



Salt stress effects on some morphological and physiological characteristics of okra (*Abelmoschus esculentus* L.)

Muhammad Adnan Shahid^{1*}, Muhammad Aslam Pervez¹, Rashid Mukhtar Balal¹, Rashid Ahmad²,
Chaudhary Muhammad Ayyub¹, Tahira Abbas¹ and Naheed Akhtar¹

¹Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan

²Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

Abstract

Salinity is worldwide problem that limits the growth and productivity of all vegetations and it is going to increasing day by day. The objective of the investigation was to study the response of okra (*Abelmoschus esculentus* L.) in terms of morphological and physiological characteristics under salt stress conditions. Okra seeds of cultivar Chinese Red were grown in plastic pots having fine sand as growth medium. After 30 days of germination, the plants were subjected to salt stress under control, 25, 50, and 75 mM NaCl. Increasing salinity caused a decrease of germination percentage, shoot and root length, plant height, pod weight, pod length, photosynthesis rate, and stomatal conductance. The Na⁺ and Cl⁻ accumulation were correlated with a decline in concentration of K⁺ in leaves and roots. Under salinity, a high concentrations of Na⁺ and Cl⁻ were noted in both leave and roots portions.

Key words: Okra, NaCl, salt stress, photosynthesis rate, stomatal conductance

Introduction

Abiotic stresses like heat, cold, drought and salinity affect the plant growth and productivity (Allakhverdiev *et al.*, 2000) but the salt stress exerts more drastic effects in terms of low productivity (Munns, 2002). The salt affected area is increasing day by day and total salinity affected area is about 831 x 10⁶ ha (Beltran and Manzur, 2005). It has been estimated that one-half of all the irrigated land (about 2.5 x 10⁸ ha) are severely affected by salinity (Rhoades and Loveday, 1990).

High salt contents reduce the growth and production by affecting physiological processes, including modification of ion balance, water status, mineral nutrition, stomatal behaviour, and photosynthetic efficiency (Munns, 1993). Most plants are salt sensitive with either a relatively low salt tolerance or severely inhibited growth at low salinity levels so differ in the growth response to salinity (Moisender *et al.*, 2002; Sheekh and Omer, 2002). Salt stress affects plant physiology at both whole plant and cellular levels through osmotic and ionic stress (Murphy and Durako, 2003). High concentration of salts in the root zone decreases soil water potential and the availability of water (Lloyd *et al.*, 1989). This deficiency in available water under saline condition causes dehydration at cellular level and ultimately osmotic stress occurs. The excessive amounts of toxic ions like Na⁺ and Cl⁻ create an ionic imbalance by reducing the uptake of beneficial ions such as K⁺, Ca²⁺, and Mn²⁺ (Hasegawa *et al.*, 2000).

The higher ratios of toxic salts in leaf apoplasm lead to dehydration and turgor loss, and death of leaf cells and tissues (Marschner, 1995). Salt stress has various effects on plant physiological processes such as increased respiration rate and ion toxicity, changes in plant growth, mineral distribution, membrane instability resulting from calcium and potassium displacement by sodium (Grattan and Grieve, 1992), membrane permeability (Gupta *et al.*, 2002), and decreased efficiency of photosynthesis (Ashraf and Shahbaz, 2003; Kao *et al.*, 2003; Sayed, 2003). The most important process that is affected by salinity is photosynthesis (Hayat *et al.*, 2010). Reduced photosynthesis under salinity is not only attributed to stomatal closure leading to a reduction of intercellular CO₂ assimilation, but also to non-stomatal factors like reduction in green pigments and leaf area. There is increasing evidence that salts affect photosynthetic enzymes, chlorophylls and ionic contents (Misra *et al.*, 1997).

Okra (*Abelmoschus esculentus* L.) is recognised as annual herbaceous plant grown in tropical and subtropical areas and serves as a source of carbohydrates, fats, vitamins and various minerals (Oyenuga, 1968). In spite of having good nutritional value, it's per hectare yield is very low. This decline in optimum yield is due to the drastic effects of salts, which are deposited in soil by the use of brackish underground water, and addition of industrial effluents in our canals also adds salts in irrigation water. This application of saline water reduces the transpiration and causes an imbalance in evapo-transpiration rate and induces

*Email: uaf_adnan777@yahoo.com

the reduction in yield (Dudley *et al.*, 2008). High ratios of salts in root zone affect different processes like root density, root turgor pressure, and its growth, and ultimately create hindrance in water absorption (Maggio *et al.*, 2004). Okra plant at earlier growth stages is more sensitive to salinity (Cedra *et al.*, 1982), as it affects water relations and nutrient uptake of plants. While later on, the ionic stress in turn reduces leaf expansion. During long term exposure to salinity, plants experience ionic stress, which can lead to premature senescence of adult leaves and thus reduction in photosynthetic rate is a common observation (Cramer and Nowak, 1992). Salinity changes photosynthetic parameters (Nadeem *et al.*, 2006), including osmotic and water potential (Azevedo-Neto *et al.*, 2004), transpiration rate (Karlberg *et al.*, 2003), leaf temperature (Maricle *et al.*, 2007), and relative leaf water content (Lee *et al.*, 2005). The aim of present study was to analyze the drastic effects of salt stress on some morphological and physiological attributes of okra plant.

Material and methods

Plant material and growth conditions

Okra (*Abelmoschus esculentus* L.) was used for this study. The experiment was carried out in net house. Seeds of okra were allowed to germinate in 9 L plastic pots filled with fine sand as growth medium. Ten seeds per pot were sown but after 15 days of germination, the plants were thinned out to five. The experiment was carried out with three replications. Plants were grown in Hoagland (Hoagland and Arnon, 1950) solution under non saline conditions for 30 days after germination. Afterwards, the salt treatment was initiated. Sodium chloride was dissolved in distilled water to obtain final concentration of, 0 (Control), 25, 50 and 75 mM and then these solutions of different NaCl concentrations were applied to create the salinity while half strength Hoagland solution was applied as nutrient medium. To prevent the plants from osmotic shock, the NaCl concentrations were imposed in 25 mM increments every day until final concentrations were reached after three days interval. Plants were grown for 15 days under salt stressed conditions. Irrigation along with half strength Hoagland solution was applied to the selected treatments according to the need of the plants by regularly observing the wetness extent of sand. Seed germination was calculated separately in Petri dishes by applying the respective concentration of NaCl solution on filter papers.

Morphological attributes

The seeds were surface sterilized with sodium hypochlorite 0.5 % (v/v) for 20 min., washed repeatedly with distilled water and then sown in Petri dishes having filter papers

moistened with respective saline solution in three replications (10 seeds each Petri dish). After five days the number of seeds germinated in each Petri plate was counted. The germination percentage was calculated as under:

Germination percentage =

$$(\text{No. of seeds germinated} / \text{No. of seeds sown}) \times 100$$

The shoot length of six randomly selected plants (two from each replication) was measured before the salinity (application and at the time of harvesting, and the difference was taken as equal to the shoot length/elongation under saline condition) in centimeters from the base to the top of shoot with the help of measuring rod. The root length of six randomly selected plants (two from each replication) was measured in centimeters, with measuring tape, from the base to the tip of longest root. The final height of the plant was recorded in centimeters (cm) from the ground level to the apical bud at maturity stage when apical growth of the main stem ceased. The plant height included final shoot length + final root length at the time of plant harvesting. For shoot elongation the shoot lengths (above ground plant for 4 plants per pot) were noted before the salinity application and the difference between this reading and final plant height represented the shoot elongation.

Shoot elongation = Plant height at the time of harvesting – Shoot length before salinity application

The marketable green pods were weighed and average pod weight was calculated for each plant by dividing the total plant yield with respective number of pods per plant. The average pod weight (g) per plant was worked out with digital balance for statistical analysis. The length of each of the picked pod was measured with vernier caliper and average pod length was worked out.

Physiological attributes

Photosynthesis rate (Pn) and stomatal conductance (g_s) and transpiration rate (E) were recorded on intact leaves using an infra-red gas analyser (Analytical Development Company, Hoddesdon, England). Measurements were performed from 9.00 to 11.00 a.m. after 15 days of salinity application, with the following specifications/adjustments: molar flow of air per unit leaf area, 403.3 mM m⁻² s⁻¹; atmospheric pressure, 99.9 kPa; water vapor pressure into chamber ranged from 6.0 to 8.9 mbar (photosynthetically active radiation) at leaf surface was maximum up to 1711 (mol m⁻² s⁻¹) because this reading was shown by IRGA (infrared gas analyzer) on its screen at the time of use, temperature of leaf ranged from 28.4 to 32.4 °C, ambient temperature ranged from 22.4 to 27.9 °C, ambient CO₂ concentration was 352 mol mol⁻¹. The digested samples of root and leaf of okra were analyzed for Na⁺ and K⁺ by

Flame photometer (Jenway PFP-7, UK). A series of standards (ranging from 10 to 100 mg L⁻¹) of Na⁺ and K⁺ was prepared and standard curves were drawn. The values of Na⁺ and K⁺ from flame photometer were compared with standard curve and original quantities were computed. The chloride contents were measured with chloride analyzer.

Statistical analysis

The experiment was arranged in completely randomized design with two factor factorial arrangement, having three replications. The data recorded were analyzed statistically using Fisher's analysis of variance technique and Duncan's Multiple Range test at 5 % probability level to compare the differences among treatment means (Steel *et al.*, 1997).

Results

The salt stress exerted a significant ($P < 0.05$) decrease in germination percentage (Figure 1a). Maximum reduction in germination was observed at 75 mM as compared to the control. Maximum germination percentage (98.05%) was recorded at lowest salinity level (25 mM) while the lowest values (69.64%) for germination percentage was observed at highest salinity level of 75 mM. Reduction in shoot length was observed with the increase in salt stress (Figure 1b). It decreased continuously with the increment in salinity from control to 75 mM. The control showed the highest (23.56 cm) shoot length followed by 25 mM (21.45 cm), 50 mM (15.67 cm) and 75 mM (11.89 cm). Salt stress also exerted a drastic effect on root growth and development by affecting its length. All the three salinity levels (25, 50 and 75 mM) caused reduction in root length of okra plant as compared to the control (Figure 1c).

The plants grown under control (no salinity application) exhibited the maximum values (10.11 cm) for root length as compared to remaining treatments, which indicated that salinity is responsible for reduction in root length.

The plants grown under 75 mM salt stress showed the lowest values (8.44 cm) of root length. A significant ($P < 0.05$) reduction in plant height was also noted in all the plants grown at different salinity levels (Figure 1d). Maximum plant height (45.67 cm) was observed in plants grown under control while 25, 50 and 75 mM NaCl salinity levels exhibited the values for plant height as 41.98, 34.02 and 26.33 cm, respectively. So, it is clear that highest salinity level 75 mM exerted the maximum drastic effects on plant height as compared to the other salinity levels. The salinity also influenced the yield of okra by affecting both the pod weight as well as pod length. The pod weights of all the plants grown under salinity represent the decrease as compared to the control (Figure 2a). But maximum

decrease was recorded at 75 mM followed by 50 and 25 mM. The plants grown under 75 mM showed the minimum (5.39 g) as compared to the non saline control with highest pod weight (7.06 g).

The salinity levels 25 and 50 mM showed the moderate pod weight values of 6.76 and 5.98 g, respectively. Similarly decline in pod length was observed at all salinity levels with maximum reduction at 75 mM and minimum reduction at 25 mM salt stress while control exhibited the maximum pod length followed by 50 mM (Figure 2b). The photosynthesis rate and stomatal conductance are also influenced by salinity in all the plants grown under saline environment. The highest salinity (75 mM) caused the maximum reduction in both photosynthesis rate (Figure 2c) and stomatal conductance (Figure 2d) as compared to the low salinity (25 mM).

Maximum photosynthesis rate ($39.67 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ S}^{-1}$) was noted at control (non saline) while other salinity levels, 25, 50 and 75 mM showed 31.78, 29.89 and $22.45 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ S}^{-1}$, respectively. So it is clear that high salt stress (75 mM) exhibited the maximum drastic effects in terms of reduction in photosynthesis rate. The stomatal conductance was also significantly ($P < 0.05$) influenced under the effect of salt stress. A decreasing trend was noted in case of stomatal conductance in response to salinity. All the salinity treatments showed significant ($P < 0.05$) variations for stomatal conductance. The plants grown under control (non saline) and 25 mM exhibited the maximum values (72.56 and $66.72 \text{ mMol m}^{-2} \text{ S}^{-1}$, respectively) for stomatal conductance as compared to the remaining two salinity levels of 50 and 75 mM with values 61.78 and $54.88 \text{ mMol m}^{-2} \text{ S}^{-1}$, respectively. Na⁺ and Cl⁻ tended to increase with the increment in salinity. So, maximum concentration of these ions was recorded at higher salinity level of 75 mM (Figure 3a and 3b).

Maximum amounts of sodium were noted in roots while maximum concentration of chloride was measured in leaves. On the other hand, salt stress caused a decrease in K⁺ contents both in leaves and roots but maximum concentration was recorded in leaves as compared to the roots. The plants grown under control showed no significant difference in K⁺ contents of both leaves and roots while the plants under 50 mM were also statistically similar for K⁺ contents in their roots and leaves. However, the 25 and 75 mM treatments exhibited the prominent difference in K⁺ contents of their leaves and roots (Figure 3c).

Discussion

The germination of the okra was affected because high salt concentration in the solutions sprayed on filter papers in

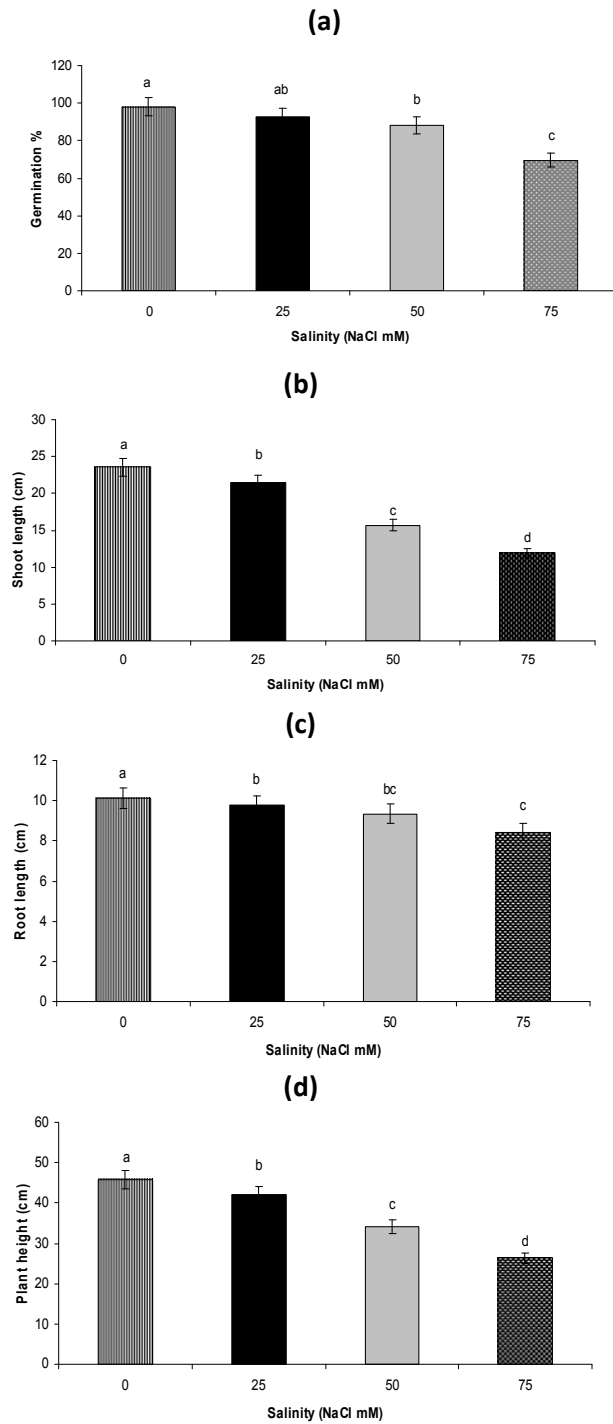


Figure 1: Effect of NaCl salt stress, germination %age, shoot length, root length and plant height of okra

Columns followed by different letter(s) is/are significantly different by DMRT at 5% level of significant
Error has $\pm$ S.E. for n = 3

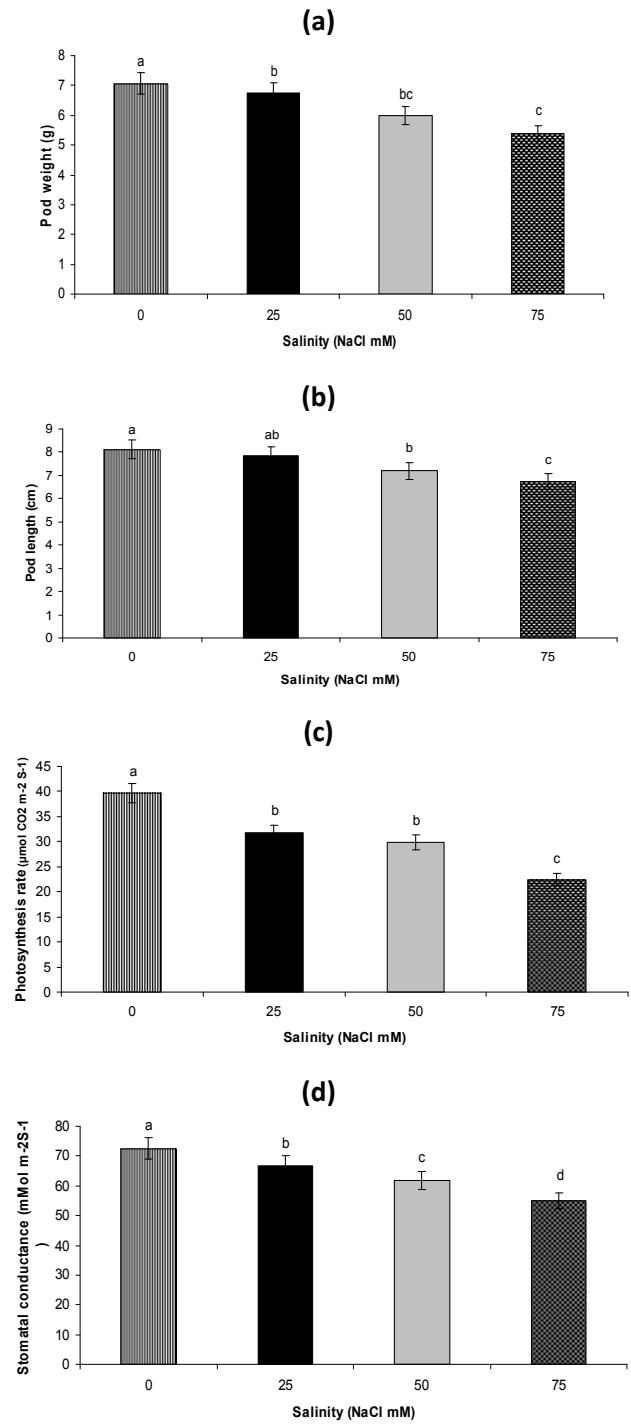


Figure 2: Effect of NaCl salt stress on pod weight, pod length, photosynthesis rate, stomatal conductance of okra

Columns followed by different letter(s) is/are significantly different by DMRT at 5% level of significant
Error has $\pm$ S.E. for n = 3

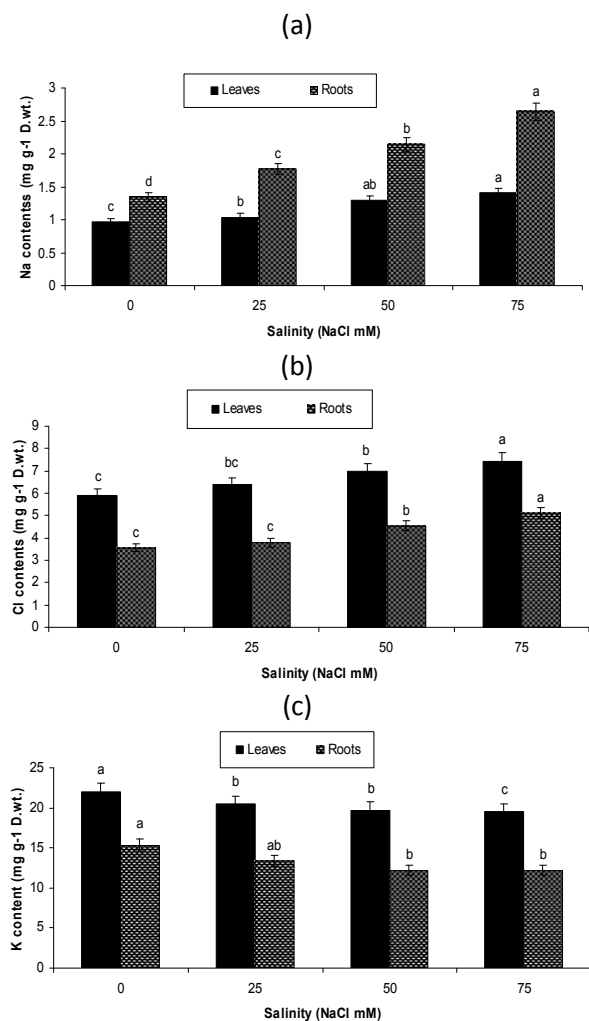


Figure 3: Effect of NaCl salt stress on sodium, chloride, and potassium contents in leaves and roots of okra

Columns followed by different letter(s) is/are significantly different by DMRT at 5% level of significant

Error has $\pm$ S.E. for $n = 3$

Petri dishes increases the osmotic potential which causes the seeds to use more energy to absorb water from the wet filter papers and hence affects the germination (Kafi and Goldani, 2001; Jamil and Rao, 2004). The depressed growth of plants may be due to the toxic effect of Na^+ and Cl^- ions present in NaCl and low water potential in the rooting medium (Silveira *et al.*, 2009). It is reported that salt stress affects the plant growth and development by influencing fresh and dry weights of roots, shoots along with shoot length (Ashraf *et al.*, 2003). In the present study, the plants exhibited the lowest germination percentage (69.64%) under 75 mM NaCl salinity as compared to the other treatments and it may be due to the

increase in osmotic potential. It has been suggested that plants having longer roots in non-saline conditions had shorter roots in saline conditions (Figure 1c). Growth attributes like plant height, shoot elongation, shoot and root length were severely decreased with salinity. It was noted that plants growing under saline condition remained stunted. The lower water potential (ψ_w) in saline soil in turn lower cell turgor causing reduction in cell elongation and cell division (Greenway and Munns, 1980). Plant growth is important character in determining the salt tolerance ability of the plants. Although plant height is genetically controlled, environmental factors also have strong influence in the expression of genes as it is very clear from the current work that all treatments of salt stress significantly influenced the plant (Figure 1d). The okra plants under normal and low salinity level (25 mM) may have adjusted osmotically to the growing conditions as a result of which they were successful in maintaining required cell enlargement so showed the maximum plant height (Figure 1d) along with root/shoot lengths as compared to the higher salinity levels (50 and 75 mM). The plants grown under high salinity (75 mM) fail to activate the dehydration avoidance mechanism like making root membranes impermeable for toxic ions of Na^+ and Cl^- so plants did not maintain stomatal conductance (Figure 2d) up to desired rate (Abbruzzese *et al.*, 2009), thus could not with-stand high salt stress and experienced the reduction in growth. Roots are directly in contact with growth media containing toxic salts that stop the long term root growth (Tyerman and Skerrett, 1999) which indirectly affect the biomass production. Under saline condition, CO_2 assimilation of plant become decreased, it is major energy source for growth and development, so, ultimately root growth decreases (Syvertsen *et al.*, 2000; Kasukabe *et al.*, 2004, 2006). The reduction in root length caused the decrease in biomass which is commonly observed under salt stress (Vasquez *et al.*, 2006; Keutgen and Pawelzik, 2008). A decrease in root length with the increments in salinity in present assessment confirms the results of Syvertsen *et al.*, 2000; Kasukabe *et al.*, 2004, 2006; Ibrahim *et al.*, 2007.

The okra plants grown under low salinity level (25 mM) might have developed osmotic adjustment mechanism, hormonal imbalance and ion exchange to alleviate the drastic effects of toxic ions, so, these plants exhibited better growth in terms of maximum root/ shoot length and height while under high salt stress (75 mM) they failed to develop the efficient osmotic adjustment mechanism and showed reduction in the above mentioned growth attributes. In the present study, rate of photosynthesis and stomatal conductance reduced with the rise in salinity (Figure 2c and 2d). Salinity severely affects the photosynthetic activity of plants and it may be because

of the variations in osmotic potential and water potential within the tissues. As the salts within the plant tissues increases osmotic potential increase while water potential decreases (Ashraf and Foolad, 2005), so, this decrease in water potential affects the opening and closing of stomata which finally causes the imbalance in gaseous exchange and disturbs the photosynthetic apparatus. On the other hand, reduction in photosynthesis may be due to reduction in stomatal conductance (Chartzoulakis *et al.*, 2002; Sudhir and Murthy, 2004). It is well documented that salinity affects growth and leaf water potential, stomatal conductance and transpiration rate (Parida and Das, 2005) for okra (Ikram, 2009). Under salt stress, tolerant plants maintain high concentrations of K^+ and low concentrations of Na^+ in the cytosol while in sensitive plants the ratio of Na^+ increases as compared to the K^+ and drastically affects the cell organelles. The plants regulate the expression and activity of K^+ and Na^+ transporters and of H^+ pumps that generate the driving force for ion transport (Zhu, 2003). A greater degree of salt tolerance in plants was found to be associated with a more efficient system for selective uptake of K^+ over Na^+ (Neill *et al.*, 2002).

The selective uptake of K^+ in contrast to Na^+ was considered one of the important physiological mechanisms contributing to salt tolerance in many plant species (Poustini and Siosemardeh, 2004). Okra grown under high salinity (75 mM) accumulated maximum amounts of Na^+ in their leaves and roots, so, the growth of these plants was affected due to high concentration of Na^+ and low ratios of K^+ (Aydin *et al.* 2002; Ahmadi *et al.*, 2009; Dashti *et al.*, 2009). The salt tolerance in okra plants may be attributed to effective exclusion of Na^+ as was also discussed by Flowers and Yeo (1981), Yeo and Flowers (1984) and Sharma (1986) in rice. There was a decrease in K^+ concentration both in leaves and roots with increased NaCl salinity in the okra (Figure 3c). Maintenance of higher K^+/Na^+ ratio under low salt stress (25 mM) may be one of the reasons for superior growth (Ashraf and Ahmad, 2000). High levels of K^+ in young leaves are associated with salt tolerance in many plant species (Gorham, 1993; Storey *et al.*, 1993; Khatun and Flowers, 1995).

It can be concluded that salt stress has affected the okra plant growth and development as well as its physiological process like photosynthesis rate and stomatal conductance. The effect can be attributed to antagonistic influence of Na^+ to K^+ ; it means Na^+ reduced the absorption of K^+ and this ion is very beneficial is stomatal conductance because it regulates the opening and closing of stomata, so, Na^+ indirectly affects the stomatal conductance by reducing the ratios of K^+/Na^+ . On the other hand, higher ratios of K^+/Na^+ under salt-stress were calculated in leaves as compared to the roots.

References

- Abbruzzese, G., I. Beritognolo, R. Muleob, M. Piazzaia, M. Sabattia, G.S. Mugnozza and E. Kuzminsky. 2009. Leaf morphological plasticity and stomatal conductance in three *Populus alba* L. genotypes subjected to salt stress. *Environmental and Experimental Botany* 66: 381-388.
- Ahmadi, A., Y. Emam and M. Pessarakli. 2009. Response of various cultivars of wheat and maize to salinity stress. *Journal of Food, Agriculture and Environment* 7: 123-128.
- Allakhverdiev, S.I., A. Sakamoto, Y. Nishijama, M. Inaba and N. Murata. 2000. Ionic and osmotic effects of NaCl-induced inactivation of photosystems I and II in *Synechococcus* sp. *Plant Physiology* 123: 1047-1056.
- Ashraf, M. and S. Ahmad. 2000. Influence of sodium chloride on ion accumulation, yield components and fibre characteristics in salt-tolerant and salt-sensitive lines of cotton (*Gossypium hirsutum* L). *Field Crops Research* 66: 115-127.
- Ashraf, M., M. Arfan and A. Ahmad. 2003. Salt tolerance study in okra: ion relations and gas exchange characteristics. *Journal of Plant Nutrition* 26: 63-79.
- Ashraf, M. and M. Shahbaz. 2003. Assessment of genotypic variation in salt tolerance of early CIMMYT hexaploid wheat germplasm using photosynthetic capacity and water relations as selection criteria. *Photosynthetica* 41: 273-280.
- Ashraf, M. and M.R. Foolad. 2005. Roles of glycinebetaine and proline in improving plant abiotic stress resistance. *Experimental and Environmental Botany* 59: 206-216.
- Aydin, A., M. Turan and Y. Sezen. 2002. Effect of sodium salts on growth and nutrient uptake of spinach (*Spinacia oleracea*) and beans (*Phaseolus vulgaris*). International Symposium on Desertification, Konya, Turkey. <http://www.topark.org.tr/isd95htm>. [Access date ???].
- Azevedo-Neto, A.D., J.T. Prisco, J. En'eas-Filho, C.F. Lacerda, J.V. Silva, P.H.A. Costa and E. Gomes-Filho. 2004. Effects of salt stress on plant growth, stomatal response and solute accumulation of different maize genotypes. *Brazilian Journal of Plant Physiology* 16: 31-34.
- Beltran J.M. and C.L. Manzur. 2005. Overview of salinity problems in the world and FAO strategies to address the problem. p. 311-313. In: Proceedings of the International Salinity Forum, April 25-27, 2005, Riverside, California.
- Cerda, A., J. Pardines, M.A. Botella and V. Martinez. 1982. Effect of potassium on growth, water relations, and organic solute contents for two maize grown under

- saline conditions. *Journal of Plant Nutrition* 18: 839-851.
- Chartzoulakis, K., M. Loupassaki, M. Bertaki and I. Androulakis. 2002. Effects of NaCl salinity on growth, ion content and CO₂ assimilation rate of six olive cultivars. *Scientia Horticulturae* 96:235-247.
- Cramer, G.R. and R.S. Nowak. 1992. Supplemental manganese improves the relative growth, net assimilation and photosynthetic rate of salt stressed barley. *Physiologiae Plantarum* 84: 600-605.
- Dashti, A., A.A. Khan and J. C. Collins. 2009. Effect of salinity on growth, ionic relations and solute content of *Sorghum bicolor* (M.). *Journal of Plant Nutrition* 58: 839-843.
- Dudley, L.M., A. Ben-Gal and U. Shani. 2008. Influence of plant, soil and water on the leaching fraction. *Vadose Zone Journal* 7: 420-425.
- Flowers, T.J. and A.R. Yeo. 1981. Variability in the resistance of sodium chloride salinity within rice (*Oryza sativa* L.) varieties. *New Phytology* 88: 363-373.
- Gorham, J. 1993. Genetics and physiology of enhanced K/Na discrimination. p. 151-159. In: Genetic Aspects of Plant Mineral Nutrition. Powal and Allen, (ed.). Kluwer Academic Publisher Dodrecht, The Netherlands.
- Grattan, S.R. and C.M. Grieve. 1992. Mineral element acquisition and growth response of plants grown in saline environment. *Agriculture Ecosystem and Environment* 38: 275-300.
- Greenway, H. and R. Munns. 1980. Mechanism of salt tolerance in non halophytes. *Annual Review of Plant Physiology* 31: 149-190.
- Gupta, N.K., S.K. Meena, S. Gupta and S.K. Khandelwal. 2002. Gas exchange, membrane permeability, and ion uptake in two species of Indian jujuba differing in salt tolerance. *Photosynthetica* 40: 535-539.
- Hasegawa, P.M., R.A. Bressnan, J.K. Zhu and H.J. Bohnert. 2000. Plant cellular and molecular responses to high salinity. *Annual Review of Plant Physiology and Plant Molecular Biology* 51: 463-499.
- Hayat, S., S.A. Hasan, M. Yusuf, Q. Hayat and A. Ahmad. 2010. Effect of 28-homobrassinolide on photosynthesis, fluorescence and antioxidant system in the presence or absence of salinity and temperature in *Vigna radiata*. *Environmental and Experimental Botany* 69: 105-112.
- Hoagland, D.R. and D.J. Arnon. 1950. The water culture method for growing plants without soil. *California Agricultural Experiment Station Circular* 347: 1-32.
- Ibrahim, M., J. Akhtar, M. Younis, M. A. Riaz, M. Anwar-ul-Haq and M. Tahir. 2007. Selection of cotton (*Gossypium hirsutum* L.) genotypes against NaCl stress. *Soil and Environment* 26(1): 59-63.
- Ikram, H. 2009. Salt tolerance study in okra (*Abelmoschus esculentus* L.). Ph.D thesis, Dept. of Plant Breeding and Genetics, University of Agriculture, Faisalabad.
- Jamil, M. and E.S. Rho. 2004. The effect of salinity (NaCl) on the germination and seedling of sugar beet (*Beta vulgaris* L.) and cabbage (*Brassica oleracea* L.). *Korean Journal of Plant Research* 7: 226-232.
- Kafi, M. and M. Goldani. 2001. Effect of water potential and type of osmoticum on seed germination of three crop species of wheat, sugarbeet, and okra. *Agriculture Science and Technology* 15: 121-33.
- Kao, W.Y., T.T. Tsai and C.N. Shih. 2003. Photosynthetic gas exchange and chlorophyll *a* fluorescence of three wild soybean species in response to NaCl treatments. *Photosynthetica* 41:415-419.
- Karlberg, L., A. Ben-Gal, P.E. Jansson and U. Shani. 2003. Modelling transpiration and growth in salinity-stressed tomato under different climatic conditions. *Ecological Modelling* 190: 15-40.
- Kasukabe, Y., L.X. He, K. Nada, S. Misawa, I. Ihara and S. Tachibana. 2006. Overexpression of spermidine synthase enhances tolerance to multiple environmental stresses and upregulates the expression of various stress-regulated genes in transgenic *Arabidopsis thaliana*. *Plant Cell Physiology* 45:712-22.
- Kasukabe, Y., N. Marshall and B. Fanton. 2004. Salt stress causes a depletion in CO₂ assimilation in okra. *Plant Cell Physiology* 55: 1016-19.
- Keutgen, A.J. and E. Pawelzik. 2008. Quality and nutritional value of strawberry fruit under long term salt stress. *Food Chemistry* 107(4):1413-1420.
- Khatun, S. and T.J. Flowers. 1995. Effect of salinity on seed set in rice. *Plant Cell Environment* 18: 61-87.
- Lee, G., R.N. Carrow and R. R. Duncan. 2005. Growth and water relation responses to salinity stress in halophytic seashore paspalum ecotypes. *Scientia Horticulturae* 104:221-236.
- Lloyd, J., P.E. Kriedemann and D. Aspinall. 1989. Comparative sensitivity of Prior Lisbon lemon and Valencia orange trees to foliar sodium and chloride concentrations. *Plant Cell Environment* 12:529-540.
- Maggio, A., S.D. Pascale, G. Angelino, C. Ruggiero and G. Barbieri. 2004. Physiological response of tomato to saline irrigation in long-term salinized soils. *European Journal of Agronomy* 21: 149-159.
- Maricle, B.R., D.R. Cobos and C.S. Campbell. 2007. Biophysical and morphological leaf adaptations to drought and salinity in salt marsh grasses. *Environmental and Experimental Botany* 60:458-467.
- Marschner, H. 1995. Mineral nutrition of higher plants, 2nd Ed. Academic Press, San Diego.

- Misra, A.N., S.M. Sahu, M. Misra, P. Singh, I. Meera, N. Das, M. Kar and P. Shau. 1997. Sodium chloride induced changes in leaf growth, and pigment and protein contents in two rice cultivars. *Biologia Plantarum* 39: 257-262.
- Moisender, P.H., E. McClinton and H.W. Paerl. 2002. Salinity effects on growth, photosynthetic parameters, and nitrogenase activity in estuarine planktonic cyanobacteria. *Microbiology and Ecology* 43: 432-442.
- Munns, R. 1993. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell Environment* 16:15-24.
- Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell Environment* 25:239-250.
- Murphy, K.S.T. and M. J. Durako. 2003. Physiological effects of short term salinity changes on *Ruppia maritima*. *Aquatic Botany* 75:293-309.
- Nadeem, S.M, Z.A. Zahir, M. Naveed, M. Arshad and S.M. Shahzad. 2006. Variation in growth and ion uptake of maize due to inoculation with plant growth promoting rhizobacteria under salt stress. *Soil and Environment* 25: 78-84
- Neill, S., R. Desikan and J. Hancock. 2002. Hydrogen peroxide signalling. *Current Opinions in Plant Biology* 5: 388-395.
- Oyenuga, V.A. 1968. Nigeria's Foods and Feeding Stuffs, their Chemistry and Nutrients Value, 3rd Ed. University Press, Ibadan.
- Parida, A.K. and A.B. Das. 2005. Salt tolerance and salinity effects on plants: a review. *Ecotoxicology and Environmental Safety* 60:324-49.
- Poustini, K. and A. Siosemardeh. 2004. Ion distribution in wheat cultivars in response to salinity stress. *Field Crops Research* 85:125- 33.
- Rhoades, J.D. and J. Loveday. 1990. Salinity in irrigated agriculture. In: Irrigation of Agricultural Crops. B.A. Stewart and D.R. Nielsen (eds.). *American Society of Agronomy Monograph* 30: 1089-1142.
- Sayed, O.H. 2003. Chlorophyll fluorescence as a tool in cereal crop research. *Photosynthetica* 41: 321-330.
- Sharma, S.K. 1986. Mechanism of tolerance in rice varieties differing in sodicity tolerance. *Plant and Soil* 93: 141-145.
- Sheekh-El, M.M. and H.H. Omar. 2002. Effect of high salt stress on growth and fatty acids content of the unicellular green algae *Chlorella vulgaris*. *American Journal Microbiology* 55: 181-191.
- Silveira, J.A.G., S.A.M. Araujo, J.P.M.S. Lima and R.A. Viegas. 2009. Roots and leaves display contrasting osmotic adjustment mechanisms in response to NaCl-salinity in *Atriplex nummularia*. *Experimental and Environmental Botany* 66: 1-8
- Steel, R.G.D., J.H. Torrie and D.A. Dicky. 1997. Principles and procedure of statistics-a biometrical approach, 3rd Ed. McGraw Hill Book international Co., Singapore.
- Storey, R., J. Gorham, M.C. Pitman, M.G. Hanson and D. Gage. 1993. Response of *Melanthra biflora* to salinity and water stress. *Journal of Experimental Botany* 44: 1551-1561.
- Sudhir, P. and S. D. S. Murthy. 2004. Effects of salt stress on basic processes of photosynthesis. *Photosynthetica* 42: 481-486.
- Syvetsen, J. P., L.S. Lee and J.W. Grosser. 2000. Limitations on growth and net gas exchange of diploid and tetraploid citrus rootstock cultivars grown at elevated CO₂. *Journal of the American Society for Horticultural Sciences* 125:228-34.
- Tyerman, S.D and I.M. Skerrett. 1999. Root ion channels and salinity. *Scientia Horticulturae* 78: 175-235
- Vasquez, E. A., E.P. Glenn, G.R. Gutenspergen, J.J. Brown and S.G. Nelson. 2006. Salt tolerance and osmotic adjustment of *Spartina alterniflora* (Poaceae) and the invasive halophyte of *Phragmites australis* (Poaceae) along a salinity gradient. *American Journal of Botany* 93:1784-1790.
- Yeo, A.R. and T.J. Flowers. 1984. Mechanisms of salinity resistance in rice and their role as physiological criteria in plant breeding. p. 151-170. In: Salinity Tolerance in Plants-Strategies for Crop Improvement. R.C. Staples and G.A. Toenniessen (eds.). John Wiley and Sons, New York, USA.
- Zhu, J.K. 2003. Regulation of ion homeostasis under salt stress. *Current Opinions in Plant Biology* 6:441-445.