Technical Journal of Engineering and Applied Sciences
Available online at www.tjeas.com
©2012 TJEAS Journal-2012-2-1/7-10
ISSN 2051-0853 ©2012 TJEAS

The Effects of Salt stress on plant growth

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ABSTRACT: Stalinization of soils or waters is one of the world's most serious environmental problems in agriculture. It is necessary to determine the environmental factors under which medicinal and aromatic plants give higher yields and better quality. The problem of salinity is characterized by an excess of inorganic salts and is common in the arid and semi-arid lands, where it has been naturally formed under the prevailing climatic conditions and due to higher rates of evapotranspiration and lack of leaching water. Although more frequent in arid lands, salt-affected soils are also present in areas where salinity is caused by poor quality of irrigation water. Saline soil induces physiological and metabolic disturbances in plants, affecting development, growth, yield, and quality of plants. Plants affects adversely as a result of salinity, seed germination, survival percentage, morphological characteristics, development and yield and its components. In general, salt stress decreases the photosynthesis and respiration rate of plants. Total carbohydrate, fatty acid and protein content were adversely affected due to salinity effect, but increased the level of amino acids, particularly proline. The content of some secondary plant products is significantly higher in plants grown under salt stress than in those cultivated in normal conditions. The salinity tolerance depends on the interaction between salinity and other environmental factors.

Key words: salinity, praline, growth and development, salt tolerance.

INTRODUCTION

Salt stress is one of the most serious limiting factors for crop growth and production in the arid regions. About 23% of the world's cultivated lands is saline and 37% is sodic(Khan and Duke, 2001). Soils can be saline due to geo-historical processes or they can be man-made. The water and salt balance, just like in oceans and seas determine the formation of salty soils, where more salt comes in than goes out. Here, the incoming water from the land brings salts that remain because there is no outlet and the evaporation water does not contain salts.

Soil salinity in agriculture soils refers to the presence of high concentration of soluble salts in the soil moisture of the root zone. These concentrations of soluble salts through their high osmotic pressures affect plant growth by restricting the uptake of water by the roots. Salinity can also affect plant growth because the high concentration of salts in the soil solution interferes with balanced absorption of essential nutritional ions by plants-(Tester and Devenport, 2003).

It is well established that higher plants can withstand high salinity by either salt exclusion or salt inclusion-(sykes, 1992). Salt excluders possess the ability to exclude salts from the entire plant or from certain organs. In such cases membrane selectivity favors the uptake of K+ over Na+, thus excluder crops are characterized by having low Na+ and Cl- content. Salt accumulators, on the other hand, are able to cope with the uptake of high salt concentrations through one of two strategies. The first, a common characteristic of halophytes, is through tolerating high levels of intercellular salts by resistant cell membranes. In such cases, high tissue Na+ to K+ ratio is evident. The second strategy is through removal of excess salt entering the plant, where root can take up salt ions but avoid their injurious effect(Badr and Shafei, 2002). To improve crop growth and production in the salt-affected soils, the excess salts must be removed from the root zone. Methods commonly used in reclamation such soils are scraping, flushing and leaching.

These methods were found to be very expensive. Recently, attention was given to use other new technologies of combating salinity, among them using halophytes. Halophytes are plants that can tolerate high salinity levels and remove the accumulated salts from the surface layer of the soil as well(Shaaban and El-Fouly, 2002). Halophytes are plants from over 80 families which evolution have developed ways to deal with large amount of salts in the water they uptake(Epstein, 1985). Some halophytes have specialized leaf cells called salt glands that excrete salt. Others have salt hairs present on the stem that excretes salt. Some plants have stomatal guard cells that are controlled by the sodium ion. These plants control their transpiration in accordance to the amount of salt present in the environment. The use of such plants to reclaim salty-affected soils has become cheaper and more practical than chemical reclamation(Ashour *et al*., 2002).

Another approach to minimize the harmful effect of salinity is the use of foliar feeding of nutrients for increasing plant salinity tolerance by alleviating Na+ and Clinjury to plants (Alpaslan *et al*., 1999; El-Fouly and Salama, 1999; Schmidhalter *et al*., 1999; El-Fouly *et al*., 2002).

Salt Stress Damage to Plants

General symptoms of damage by salt stress are growth inhibition, accelerated development and senescence and death during prolonged exposure. Growth inhibition is the primary injury that leads to other symptoms although programmed cell death may also occur under severe salinity shock. Salt stress induces the synthesis of abscisic acid which closes stomata when transported to guard cells. As a result of stomatal closure, photosynthesis declines and photoinhibition and oxidative stress occur. An immediate effect of osmotic stress on plant growth is its inhibition of cell expansion either directly or indirectly through abscisic acid.

Excessive sodium ions at the root surface disrupt plant potassium nutrition. Because of the similar chemical nature of sodium and potassium ions, sodium has a strong inhibitory effect on potassium uptake by the root. Plants use both low- and high-affinity systems for potassium uptake. Sodium ions have a more damaging effect on the low-affinity system which has a low potassium/sodium selectivity. Under sodium stress, it is necessary for plants to operate the more selective high-affinity potassium uptake system in order to maintain adequate potassium nutrition. Potassium deficiency inevitably leads to growth inhibition because potassium, as the most abundant cellular cation, plays a critical role in maintaining cell turgor, membrane potential and enzyme activities.

Once sodium gets into the cytoplasm, it inhibits the activities of many enzymes. This inhibition is also dependent on how much potassium is present: a high sodium/potassium ratio is the most damaging. Even in the case of halophytes that accumulate large quantities of sodium inside the cell, their cytosolic enzymes are just as sensitive to sodium as enzymes of glycophytes. This implies that halophytes have to compartmentalize the sodium into the vacuole, away from cytosolic enzymes. An important factor in the battle between sodium and potassium ions is calcium. Increased calcium supply has a protective effect on plants under sodium stress. Calcium sustains potassium transport and potassium/sodium selectivity in sodium-challenged plants. This beneficial effect of calcium is mediated through an intracellular signalling pathway that regulates the expression and activity of potassium and sodium transporters. Calcium may also directly suppress sodium import mediated by nonselective cation channels.

Effect of salt stress on nutrient uptake

Nutrient disturbances under salinity reduce plant growth by affecting the availability, transport, and partitioning of nutrients. However, salinity can differentially affect the mineral nutrition of plants. Salinity may cause nutrient deficiencies or imbalances, due to the competition of Na+ and Cl^- with nutrients such as K^+, $Ca2^+$, and $NO3^-$. Under saline conditions, a reduced plant growth due to specific ion toxicities(e.g. Na^+ and Cl^-) and ionic imbalances acting on biophysical and/or metabolic components of plant growth occurs(Grattan and Grieves, 1999). Increased NaCl concentration has been reported to induce increases in Na and Cl as well as decreases in N, P, Ca, K and Mg level in fennel(Abd El-Wahab, 2006) ;Trachyspermum ammi (Ashraf and Orooj, 2006); peppermint and lemon verbena(Tabatabaie and Nazari, 2007), Matricaria recutita(Baghalian et al., 2008), Achillea fragratissima(Abd EL-Azim and Ahmed, 2009).

Changes in Metabolism During Salt Stress

Perhaps, the most dramatic change in metabolism occurs in the ice plant(Mesembryanthemum crystallinum) under salt stress. Within days, salt stress can elicit a change from C3 to the CAM (crassulacean acid metabolism) mode of photosynthesis in this succulent plant. Some of the enzymatic machinery for CAM metabolism, e.g. phosphoenolpyruvate(PEP) carboxylase, is induced by a few hours of salt stress. The main advantage of the CAM metabolism is an increased water use efficiency because the stomata only open at night when evaporative water loss is at a minimum.

A metabolic change common to most if not all plants is the accumulation of low molecular weight organic solutes under salt stress. These solutes include linear polyols(glycerol, mannitol or sorbitol), cyclic polyols(inositol or pinitol and other mono- and dimethylated inositol derivatives), amino acids(glutamate or proline) and betaines(glycine betaine or alanine betaine). Plants that often experience nitrogen limitation may accumulate sulfonium compounds, e.g. dimethylsulfonium propionate, which are equivalent to the nitrogen-containing betaines. Unlike the inorganic solutes such as sodium and chloride ions, these organic solutes even at high concentrations are not harmful to enzymes and other cellular structures. For this reason, these organic compounds are often referred to as compatible osmolytes. At high concentrations, compatible solutes certainly function in osmotic adjustment. This is especially true in halophytes, which often accumulate between 0.5 and 4.0 mol L^{-1} of compatible osmolytes in the cells. The high concentration of compatible osmolytes reside primarily in the cytosol, to balance the high concentration of salt outside the cell on one side, and on the other, to counter the high concentrations of sodium and chloride ions in the vacuole.

Not only are the organic solutes not harmful, they may also have a protective effect against damage by toxic ions or dehydration. Genes encoding rate-limiting enzymes for polyol, proline and glycine betaine biosynthesis have been overexpressed in transgenic tobacco and A. thaliana. The transgenic plants constitutively producing compatible osmolytes perform better than control plants under salt stress. The protective effect cannot be fully explained by the osmotic adjustment theory because in most cases the transgenic plants only produce several millimoles per litre more of the engineered osmolytes, concentrations too low to contribute significantly to osmotic adjustment. Data suggest that the low amount of compatible osmolytes may protect plants by scavenging oxygen-free radicals caused by salt stress. The importance of antioxidants in salt stress tolerance is also supported by experiments showing a positive effect of genetically engineered production of oxygen-free radical scavenging enzymes on plant performance under salinity.

Osmolytes And Osmoprotectants

During stress conditions plants need to maintain internal water potential below that of soil and maintain turgor and water uptake for growth(Tester and Davenport, 2003). This requires an increase in osmotica, either by uptake of soil solutes or by synthesis of metabolic solutes. To accommodate the ionic balance in the vacuoles, cytoplasm accumulates low-molecularmass compounds, the compatible solutes because they do not interfere with normal biochemical reactions(Zhifang and Loescher, 2003); rather, they replace water in biochemical reactions.

With accumulation proportional to the change of external osmolarity within species-specific limits, protection of structures and osmotic balance supporting continued water influx(or reduced efflux) are accepted functions of osmolytes(Hasegawa et al., 2000). While some compatible osmolytes are essential elemental ions, such as K+, the majority are organic solutes(Yokoi et al., 2002). However, the solutes that accumulate vary with the organism and even between plant species and a major category of organic osmotic solutes consists of simple sugars(mainly fructose and glucose), sugar alcohols(glycerol and methylated inositols) and complex sugars (trehalose, raffinose and fructans) (Bohnert and Jensen, 1996). Others include quaternary amino acid derivatives-(proline, glycine betaine, β-alanine betaine, proline betaine, tertiary amines 1,4,5,6-tetrahydro-2-mehyl-4-carboxyl pyrimidine), and sulfonium compounds (choline osulfate, dimethyl sulfonium propironate) (Yokoi et al., 2002).

CONCLUSIONS

Salt stress causes huge losses of agriculture productivity worldwide. Therefore, plant biologists aimed at overcoming severe environmental stresses needs to be quickly and fully implemented. Together with conventional plant physiology, genetics and biochemical approaches to studying plant responses to abiotic stresses have begun to bear fruit recently. Relevant information on biochemical indicators at the cellular level may serve as selection criteria for tolerance of salts in agricultural crops. Although there were many transgenic plants with high stress tolerance generated, plant abiotic stress tolerance is a complex trait that involves multiple physiological and biochemical mechanisms and numerous genes.

Transgenic plants with commercial value should at the same time retain relatively high productivity and other traits important for agriculture. Moreover, genetic modification should be combined with marker-assisted breeding programs with stress-related genes and QTLs, and ultimately, the different strategies should be integrated, and genes representing distinctive approaches should be combined to substantially increase plant stress tolerance.

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