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Impact of salt stress on growth, productivity and physicochemical properties of plants: A Review

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Abstract
Amongst the detrimental effect of several factors governing yield resulting in declining agricultural productivity, environmental stress is the most contributive. The higher salt concentration in the soil makes it unfavorable for the crop plants to produce the desirable yield. This unfavorable condition leading to salt stress adversely affects the plant growth and development simultaneously bringing about changes in the plant metabolism which may or may not be profitable. Sometimes these physicochemical changes in plants helps in the development of tolerance mechanism by the plants against the stress condition. There is also decline in suitable arable land area due to development of saline soils on account of faulty agronomic practices like improper fertilization, irrigation with saline water etc. This review summarizes the impact of salt stress at different crop phenophases on the various growth, yield and physicochemical parameters.

Keywords: Arable land; Environmental stress; Fertilization; Growth; Phenophases; Physiochemical changes; Productivity; Saline water; Salt stress.

1. Introduction

Globally, the highest net cropped area is occupied by India followed by US and China, but it lacks behind in agricultural productivity on account of largest arable area falling under stress condition. The term stress was conceptualised as "any environmental factor which is potentially unfavourable to the living organisms by *Levitt* in 1980 [30]. The declining productivity, quality and the shrinking cultivable area of agricultural crops in the recent past can be attributed to the environmental stresses in form of extremes temperature, high wind, excess and deficit of water, radiation intensity, heavy metals deposits, chemical stressors etc., among which soil salinity is one the most catastrophic environmental stressors (Yamaguchi and Blumwald, 2005; Shahbaz and Ashraf, 2013) [59, 49] affecting the plant growth. About 400 million hectares of the world's land area and that of 6.727 million hectares of India is affected by salinity which is expected to rise up to 17 million hectares by 2050 and 25% of ground water used for irrigation is found to be saline (Anonymous, 2008) [4]. The accelerated expansion of saline soil cover across our continent is the consequence of low precipitation, high surface evaporation, weathering of native rocks, faulty fertilizer application method, irrigation with saline water, and poor cultural practices.

Salt stress can be generally viewed as the toxicity to the plants due to development of salinity. The stress condition resulting from higher salt concentration which is sufficient to lower the water potential (0.5 to 10 bars) is termed salt stress. The soils in which the electrical conductivity (EC) of the saturation extract (EC_e) in the root zone exceeds 4 dSm^{-1} (approximately 40 mM NaCl) at 25 °C and has an exchangeable sodium of 15% are identified as saline soils. Most of the crops experiences yield reduction at this electrical conductivity of the saturation extract though many crops exhibit yield reduction at lower EC_es (Munns, 2005; Jamil *et al.,* 2011) [41, 25]. When the salinity in soil develops as a result of natural accumulation of salts for a longer time period, whether in the form of sea salt deposition by winds and water or due to salts release from erosion of rocks, is referred to as primary salinization. However, secondary soil salinization is the results of human activities such as faulty practices of irrigation in agriculture. There is excessive accumulation of salts ions in the soil such as sodium (Na^+), chlorine (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (S), and bicarbonate (HCO_3^-), resulting in buildup of salinity and affecting plant growth and development (Lewis, 1984) [31]. Saline soils are reported to bring about changes in morphological, physiological and biochemical responses of plants (Amirjani, 2010; Siringam *et al.,* 2011) [3, 54]. The effects of drought as well as salt stress on plants is very similar. Under both the phenomena, the absorption of water and minerals by the roots is inhibited. Among the cereals production worldwide, 69% of the total wheat production is adversely affected by high salinity (Isayenkov, 2012) [24].

Salt stress is one of the most important abiotic stressors leading to reduction in plant growth, development and productivity worldwide. Salinity stress changes the physiological, morphological and biochemical responses of plants (Siringam *et al*., 2011) [54]. It causes significant changes in the SOD (Super oxide dismutase), antioxidant enzymes, growth regulators, lipid per-oxidation, total chlorophyll content and roots and shoots fresh weight of the plant. The different physiological processes which are adversely affected by salt stress are mineral distribution, membrane permeability, membrane instability due to calcium displacement by sodium (Gupta *et al*., 2002) [20] and decrease in photosynthetic efficiency (Hasegawa *et al.,* 2000) [21].

On account of the shrinking agricultural land area for the sustainable crop production there is a need to utilize the areas under stress conditions for crop production and other uses through appropriate management techniques like adopting suitable agronomic practices involving tilling with sub-soiler, mulching, growing of salt tolerant crops, reclamation measures, judicious application of fertilizers, practicing INM (Integrated nutrient management) and irrigating with saline water in combination with two-three turns of fresh water particularly in regions under salt stress. This review outlines the biological and physicochemical alteration observed in plant response against salt stress condition at different phenophases and summarizes the extensive research on development of salinity tolerance traits in plants.

2. Impact of salt stress on crop growth and development

Salt stress affects plant development in various ways such as specific ion toxicity or nutritional imbalance and osmotic activities (Lauchli and Epstein, 1990) [29]. The extent of inhibition caused by different mechanisms depends on various factors like species, plant stage, ionic strength of salinity and organs in the question. The occurrence of salt stress cause characteristic changes in plant from the time of occurrence until maturity (Munns, 2002) [40]. The plant cell shrink and dehydrated immediately after salt stress is imposed, however it is recovered hours later. Despite this recovery, cell elongation and to a lesser extent the cell division is affected which in turn results in lower root and leaf growth rate. A week after salinity stress occurrence, lateral shoot enlargement is affected and a months later, clear differences in overall growth and injury can be noticed between salt-stressed plants and their non-stressed controls. This response is due to changes in cell-water relation resultants of osmotic changes outside the root (osmotic effect). The osmotic effect leads to reduction in the capability of crops to absorb water. The osmotic effect is similar to water stress and shows little genotypic differences (Munns, 2005) [41].

Zheng *et al.* (2009) [62] observe that salt-sensitive variety of wheat (JN17) significantly reduced its gas exchanges by increase senescence under salt stress, which became more intense when salt concentration increased, especially at 21 days after anthesis however, statistically no differences between the two cultivars (salt-sensitive and tolerant cultivars) in stomatal conductance and net photosynthetic rate in control plants under normal soil conditions. Shoot and root fresh weights of the pumpkin significantly decreased due salt stress. It is observed that tolerant genotypes (Iskenderun-4, AB-44) maintain their performance whereas, sensitive genotypes (CU-7 and A-24) shoot and root fresh weights reduced due to salt stress and the decrement in the range of 24.56 to 42.75%. The reduction in growth might be due to reduction in the cell elongation. Salt stress can affect plant height, survival and plant biomass. Such morphological changes alter the ability of a plant to harvest water, nutrients and light (Locy *et al.,* 1996) [32].

2.1. Germination and seedling emergence

It has long been documented that a crop's sensitivity to salt stress varies from one growth stage to the other (Bernstein and Hayward, 1958) [8]. Seed germination of rice was not significantly affected up to 16.3 dSm^{-1} but was severely inhibited when salinity increased to 22 dS/m. The suppression of seed germination was might be due to increased osmotic pressure due to salt stress (Heenan *et al.*, 1988) [22].

Even though there are exceptions, the majority of the research indicates that most annual crops are tolerant at germination but are sensitive during emergence and early vegetative development (Lauchli and Epstein, 1990; Maas and Grattan, 1999) [29, 34]. As plants grow towards the mature, it becomes more tolerant to salinity, especially at later stages of development. Although these statements are in general true (with the exception of a few crops), it is important to highlight that the meaning of salt tolerance is not the same for each growth stage. Initially germination and emergence, tolerance is depends on the percent survival, while during the later stages, tolerance is generally based on relative growth reductions.

Usually most crop plants are tolerant during germination but salt stress prolongs this process however, no variation was reported in the percentage of germinated seeds from one treatment to another (Maas and Poss, 1989a). Mauromicale and Licandro (2002) [35, 39] observed that at higher salt concentration percentage of germinated seeds will reduce, but in case of sugar beet which considered as salt tolerant crop is somewhat sensitive to salinity at germination (Lauchli and Epstein, 1990) [29]. The salinity tolerant barley varieties showed much higher germination percentage and faster germination rate then sensitive one (Tajbakhsh *et al.,* 2006). Ali *et al*. (2007) and Belaqziz *et al.* (2009) [55, 2, 7] reports that salinity affects germination by destroying the embryo or drastically decreasing the soil potential might be due to hampered water uptake. Despite the consequences, screening of salt tolerant varieties, germination cannot be used as core information. In contrast to germination stage, most of the crops are susceptible to salt stress at emergence which depends on observation rather than quantitative research. It was reported that seedling emergence is affected by inhibiting reserve food mobilization, cell division, enlarging and injuring hypocotyls (Banerjee and Roychoudhury, 2017) [5]. For the study of emergence different types root media are used under diverse environmental conditions and interpretation was made by comparing with other studies (Grattan and Oster, 2003) [19]. Studies at seedling stage showed significant growth reduction in term of leaf mortality and shoot fresh weight in all tested lines under salinity (Shereen *et al*. 2005) [50].

Salt stress affects both vegetative and reproductive growth which has intense implications depending on whether the harvested organ is a root, shoot, stem, leaf, fruit, fiber and/or grain.

2.2. Vegetative stage

Most of the research studies revealed that crop plants are more sensitive to salt stress particularly seedlings and early vegetative stage in comparison to germination. Examples are found in melon (Botia *et al.,* 2005) [9], tomato (del Amor *et al.,* 2001) [13], spinach (Wilson *et al*., 2000) [56], rice (Pearson and Ayers, 1966) [46], sorghum (Maas *et al.,* 1986) [38] and wheat (Maas and Poss, 1989a) [36]. Maas *et al*., (1983) [37] in a greenhouse experiment with corn and wheat, observes that salinity's overall effect on relative grain yield was much lower than the effect on total shoot biomass of salt-stressed plants relative to non-stressed plants. Cramer *et al.* (1988) [10] found that salinity with an abundance supply of calcium emaciate shoot growth, mainly leaf area, more than root growth. However, poor Ca supply can adversely affect membrane function and root growth within minutes. High salt stress increased the deposition rate of Na in the growing region of the root and hence decreased the selectivity for K versus Na and this salinity effect mitigated by application of calcium but only the apical (2 mm) region (Zhong and Läuchli, 1994) [63].

Lauchli and Epstein, (1990) [29] reported that salinity often decreases shoot growth more than root growth and can decrease the number of florets per ear, affect the time of flowering and increase sterility and and maturity in both wheat (Maas and Poss, 1989a) [25] and rice (Khatun *et al.* 1995) [26]. Since salt-tolerance from an agronomic or horticulturist perspective is based on the yield of the harvestable organ, relative to that in non-stressed environments, understanding how salinity affects vegetative and reproductive development is important for developing management strategies that can minimize stress at critical times. It was observed by Sevengor *et al.* (2011) [48] that NaCl stress inhibited shoot and root dry weight, total root length, number of lateral roots, root average diameter and total root volume of wheat. When plants subjected to salinity levels of 12 dSm^{-1} for a week at seedling stage causes retardation in growth and photosynthesis. This might be due to a direct effect of salt stress on stomatal resistance due to reduction in guard cell turgor pressure, results to a reduction in intercellular partial pressure CO_2 (Dionisio-Sese and Tobita, 1998) [14].

2.3. Reproductive stage

The most of the research indicates that when plant growth advanced its sensitivity to salt stress decreased. In a research with wheat (Maas and Poss, 1989a) [35], sorghum (Maas *et al*., 1986) [38] and cowpea (Maas and Poss, 1989b) [36], found that these crops are more sensitive during vegetative and early reproductive stages, less sensitive during flowering and least sensitive during the seed filling stage.

3. Impact of salt stress on yield attributes and yield

Yield is a very complex character which comprises of many components and these yield components are related to final grain yield which are also severely affected by salinity. Yield contributing components of rice like length of panicle, spikelet number per panicle, number of grain per spikelet, and grain yield were significantly affected by salt treatments except test weight (Zeng, L. and Shannon, M. C. 2000) [61]. Sterility was considered the major cause for reduction in yield under salt stress condition as observed by Shereen *et al.* 2005 [50]. Further Khatun *et al.,* 1995 [26] reported delay in panicle emergence and flowering and also observed reduced seed set through decreased flowers and pollen viability. These components were least affected (10-20%) at 50mM NaCl in all tested lines except in L. No. 64, where an approximate reduction of 50% was observed in all contributing components which resulted in severe reduction in their grain yield (77%) at lower level of salinity (Shereen *et al.* 2005) [50]. However, Siband *et al.,* (1999) [52] observed that newly formed yield component decreased when the earlier formed component increased. This phenomenon was found in non stresses condition but in stress condition a compensatory relationship was observed in maize (*Zea mays* L.) between two successively formed yield components. Munns, (2002) [40], discussed that the magnitude of salt induced yield losses could not be attributed only to single factor rather different physiological, biochemical factors at different stages of rice plants may be involved. One of the factor may be the overall control mechanism (before flowering) of sodium uptake through root properties and its subsequent distribution in different vegetative and floral parts especially in leaves where it causes leaf mortality thereby reduces transportation of total assimilates to the growing region (Murty & Murty, 1982) [42], further added that the severe inhibitory effects of salts on fertility may be due to the differential competition in carbohydrates supply between vegetative growth which constrains its distribution to the developing panicles whereas other is probably linked to reduce viability of pollen under stress condition, thus resulting failure of seed set (Abdullah *et al.,* 2001) [1]. The decreased harvest index with the increase of salinity was consistent with this hypothesis.

3. Impact of salt stress on crop physiology

3.1. Chlorophyll content:

Chlorophyll content in leaves and their photosynthetic function was inversely related to salinity level (Ota and Yasue, 1962). Nieves *et al.,* (1991) [45, 44] observed a decrease in chlorophyll content of rice when grown in saline condition. The decrease in chlorophyll content under salt stress is reported by Yasar *et al.* (2008), Kusvuran (2010), and Nazarbeygi *et al.* (2011) [60, 27, 43]. In sensitive genotypes of pumpkin chlorophyll decreased by 24.11- 59.67% when compared to control plants while, tolerant genotypes protected their chlorophyll content. The reduction in chlorophyll substance might be due to increased activity of chlorophyll degrading enzyme "chlorophyllase" *(*Sevengor *et al.,* 2011) [48]. In salt tolerant genotypes the chlorophyll content may be protected from degradation due to present of anti-oxidant enzyme activity. The inhibition in chlorophyll synthesis resulting in loss of photosynthetic activity leading to senescence of the leaves (De Michele *et al.* 2009) [12] cause reduction in the growth of the crops (Garg and Manchanda, 2009). Senguttuvel, P. (2014) [16, 47] reported that salinity level of 120 mM and 60 mM considerably reduced the chlorophyll content up to 60.8% and 30.9% respectively, compared to control. The average mean salinity levels which do not cause any harmful effects on crops range between 0.62 mg g^{-1} to 0.86 mg g^{-1}.

3.2. Tolerance mechanism

Various researchers have identified and reported different adaptive mechanism of tolerance against salinity at different organs and metabolic level. The metabolic products responsible for development of tolerance in plants includes amino acids, dimethylsulfonium, sugars, polyols and plant hormones. These metabolites acts as osmoregulators and shields the plants against extreme environmental condition of salt as well as drought stress (Shulaev *et al*., 2008) [51].

3.2.1. Accumulation of Proteins

Most of the salt tolerant crops have been reported to accumulate proteins in their cells to adapt in the extreme stress environment. Tobacco is one such crop that accumulates osmotin in the vacuole of cells particularly that are salt affected in order to tolerate the stress. The application of abscisic acid (ABA) helps in the regulation of osmotin at the transcriptional level (Singh *et al.,* 1989) [53], whereas the protein accumulation is controlled through the post transcriptional regulation (LaRosa *et al.,* 1992) [28]. The polypeptide sequence of osmotin possess similar features to that of trypsin or α-amylase found in maize. Proline and glycine betaine are the other proteins upregulating the enzymes and serving as osmoprotectants in stress environment (Holmstrom *et al.,* 2000) [23]. A phospholipid hydroperoxide GSH peroxidase has been identified for the first time in citrus as a salt stress associated protein (Beeor-Tzahar *et al.,* 1995). Golldack and Dietz, 2001 [6, 18] reported that under salinity stress the vacuolar type (H^+), ATPase increases the enzyme activity and is also responsible for regulating the sodium sequestration in the central vacuole.

3.2.2. Release of plant hormones

The remarkable adaptation under drought, low temperature and salinity is also aided through the release of plant hormones like Abscisic acid (ABA) (Xiong *et al.,* 2002) [58] and Methyl Jasmonate (MeJA) (Creelman and Mullet, 1997) [11]. It has been reported that MeJA up regulates the genes encoding for stress tolerance and those for defence protein whereas it down regulates the Ribulose bisphosphate carboxylase/ oxygenase, light harvesting complex II and chlorophyll a/b binding protein. However, the ABA level seems to rise when the plant is put under environmental stress in order to up- and/ or down regulate various genes during the metabolic process.

Table 1: Salt tolerance mechanism through release of metabolites

Crops	Tolerance mechanism	Reference
Alfalfa	Increased production of proline and carbohydrates	Fougere *et al*. 1991
Barley	Increased level of hexose phosphates, TCA cycle intermediate, and raffinose	Widodo *et al*. 2009
	Polyols, high level of sugar, active photosynthesis in leaves	Wu *et al*. 2013
Maize	Increased levels of glutamate, alanine, asparagine, glycine betaine, sucrose and levels of *trans*-aconitic acid, malic acid, and glucose decreased in a dose-dependent manner in shoots.	Gavahan *et al*. 2011
Soybean	Synthesis of compatible osmolytes, ROS scavengers	Lu *et al*. 2013

4. Conclusion

Several studies by different scientists has revealed the adverse effect of salt stress on the growth and development of crop plants resulting in major yield losses. Presence of salt in higher concentration in the soil as well as in irrigation water has added to saline soil cover in our country and reduction in yield in most of the crops except some halophytes, has been recorded due to salt stress. Although plant breeders and physiologists have developed salinity tolerant varieties through different breeding techniques like molecular genetics through biotechnological strategies, there is still requirement of utilizing several mechanism and incorporating the resistant traits of ideotypes for developing multiple stress tolerant varieties against environmental stresses so that the desirable yield is obtained while maintaining soil health.

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