A review: Impact of salinity on plant growth

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Abstract: The environmental stress is a major area of scientific concern because it constraints plant as well as crop productivity. Salinity stress limits crop yield affecting plant growth and restricting the use of land. As world population is increasing at alarming rate, agricultural land is shrinking due to industrialization and/or habitat use. Hence, there is a need to utilize salt affected land to meet the food requirement. Excessive salt above what plants need limits plant growth and productivity and can lead to plant death. About 20% of all irrigated land is affected by soil salinity, decreasing crop yields (Kader, 2010 March). Plants are affected by salt stress in two main ways: osmotic stress and ionic toxicity. These stresses affect all major plant processes, including photosynthesis, cellular metabolism, and plant nutrition. This paper examines the ways in which salt inhibits plant function and the correlating responses of plants to salt stress. Plants can be divided into two categories in regards to salt stress: glycophytes and halophytes. Glycophytes are extremely sensitive to salt in soils; halophytes are salt tolerant and often grow in salty environments. Glycophytes comprise the majority of plant life and all major crops, so the increasing salinity in soils is of major concern.
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Introduction

Salinity of arable land is an increasing problem of many irrigated, arid and semi-arid areas of the world where rainfall is insufficient to leach salts from the root zone, and it is a significant factor in reducing crop productivity (Francois and Maas, 1994). Saline soils are defined by Ponnamperuma (1984) as those that contain sufficient salt in the root zone to impair the growth of cropplants. However, since salt injury depends on species, variety, growth stage, environmental factors, and nature of the salts, it is difficult to define saline soils precisely. The most widely accepted definition of a saline soil has been adopted from FAO (1997) as one that has an electrical conductivity of the saturation extract (ECe) of 4 dS m-1or more, and soils with ECe's exceeding 15 dS m-1are considered strongly saline. The common cations associated with salinity are Na+, Ca2+and Mg2+, while the common anions are Cl-, SO42-and HCO3-. However, Na+ and Cl ions are considered the most important, since Na+ in particular causes deterioration of the physical structure of the soil and both Na+ and Cl are toxic to plants (Hasegawa et al., 2000). Soils were historically classified as saline, sodic, or saline-sodic based on the total concentration of salt and the ratio of Na+ to Ca + Mg in the saturated extract of the soil (Dudley, 1994). However, this classification has been abandoned in favor of a management-oriented approach, and a soil that contains excessive salt is presently referred to as saline or salt-affected regardless of the specific nature of the problem. Due to an increase in population, there is competition for fresh water among the municipal, industrial and agricultural sectors in several regions. The consequence has been a decreased allocation of freshwater to agriculture (Tilman et al., 2002). This phenomenon is expected to continue and to intensify in less developed, arid region countries that already have high population growth rates and suffer from serious environmental problems. According to Carvajal et al. (1999) the direct effects of salts on plant growth may be divided into three broad categories: (i) a reduction in the osmotic potential of the soil solution that reduces plant available water, (ii) a deterioration in the physical structure of the soil such that water permeability and soil aeration are diminished, and (iii) increase in the concentration of certain ions that have an inhibitory effect on plant metabolism (specific ion toxicity and mineral nutrient deficiencies).

Types of salinity

Primary salinity-naturally occurring salinity

Most of the saline-sodic soils are developed due to natural geological, hydrological and pedological processes. Some of the parent materials of these soils include intermediate igneous rocks such as phenolytes, basic igneous rocks such as basalts, undifferentiated volcanic rocks, sandstones, alluviam and lagoonal deposits (Wanjogu et al., 2001). Climatic factors and water management may accelerate salinization. In arid and semi-arid lands (ASAL) evapotranspiration plays a very important role in the pedogenesis of saline and sodic soils. Wanjogu et al. (2001) reported that most of the ASAL receive less than 500 mm of rainfall annually and this, coupled with an annual potential evapotranspiration of about 2000 mm leads to salinization.

Secondary Salinity

Secondary salt-affected soils are those that have been salinized by human-caused factors, mainly as a consequence of improper methods of irrigation. Poor quality water is often used for irrigation, so that eventually salt builds up in the soil unless the management of the irrigation system is such that salts are leached from the soil profile. Szabolcs (1992) estimated that 50% of all irrigated schemes are salt affected. Anthropic salinization occurs in arid and semi-arid areas due to water logging brought about by improper irrigation (Ponnamperuma, 1984).

- Dry land—non-irrigated landscapes, generally as a result of clearing vegetation and changes in land use.
- Deforestation is recognized as a major cause of salinization and alkalization of soils as a result of the effects of salt migration in both the upper and lower layers.
- Sea water intrusion—coastal aquifer systems where sea water replaces groundwater that has been over-exploited.
- Point source—large levels of salt in effluent from intensive agriculture and industrial wastewater.
- Salinization caused by contamination with chemicals—This kind of salinization more often occurs in modern intensive agricultural systems, particularly in greenhouses and intensive farming systems. In closed or semi closed systems (e.g. greenhouses) saltstend to accumulate if chemicals are not removed regularly, resulting in salinity or alkalinity. In countries with intensive agriculture such as Japan and the Netherlands, this type of salinization appears more frequently (Pessarakli, 1991).
- Overgrazing— Szabolcs (1994) reported that this process occurs mainly in arid and semi arid regions, where the natural soil cover is poor and scarcely satisfies the fodder requirement of extensive animal husbandry. Because of overgrazing, the natural vegetation becomes sparse and progressive salinization develops, and sometimes the process ends up in desertification as the poor pasture diminishes.

Salinity effects on plants growth

Plants regularly face abiotic stress conditions during growth and development, such as drought, chilling, freezing, high temperatures and salinity. Stress condition can delay growth and development, reduce productivity, and, in extreme cases cause plant death (Krasensky and Jonak, 2012). Salinity imposes detrimental effects on plant growth through low osmotic potential of soil solution and nutritional imbalance (Munns and Tester, 2008). As a consequence of these primary effects of salt stress, caused by its hyperosmotic effect, secondary stresses, such as oxidative damage, often occur (Zhu, 2001). Salinity is the most important abiotic stress that inhibits growth and productivity of crop and it is one of the world's oldest and most widely distributed environmental challenges. Salinity is defined as the presence of an excessive concentration of soluble salts in the soil which suppresses plant growth (Zaki, 2011). Increased salinity is a stringent problem and a major limiting factor for crop production around the globe (Wahid et al., 2007). Most of the water on the Earth contains about 30 g of sodium chloride per litre. This can make the Earth a really salty planet. The salt stresses affect badly to the plant morphology, functioning and homeostasis, and decrease the plant biomass (Parvaiz, 2014). High levels of soil salinity can significantly inhibit seed germination and seedling growth, due to the combined effects of high osmotic potential and specific ion toxicity. Salt stress had adverse effects on the functioning and metabolism of plants considerably hinders the productivity (Khan and Srivastava, 1998). Salinity has diverse outcome on plants; for example salt in the soil solution diminishes the accessibility of water to the roots and the salt reserved in the plant will raise to poisonous points in several tissues of plants (Munnus et al., 1995). Salinity has an adverse effect on seed germination of many crops by creating anosmotic potential outside the seed inhibiting the absorption of water, or by the toxic effect of $Na+$ and Cl^- (Khajeh-Hosseini et al., 2003). Several investigators have reported plant growth reduction as a result of salinity stress, e.g. in tomato (Romero-Aranda et al., 2001), cotton (Meloni et al., 2001) and sugar beet (Ghoulam et al., 2002). However, there are differences in tolerance to salinity among species and cultivars as well as among the different plant growth parameters recorded. For instance, Aziz and Khan (2001) found that the optimum growth of Rhizophora mucronataplants was obtained at 50% seawater and declined with further increases in salinity while in Alhagi pseudoalhagi (a leguminous plant), total plant weight increased at low salinity (50 mM NaCl) but decreased at high salinity (100 and 200 mM NaCl) (Kurban et al., 1999). In sugar beet leaf area, fresh and dry mass of leaves and roots were dramatically reduced at 200 mM NaCl, but leaf number was less affected (Ghoulam et al., 2002). Fisarakis et al. (2001), working with sultana vines recorded a larger decrease in accumulation of dry matter in shoots than in roots, particularly at high NaCl concentration, indicating partitioning of photo-assimilates in favor of roots. They proposed that the results may be due to a greater ability for osmotic adjustment under stress by the roots.

Effects of salinity on photosynthesis

Growth of plants is dependent on photosynthesis and, therefore, environmental stresses affecting growth also affect photosynthesis (Taiz and Zeiger, 1998). Studies conducted by a number of authors with different plant species showed that photosynthetic capacity was suppressed by salinity (Romero-Aranda et al., 2001). A positive association between photosynthetic rate and yield under saline conditions has been found in different crops such as Gossypium hirsutum (Pettigrew and Meredith, 1994) and Asparagus officinal is (Faville et al., 1999). Fisarakis et al. (2001) found that inhibition of vegetative growth in plants submitted to salinity was associated with a marked inhibition of photosynthesis. In contrast, there are many studies in which no or little association between growth and photosynthetic capacity is evident, as in Triticum repens (Rogers and Noble, 1992) and Triticum aestivum (Hawkins and Lewis, 1993). The effect of salinity on photosynthetic rate depends on salt concentration and plant species. There is evidence that at low salt concentration salinity may stimulate photosynthesis. For instance, in B. parviflora, Parida et al. (2004) reported that photosynthetic rate increased at low salinity and decreased at high salinity, whereas stomatal conductance was unchanged at low salinity and decreased at high salinity.

Iyengar and Reddy (1996) attributed decreases in photosynthetic rate as a result of salinity to a number of factors:

(1) Dehydration of cell membranes which reduce their permeability to CO2. High salt concentration in soil and water create high osmotic potential which reduces the availability of water to plants. Decrease in water potential causes osmotic stress, which reversibly inactivates photosynthetic electron transport via shrinkage of intercellular space.

(2) Salt toxicity caused particularly by Na+ and Cl ions. According to Banuls et al. (1990), Cl inhibits photosynthetic rate through its inhibition of NO3-N uptake by the roots. Fisarakis et al. (2001) found that NO3-N was significantly reduced in salt-stressed sultana vines and this reduction was correlated with photosynthetic reduction. The reduced NO3-N uptake combined with osmotic stress may explain the inhibitory effect of salinity on photosynthesis.

(3) Reduction of CO2supply because of closure of stomata. The reduction in stomatal conductance results in restricted availability of CO2for carboxylation reactions (Brugnoli and Bjorkman, 1992). Iyengar and Reddy (1996) reported that stomatal closure minimizes loss of water by transpiration and this affects chloroplast light-harvesting and energy-conversion systems thus leading to alteration in chloroplast activity. Higher stomatal conductance in plants is known to increase CO2 diffusion into the leaves and thereby favor higher photosynthetic rates. Higher net assimilation rates could in turn favor higher crop yields as was found by Radin et al. (1994) in Pima cotton (Gossypium barbadense). However, the results for photosynthetic rate and stomatal conductance presented by Ashraf (2001) for six Brassicaspecies did not show any significant relationship. There are also reports of nonstomatal inhibition of photosynthesis under salt stress. Iyengar and Reddy (1996) reported that this nonstomatal inhibition is due to increased resistance to CO2diffusion in the liquid phase from the mesophyll wall to the site of CO2reduction in the chloroplast, and reduced efficiency of RUBPC-ase.

Other causes of reduced photosynthetic rates due to salinity have been identified by Iyengar and Reddy (1996) as: (4) enhanced senescence induced by salinity, (5) changes of enzyme activity induced by changes in cytoplasmic structure, and (6) negative feedback by reduced sink activity. Although the rate of photosynthesis is reduced under salt stress, this is not the cause of reduction in the rate of cell expansion as suggested by several lines of evidence.

Effects on plant water uptake and ion homeostasis

Salt has two major effects on plants: osmotic stress and ionic toxicity, both of which affect all major plant processes (Yadav et al., 2011). Plants are able to take up water and essential minerals because they have a higher water pressure than the soil under normal conditions. When salt stress occurs, the osmotic pressure of the soil solution is greater than that in plant cells. Thus, the plant cannot get enough water (Kader, 2010 March). In addition, its cells will have decreased turgor and its stomata will close to conserve water. Stomatal closing can lead to less carbon fixation and the production of Reactive Oxygen Species (ROS) such as superoxide and singlet oxygen. ROS disrupts cell processes through damage to lipids, proteins, and nucleic acids (Parida and Das, 2005). Ionic toxicity occurs when concentrations of salts are imbalanced inside cells and inhibit cellular metabolism and processes. Sodium ions at the root surface disrupt plant nutrition of the similar cation potassium by inhibiting both potassium uptake and enzymatic activities within the cell. Potassium is an important nutrient in a plant, regulating over 50 enzymes (Kader, 2010 March). Essential for maintaining cell turgor pressure, creating membrane potential, and regulating enzymatic activities, potassium must be maintained at 100-200mM in the cytosol. Sodium, on the other hand, causes stress at concentrations higher than 10mM in the cytosol (Kader, 2010 March). Na+ is a cation similar to K+and easily crosses the cell membrane. It also acts as an inhibitor to many enzymes, affecting metabolic processes. Calcium cations, however, protect some plants through signaling pathways that regulate potassium sodium transporters (Parida and Das, 2005). When a plant senses salt stress through transmembrane proteins or enzymes in the cytosol, the amount of calcium in the cytosol increases (Kader, 2010 March). Calcium is a second messenger important to many biochemical pathways and can aid plants in responding to salt stress. The osmotic and ionic stress induced by salinity can halt plant growth as the plant focuses its energy on conserving water and improving ionic balance. In order for plants to return to normal functioning and photosynthesis, the plant must facilitate its own detoxification – damage must be prevented or lessened, homeostasis must be reestablished, and growth must resume (Zhu, 2001).

Glycophytes

Glycophytes comprise the majority of all plant life, including important economic and food crops. Glycophytes cannot tolerate salt stress, though they can develop protective measures against it. These plants are extremely sensitive to salt concentrations – inhibition or death can result from 100-200 mM salt. Fruit trees, such as citrus and avocado, are even more sensitive, requiring soil below a few millimoles per liter of NaCl (Zhu, 2007). Salinity affects seed germination as well as normal plant processes in a growing plant (Malcolm et al., 2003). Glycophytes cannot be said to have salt tolerance; instead, they have salt resistance mechanisms. Glycophytes cope to a point by creating a high K+/Na+ ratio through active ion transport, shifting ionic and electrochemical gradients to be more favorable to cytosolic processes (Yadav et al., 2011). Salt accumulates in the reproductive organs and the leaves, and the plant focuses on mere survival rather than growth or reproduction (Zakharin and Panichkin, 2009). Arabidopsis thaliana is a model glycophyte that has allowed researchers to better understand salt resistance in glycophytes on a genetic, cellular, and whole plant level (Zhu, 2001). However, there is not much glycophytes can do in order to adapt to salty conditions; research is being done into transgenetic plants that utitlize genes from halophytes to increase salt tolerance in a glycophyte. In order to combat the negative effects of salt stress on glycophytes, soil salinity must decrease or glycophytes must slowly adapt through natural processes or anthropogenic breeding or genetic modification (Zhu, 2001).

Halophytes

One percent of plants are halophytes and can tolerate levels of salt concentration anywhere from 300-1000 mM of salt (Zhu 2007). The major important differences in halophytes are their abilities to compartmentalize sodium and accumulate osmolytes while maintaining constant potassium concentrations. They can accumulate more salt in leaves and roots, and can force Sodium across the tonoplast with highly Na+/K+ selective protein transporters (Radyukina et al., 2007). Most halophytes respond to salinity by exclusion (Yadav et al., 2011). In mangroves, 99% of salts are excluded by the roots (Aslam et al., 2011). Even so, plants must take up salt under salt stress and store it in vacuoles or tissues where its damage is least or secrete. Secretion occurs through shedding of salty leaves and also through salt glands, specialized cells on the leaves and stem that secrete salt, which is then washed away by rain or wind (Aslam et al., 2011). Halophytes and glycophytes share some similar genes, and some of the genes glycophytes express under salt stress are always expressed in halophytes (Radyukina et al., 2007). In halophytes, gene expression includes the LEA protein, enzymes for biosynthesis of osmolytes, transporters for ions, and regulatory molecules like protein kinases and phosphatases (Aslam et al., 2011). Of particular importance is the synthesis of osmolytes. Osmolytes are low molecular weight compounds that do not interfere with normal biochemical reactions, but do help maintain a water potential more negative than the soil so that water uptake can take place (Parida and Das, 2005). For example, gene expression is responsible for higher levels of the osmolytes proline in Thellungiella halophila, the model halophyte organism (Kant et al., 2006). Halophytes also have a mechanism for scavenging Reactive Oxygen Species and eliminating them (Parida and Das, 2005). Transgenic traits from halophytes could be used in glycophyte crops in order to increase salt tolerance, specifically, inserting genes that regulate the production of osmolytes in the cytosol to re-establish an ion gradients and electrochemical gradients (Zhu 2001).

Interactions between salinity and environmental factors

The ability of plants to tolerate salinity depends on the interaction between salinity and environmental factors such as soil, water, and climatic conditions (Shannon et al., 1994). For instance, many crops are less tolerant to salinity when grown under hot and dry conditions than under cool and humid conditions (Maas and Hoffman, 1977). Under hot and dry conditions yield will decrease more rapidly with increasing salinity compared to yield reduction under cool and humid conditions. This is mainly due to decreased ion accumulation and/or improved plant water relations in the latter conditions (Salim, 1989). Hence, a basic understanding of these interactions is necessary for an accurate assessment of salt tolerance.

Managing salinity in agricultural production

Saline lands can be converted to more productive croplands by preventing the influx of salt water through proper farm management practices, correcting soil toxicities and nutrient deficiencies, and leaching the salts out of the root zone. The reclamation costs can be reduced by growing salt-tolerant cultivars. These practices are discussed below.

Farm management practices

Salinity can be restricted by changed farm management practices. Munns et al. (2002) proposes that irrigated agriculture could be sustained by better irrigation practices such as adoption of partial root zone drying methodology, and drip or micro-jet irrigation to optimize use of water. They suggested that salinity could also be contained by reducing the amount of water passing beyond the roots by re-introducing deep rooted perennial plants that continue to grow and use water during the seasons that do not support annual crop plants. This may restore the balance between rainfall and water use, thus preventing rising water tables and the movement of salt to the soil surface. Deep-rooted perennial lucerne (Medicago sativa) has been found to lower the water table sufficiently to allow subsequent cropping (Ridley et al.,2001). Such practices will rely on plants that have a high degree of salt tolerance. Salt tolerance in crops will also allow the more effective use of poor quality irrigation water. Niknam and McComb (2000) suggested that trees could be planted to take up some of the excess salt since they have high water use and can lower water tables to reduce salt discharge into streams and prevent secondary salinization of the surrounding areas. However, it has not been proven to what extend the tree planting would assist in preventing salt stress in neighboring fields.

Amelioration through fertilization

Salinity causes nutrient imbalances, mainly resulting in lower concentrations of the macro-elements (N, P, K and Ca) in plant tissues. Hence, the most direct way to recover the normal nutrient concentrations within the plant would be by raising their concentrations in the root zone by higher fertilizer dosages. Many studies have shown that salt stress can be alleviated by an increased supply of calcium to the growth medium (Kaya et al., 2002). Depending on the concentration ratio, sodium and calcium can replace each other from the plasma membrane, and calcium might reduce salt toxicity (Rausch et al., 1996). Song and Fujiyama (1996) found that tomato plants grown in saline medium with supplemental Ca2+ accumulated 40% less Na+ and 60% more K+ than salinized plants without such supplement. Increased Na+ in the growth medium generally decreases the K+ content, suggesting an antagonism between Na+ and K+ (Adams and Ho, 1995). Addition of K+ to the nutrient solution has been found to raise K+ concentrations in the leaves and ameliorate salinity stress effects (Kaya et al., 2001). The effect of salinity on P in plants depends on P concentration in the nutrient solution. At high P concentrations, leaf injury has been interpreted as P toxicity induced by salinity (Awad et al., 1990). However, at low P concentrations in the root medium, salinity was reported to inhibit P uptake by roots and translocation to the shoot (Martínez et al., 1996). At low P concentration in the root medium, supplementary P applied to the saline growth medium enhanced the capacity of tomato plant to regulate Na+, Cl and K+ distribution, and improved plant growth (Awad, et al., 1990; Kaya et al., 2001). Under salt stress conditions, the uptake of N by plants is generally affected, and application of supplementary N has been found to ameliorate the deleterious effects of salinity (Gómez et al., 1996). The approach of raising fertilizer dosages may work for irrigation with water at low salt concentrations. When water of high salinity is applied, however, the concentration of antagonistic ions required is so high that it causes a marked increase in the osmotic pressure of the soil solution, compounding the stress imposed by the salinity ions (Feigin, 1985). Furthermore, Grattan and Maas (1988) reported that in some species a very high concentration of nutrients, e.g. P, could interact negatively with salinity ions, resulting in severe toxic effects.

Leaching

Leaching soils to remove soluble salts is the most effective method known to reclaim saline soils. This requires good permeability of the soil and good quality irrigation water. Removal of salts by leaching reduces salt hazard for plants but might cause permeability to decrease and pH to increase resulting in decomposition of roots as soil is changed from saline-sodic to sodic (Dregne, 1976). Although the best long-term solution to salinization is to provide adequate drainage, this process is expensive. Hence, many irrigation schemes, particularly in developing countries lack, adequate drainage (Toenniessen, 1984).

Uses of salt stress tolerant plants

Some areas have naturally occurring salinity and salt-tolerant crop plants may provide a better or perhaps the only means of utilizing these resources for food production. Salinity can possibly also be managed through biologically manipulating the plants (Shannon, 1984). Identification of plant genotypes with tolerance to salt, and incorporation of desirable traits into economically useful crop plants, may reduce the effects of salinity on productivity. Developing crop plants tolerant to salinity has the potential of making an important contribution to food production in many countries. This will permit the use of low quality water and thereby reduce some of the demand for higher quality water. Great effort is, therefore, being directed toward the development of salt-tolerant crop genotypes through the use of plant-breeding strategies involving the introgression of the genetic background from salt-tolerant wild species into cultivated plants (Shannon, 1984; Pitman and Laüchli, 2002). However, it should be borne in mind that there is also the risk that the availability of salt tolerant genotypes will result in less effort to reclaim saline areas or to prevent salinization. In the longer term this will be counter productive.

Conclusion

To summarize, salt stress in plants is of growing concern in agriculture but has effects on many different plants and ecosystems. It induces a water deficit and ionic toxicity in plants, causing major plant processes like photosynthesis and metabolism to slow or halt. Halophytes and glycophytes deal with salt stress differently, and glycophytes do not have a mechanism for salt tolerance. Because glycophytes are essential to food supply, researchers are seeking ways that halophytes could be adapted for food or used to increase salt tolerance in glycophytes.

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