on plants of a field but cannot improve the yield since vegetative growth is more favored than crop yield (Ali *et al.,* 2009). Soil Salinization decreases shoot growth, germination and seed yield with low fiber quality of cotton crop (Dong *et al.,* 2009; Higbie *et al.,*2010). Rice crop in the coastal regions of Asia is frequently affected by exposure to sea water brought in by cyclones (Sultana *et al.,* 2001). Rice (*Oryza sativa*) is one of the most sensitive and barley (*Hordeum vulgare*) is the most tolerant cereal to the soil salinity, whereas

Bread wheat (*Triticum aestivum*) is moderately tolerant. Tall wheatgrass (*Thinopyrum ponticum*, syn. *Agropyron elongatum*) is one of the most tolerant member of salinity among the monocots, where its growth proceeds in the concentrations of salt as high as in seawater (Munns, 2005). The variation in salinity tolerance of dicotyledonous species is even greater than in monocotyledonous species. Salt treatment caused a significant decrease in relative water content (RWC) in sugarbeet varieties (Ghoulam *et al.*, 2002). Legumes are very sensitive, to salinity. Alfalfa (*Medicago sativa*) is highly tolerant along with halophytes such as saltbush (*Atriplex* spp.), which grows well at salinities greater than that of seawater (Mariam *et al.*, 2006).

Response of plants to salinity stress: Salinity is an increasing threat to many irrigated, arid and semi-arid areas of the world, accomplished by the insufficient atmospheric precipitations to leach the salts from the root zone adversely affecting the crop productivity (Neumann, 1997). The performance of the plants in saline conditions also depends on the, environmental conditions such as humidity, temperature, light, growth stage, sensitivity of the plants etc (Munns, 2002). Effects of salinity on plants are similar to that of water deficiency, where long term exposure will have specific affects, such as reduced rate of leaf emergence and heavier impact on leaves than on roots. Extended exposure of plants to salts for months leads to death of whole plant before seed maturation (Maggio *et al.*, 2011).

Photosynthesis and antioxidant defense system: Primary response of crop plants to the increased amounts of salts is stunted growth (Romero-Aranda *et al.*, 2001). Accumulation of salts in the leaves causes premature aging, reduces the nutrient supply and products of photosynthesis thus impairing the growth of the entire plant. In salt sensitive genotypes, the accumulation of salts will lead to their death. Photosynthesis is extremely sensitive to salinity stress. Accumulation of salts causes an irreparable damage to the photosynthetic apparatus due to dehydration of cell membranes and closure of stomata which reduces their permeability to CO_2 (Piotr *et al.*, 2009). High concentrations of salts (above 250 mM) will cause metabolic limitations of photosynthesis in leaves (Munns *et al.*, 2006). Genes involved in the photosynthetic pathways are not much altered by the salinity stress in stress tolerant plant *Thellungiella* (Wu *et al.*, 2012),while in rice alterations in photosynthesis related genes are mostly associated with stress recovery (Zhou *et al.*,2009). High salt concentrations in the soil will trigger many changes in the plants, leading to their recovery and enhanced tolerance, which are less understood. Facultative halophyte *Mesembryanthemum crystallinum* uses CAM pathway under high salinity concentrations instead of the usual C3 pathway (Cushman *et al.*, 2008). Another plant *Atriplex lentiformis* is salt tolerant due to the property that the C4 pathway runs along instead of C3 biochemical pathway (Zhu and Meinzer, 1999).

One of the byproducts of the vital photosynthetic reactions taking place in the plants is the reactive oxygen species (ROS), whose production is enhanced under abiotic stress causing irreparable damage to the cells (Candan and Tarhan, 2003). The reduced rate of photosynthesis increases the formation of reactive oxygen species ROS(Foyer and Noctor, 2005). Basically, ROS are partially reduced forms of atmospheric oxygen. In order to produce water in these processes, four electrons are required for the reduction of oxygen. But the transference of one, two and three electrons results in the formation of ROS respectively, to O_2 to form superoxide ($O_2^{\cdot -}$), hydrogen peroxide (H_2O_2) and hydroxyl radical ($HO^{\cdot}$). These species of oxygen are highly toxic and reacts with biomolecules such as lipids, proteins, nucleic acid, etc. causing lipid peroxidation, protein denaturing and DNA mutations (Seyed *et al.*, 2011).

The plants have developed defense mechanisms comprising of enzymatic and non-enzymatic antioxidant system (Ramana *et al.*, 2012). The alleviation of oxidative damage and increased resistance to environmental stresses is often correlated with an efficient antioxidative system comprising enzymatic antioxidants such as superoxide dismutase, (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR) and monodehydroascorbate reductase (MDAR) and non-enzymatic antioxidants - glutathione, ascorbate and carotenoids whose concomitant effort will reduce the toxicity of the ROS (Attia *et al.*, 2009). Activity of Mn-SOD was enhanced under salt stress in wheat, while Cu/Zn-SOD activity remained constant (Hernandez *et al.*, 1999). Under elevated levels of SOD, scavenging of superoxide radical will be properly done, minimizing the damage to membranes there by leading to the increased tolerance to oxidative stress (Mitler, 2002). Over expression of genes leading to increase in the activities of Mn-SOD, Fe-SOD, Cu/Zn-SOD, bacterial catalase and glutathione-S-transferase (GST)/glutathione peroxidase (GPX) can increase the performance of plants under salinity stress. In leaves of rice plant, salt stress enhanced the contents of H_2O_2 and the activities of APX and GPX (Lee *et al.*, 2001). Tomato plants under high salinity concentrations showed higher antioxidant enzyme activities (Rodriguez-Rosales *et al.*, 1999).

Accumulation of osmolytes and proteins: Plants adapt to salinity through maintaining internal water potential below that of soil and turgor pressure for uptake of water by synthesizing and accumulating low molecular weight compatible osmolytes (Tester and Davenport, 2003). During osmotic stress, cytoplasm synthesizes osmolytes because they are inert to the biochemical reactions and they replace water. Majority of the osmolytes are organic solutes consisting of simple sugars (glucose and fructose), sugar alcohols (glycerol), complex sugars (Trehalose), quarternary amino acid derivatives (proline and glycine betaine), sulfonium compounds (choline-*o*-sulfate and dimethyl sulfonium propironate) with a very few exceptions like K^+ ion (Yokoi *et al.*, 2002). The accumulation of carbohydrates such as glucose, fructose, sucrose, fructans has been widely reported in plants as a response to salinity stress, playing a major role in osmoprotection, osmotic adjustment, carbon storage and radical scavenging (Nasrin *et al.*, 2010). Trehalose, a suppressor of apoptotic cell death accumulates under abiotic stresses like salinity, protects membranes and proteins in cells and reduces the aggregation of denatured proteins (Yamada *et al.*, 2003). Proline is a very active compatible osmolyte, whose accumulation contributes to the membrane stability and mitigates the effect of NaCl on cell membrane disruption (Farouk, 2011). Transgenic tobacco plants, which induces over-production of proline showed tolerance to the NaCl (Hong *et al.*, 2000). Glycine betaine is a small organic water soluble non-toxic metabolite that plays a crucial role in effective protection against salt stress (Chen and Murata, 2008). The major role of glycine betaine is protecting plant cells from salt stress by osmotic adjustment, protein stabilization, photosynthetic apparatus protection and reduction of oxygen radical scavengers (Suriyan and Chalermpol, 2010). Glycine betaine is reported to get accumulated in response to osmotic stress in many crops, including spinach, barley, tomato, potato, rice, carrot and sorghum (Yang *et al.*, 2003).

Acclimation of plants to environmental factors like salinity will occur by internal adjustments within the tissues and cells, enabling the plant metabolism to proceed under these conditions. In contrast to adaptation that occurs in plant phylogeny, acclimation occurs during plant ontogeny, describing enhanced stress tolerance of a particular individual, which was widely reported in many plant species with increasing ability to tolerate salt stress after being exposed to a brief period of time (Djanaguiraman *et al.*, 2006). The acclimation of plants to salinity will benefit them agronomically by improved survival rate, higher growth rate with less biomass reduction and physiologically by lowering the Na^+ accumulation in the shoot, facilitating better osmotic adjustment (Camilla *et al.*, 2012). However, the plant protection and acclimation mechanisms beyond this acquired resistance to salinity remain largely a matter of conjecture.

Conclusions and future perspectives: Soil salinity is causing huge amount of damage to the agriculture and crop productivity globally, conventional approaches are being followed using the available information in plant physiology, genetics and biochemical methodologies for studying plant responses to abiotic stresses have begun to bear fruit in order to combat with the toxicity generated by the salinity in soils. Transgenic plants with enhanced tolerance to the salinity stress were generated, whose productivity in the field and price is yet to be stabilized.

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