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Review Article

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Influence of salt stress on water uptake, pigments system, ion-homeostasis in crop plants

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Abstract Increased salinization of arable land is expected to have devastating global effects, resulting in 30% land loss within the next 25 years and up to 50% by the middle of twenty-first century. High soil salinity causes both hyperionic and hyperosmotic stress and can lead to plant demise. Salinity in a given land area depends upon various factors like amount of evaporation (leading to increase in salt concentration), or the amount of precipitation (leading to decrease in salt concentration). Changes of pigment system contents under salt stress are used as parameter for selection of tolerant and sensitive cultivars in crop plants. Chlorophyll a, chlorophyll b, chlorophyll a/b and carotenoid contents showed increase and decrease depending on exposure time of NaCl exposure in many plants. When K substitute by Na in biochemical reactions then Ion cytotoxicity is happening and when Na and Cl ions interfere with non covalent interactions between their amino acid, then proteins don't function, thus in salinity condition poisonous levels of sodium and also inadequate amount of K for enzymatic reactions and osmotic adjustment is happened.

Keywords Toxicity, Morphological Adaptations, Salinity

Introduction

High salt depositions in the soil generate a low water potential zone in the soil, making it increasingly difficult for the plant to acquire both water as well as nutrients. The basic physiology of high salt stress and drought stress overlaps with each other. Salinization of soil is a serious land degradation problem and is increasing steadily in many parts of the world, in particular in arid and semiarid areas [1-2]. Increased salinization of arable land is expected to have devastating global effects, resulting in 30% land loss within the next 25 years and up to 50% by the middle of twenty-first century [3]. High soil salinity causes both hyperionic and hyperosmotic stress and can lead to plant demise. Salinity in a given land area depends upon various factors like amount of evaporation (leading to increase in salt concentration), or the amount of precipitation (leading to decrease in salt concentration) [4]. Therefore, salt stress essentially results in a water-deficit condition in the plant and takes the form of a physiological drought [4]. In plants, both drought and salinization are manifested primarily as osmotic stress, resulting in the disruption of homeostasis and ion distribution in the cell [5]. Increased salinization of arable land is expected to have devastating global effects, resulting in 30% land loss within the next 25 years and up to 50% by the middle of twenty-first century [3].

Toxicity in plants

Toxicity in plants results mainly from high concentrations of ions Na^+, CI^-, [6], although most studies on salinity effect on plants are associated with NaCI excess and few studies have focused on Na_2SO_4 performance in growth [7-8] and in physiology of plants [9]. Na^+ and CI^- are present in greater amounts in seawater; thus, aquatic environments close to the sea may present high concentrations of Na^+ and CI^-. High concentrations of SO_4^{2-} may be found in aquatic environment where there are ores and anthropogenic activities such as agriculture [10]. Proximity to seawater also influences sulphate concentration in coastal aquatic environments [11].

Morphological Adaptations

Munns (1992) [12] concluded that the salts absorbed by plants do not control growth directly, but that they do influence turgor, photosynthesis and/or the activity of specific enzymes. Demonstrating the complexity of salt stress, this author developed a model showing a two-phase effect of salinity on plant growth. Growth is first reduced by a decrease in the soil water potential (osmotic phase) and, later, a specific effect appears as salt injury in leaves, which die because of a rapid increase in salt in the cell walls or cytoplasm when the vacuoles can no longer sequester incoming salts (ionic phase). Munns (1992) [12] found that this salt accumulation in the old leaves accelerates their death and thus decreases the supply of carbohydrates and/or growth hormones to the meristematic regions, thereby inhibiting growth. The fact that plant growth is limited by a reduction in the photosynthesis rate and by an excessive uptake of salts affects the production of specific metabolites that directly inhibit growth (Azza et al., 2007). Salinity reduces plant growth through osmotic and toxic effects, and high sodium uptake ratio values cause sodicity, which increases soil resistance, reduces root growth, and reduces water movement through the root with a decrease in hydraulic conductivity [13]. Root hydraulic conductivity in field crops may vary in response to the salt content of the irrigation water applied [14]. In general, the root hydraulic conductivity in plants irrigated with poor quality water tends to decrease. In fact, the effect on root hydraulic conductivity is one of the main factors determining the sustainability of a reclaimed water irrigation system. Normally, root hydraulic conductance is expressed in terms of the whole root dry weight, without taking into account the role of root architecture in the water uptake capacity. Nonetheless, for any given root dry weight value, the amount of fine roots, which determine the root length and surface area, may vary greatly, thus, affecting the water absorption level [15]. Moreover, in assays where the grafted technique has been applied, the rootstock properties can affect the plant response to salinity. Salt-tolerant rootstocks alleviate the negative effects of abiotic stress to a greater extent than salt-sensitive rootstocks. Navarro et al. (2010) [16] described worse fruit yield and quality in Clemenules mandarin trees grafted on Carrizo (salt-sensitive rootstock) compared with Cleopatra (salt-tolerant rootstock), both irrigated with a NaCl solution (30 mM). The anatomy of the root system (length, root diameter, etc.) determines root performance, enabling plants to acquire water and nutrients and thereby increase the replacement rate of plant water lost [17]. Optimum root systems can support shoot growth and improve plant yields, since roots serve as an interface between plants and the soil [18]. A proliferated root system would therefore appear to be better for plants, for it allows them to penetrate deeper layers of soil to acquire water and nutrients [19]. Recent studies, however, have shown that species with other root features, including small roots, can be more advantageous for shoot development [20]. For example, just a few roots in moist soil can provide amounts of water independent of the root number. Other root characteristics, such as the number and diameter of xylem vessels, width of the root cortex, number of root hairs, and the suberin deposition in both the root exodermis and endodermis, also determine the permeability of roots to water [21]. Furthermore, environmental factors in the soil (changes in temperature, lack of O_2, mechanical impedance, salinity) can also produce marked impacts on root anatomy. The cell walls of root cells of salinized plants are often unevenly thickened and convoluted [22]. Salts often promote the suberisation of the hypodermis and endodermis in woody tree roots, resulting in the formation of a well-developed casparian strip closer to the root apex, different to that found in non-salinized roots [23]. Furthermore, the morphology of some plants shows their sensitivity to salinity. For example, in avocado trees, the root system is quite superficial and presents low ramification, thus reducing the water and nutrient absorption capacity [24], resulting in a higher sensitivity to soil salinity [25]. These morphological features limit the distribution of this crop to areas where irrigation water is of good quality. Saline water irrigation has also been found to alter the root system morphology of Callistemon citrinus plants [26].

Pigments system

Net photosynthesis and stomatal conductance are significantly affected by salt stress due to changes in chlorophyll content and chlorophyll fluoresance, damage of photosynthetic apparatus and chloroplast structure [27]. Plant pigments content were determined in different tolerant and sensitive plant varieties at wide range of salt concentrations [28]. Chlorophyll a, chlorophyll b and carotenoid are main photosynthetic pigments and they play important role in photosynthesis. The changes in the amount of pigments system were evaluated as the changes in photosynthesis. Changes of pigment system contents under salt stress are used as parameter for selection of tolerant and sensitive cultivars in crop plants [29]. Chlorophyll a, chlorophyll b, chlorophyll a/b and carotenoid contents showed increase and decrease depending on exposure time of NaCl exposure in many plants [30]. The reduction of chlorophyll a and chlorophyll b amounts with NaCl application was reported in many plants such as Zea mays, Carthamus tinctorius, Bean and Paulownia imperiallis that this due to increasing of destructive enzymes called chlorophyllase [31]. Pigments system reduction is attributed to a salt induced weakening of protein-pigment-lipid complex or increased chlorophyllase enzyme activity [32]. Also, increase in pigment content was observed in salinity stressed plant such as Rice [27] and Purslane [31], that this increment may be due to increase in the number of chloroplast in the stressed plant leaves [33]. In other hand, the changes in pigment system were affected by exposure time and salt concentration [27].

Plants growing in saline soil

Plants growing in saline soil are subjected to three distinct physiological stresses. First, the toxic effects of specific ions such as sodium and chloride, prevalent in saline soils, disrupt the structure of enzymes and other macromolecules, damage cell organelles, disrupt photosynthesis and respiration, inhibit protein synthesis, and induce ion deficiencies [34]. Second, plants exposed to the low osmotic potentials of saline soil are at risk of physiological drought because they must maintain lower internal osmotic potentials to prevent water moving from the roots into the soil. Finally, salinity also produces nutrient imbalance in the plant caused by decreased nutrient uptake and/or transport to the shoot [35-36]. As a consequence, salt stress affects all the major processes, such as growth, photosynthesis, protein synthesis, and energy and lipid metabolisms [37].

Ion-homeostasis

Salinity interrupts homeostasis ion distribution and water potential at cellular and whole plant levels [38-39]. When K substitute by Na in biochemical reactions then Ion cytotoxicity is happening and when Na^+ and Cl- ions interfere with non covalent interactions between their amino acid, then proteins don't function, thus in salinity condition poisonous levels of sodium and also inadequate amount of K for enzymatic reactions and osmotic adjustment is happened [40-42]. Potassium is necessary in high concentrations, and functions in the cell through direct interacting in enzyme activation, stabilization of protein synthesis, and neutralization of negative charges on proteins [43-45] also the positive correlation between potassium content and final yield in different crops was reported [41, 46-47]. When potassium shortage is happened, acidification and sodium transport are increased [48-49].

Water uptake

Salt has two major effects on plants: osmotic stress and ionic toxicity, both of which affect all major plant processes [50]. 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 [51]. 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 [52]. 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). 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

[51]. 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 [52]. When a plant senses salt stress through transmembrane proteins or enzymes in the cytosol, the amount of calcium in the cytosol increases [51]. 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 [39].

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