Pak. J. Bot., 54(1): DOI: http://dx.doi.org/10.30848/PJB2022-1(30)

POTASSIUM DYNAMIC IN THE RHIZOSPHERE OF MAIZE (*ZEA MAYS* L.) GROWN UNDER INDUCED SALINE SODIC CONDITION

NABEEL RIZWAN[1], QUDRAT ULLAH KHAN[1] AND ASGHAR ALI KHAN[2]

[1]*Department of Soil Science, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan.*
[2]*Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan.*
[*]*Corresponding author's email: qudrat@gu.edu.pk*

Abstract

To study the fate of potassium in the maize rhizosphere under induced saline sodic conditions an experiment was conducted at Department of Soil Science, Gomal University, Dera Ismail Khan (Pakistan) during year 2019. In a factorial experiment six potassium levels i.e. 0, 45, 60, 75, 90 and 120 kg ha^{-1} and three NaCl concentrations viz. 60, 120 and 180 mM were investigated. Different soil and agronomic parameters were studied. The result showed that in the treatments where no potassium was applied the pH, electrical conductivity (EC) and Sodium Adsorption Ratio (SAR) was increased and potassium declined by increasing the NaCl to 180 mM. The increment of potassium has significantly reduced pH, EC and SAR and increased potassium in the soil. Comparing the uptake of potassium by shoot and root of maize it has showed greater uptake of potassium in the shoot as compared to the roots. However, the potassium levels significantly influenced the uptake of potassium under severe saline sodic conditions. The growth parameters including chlorophyll contents, plant height and root size was significantly influenced by application of potassium levels and high concentration of salts. The fresh and dry weight of shoot and root were also significantly influenced by the application of potassium levels and increasing salt concentration. It was evident that the fresh and dry shoot and roots tend to tolerate the salt content more effectively by increasing levels of potassium. From the research it is concluded that increment of potassium at higher level under induced salt condition may improve the soil properties and growth of crop.

Key words: Maize, Potassium, Salt stress, Uptake, Soil properties

Introduction

The problem of salinity is extensively due to changing climate especially in the dryland areas. Globally the agricultural productivity faces serious threats due to soil salinity (Wang *et al*., 2003). In Pakistan the soil of Indus plains have the inherent salinity problem due to soil formation and also the rivers, canal and its tributaries (Qureshi *et al*., 2008). The saline sodic soil in Pakistan is estimated to be 6.30 mha and mostly situated in these plains (Alam *et al*., 2000). Due to continuous and intensive use of surface irrigation under the Indus river plain the hydrological equilibrium has changed.

Maize (*Zea mays* L.) is an important crop grown throughout the world for its grains, oil and feed for the livestock. Also it is used as a raw material in the industries (Khatoon *et al*., 2010). Plant grown under saline condition are badly affecting the biochemical and physiological processes of plant, which ultimately reduce plant growth and development (Munns, 2002; Tester & Davenport, 2003). Apse & Blumwald (2002) reported adverse effect of salt stress causing direct injury to plant cells through the accumulation of toxic ions or by restricting the flow of water and nutrients into the plants. Under the environmental stress conditions the rate of photosynthesis is affected, which ultimately influence the growth and development of plants (Salisbary & Ross, 1992; Dubey, 1997; Taiz & Zeiger, 1998). A marked inhibition of photosynthesis was linked with the inhibition of vegetative growth in plants exposed to salinity (Fisarakis *et al*., 2001). Photosynthesis rate was decreased at high salinity and increased at low salinity, and stomatal conductance was decreased at high salinity and remained unchanged at low salinity (Parida *et al*., 2004).

Potassium fertilizer has been believed to played a vital function in reducing the toxic effects of salts on some biochemical and physiological traits (Dawood *et al*., 2014). The ionic absorption could not be reversed even if some of the nutrients as N, P and K are present in a greater quantity (Katerji *et al*., 2000). With increasing salinity, the response of young maize plants to nutrient applications gradually decrease. According to Hussain *et al*., (2013) potassium and sodium possesses positive charge and are found together in soil. Under salinity stress, they employ both synergizing or antagonizing affects during reciprocal absorption and translocation. The adverse effects of increasing salt concentration may be lessened by supplementary K^+ (Kavitha *et al*., 2012). Keeping in view importance of potassium fertilizer under saline sodic condition the current study was designed with maize a test crop.

Material and Methods

A pots experiment was conducted to study the behavior of potassium in maize rhizosphere grown under saline-sodic conditions. In a randomized complete design, factorial experiment was conducted at Department of Soil Science, Gomal University, Dera Ismail Khan. Six level of potassium and three levels of salinity at variable concentration were used. Potassium levels used were 0, 45, 60, 75, 90 and 105 kg ha^{-1} while three salinity levels included 60, 120 and 180 mM NaCl was used.

The soil used for the experiment was collected from the site of rive Indus, Khyber Pakhtunkawa providence of Pakistan. A composite soil sample was collected prior to filling of pots for physicochemical properties analysis (Table 1). Maize variety SG-2002 was grown and seven healthy seeds were sown in each pot on 2nd week of February 2019. The starter dose of nitrogen and phosphorus were applied at the rate of 60 and 80 kg ha^{-1} respectively to all treatments.

Three different concentrations of salinity and sodicity i.e 60, 120 and 180 mM were created through sodium chloride (NaCl). After creating the NaCl levels the given samples were used to measure the EC and SAR (Table 2).

Analysis of the soil samples were carried out to determine the soil properties viz. pH and EC using pH-meter and EC meter respectively in a 1:1 soil: water solution (Ryan *et al*., 2001). The flame photometric analysis of Sodium Adsorption Ratio (SAR) was carried out using the procedure given by Richards (1954), extractable cations K, Ca, Mg and Na in 1 N ammonium acetate solution was determined by using the procedures given by Bayraklı (1987).

Table 1. Physicochemical properties of soil before experiment.

Properties	Soil
pH	7.1
EC (ds m^{-1})	1.3
Bulk density	1.22
Organic matter %	0.72
Total nitrogen %	0.036
Na ($mmol_c$ L^{-1})	20.55
Ca ($mmol_c$ L^{-1})	16.31
Mg ($mmol_c$ L^{-1})	14.22
SAR	4.6
K (mg kg^{-1})	116.2
Phosphorus (mg kg^{-1})	7.51
Caly %	22
Silt %	59
Sand %	19
Texture class	Silt loam

Table 2. EC and SAR of NaCl concentrations.

NaCl Concentrations	EC (ds m^{-1})	SAR
60 Mm	3.13	10.4
120 Mm	7.00	16.2
180 Mm	10.60	21.8

Different plant parameters measured during the experiment were chlorophyll content, plant height, root length, fresh and dry shoot and root weight. Chlorophyll content in the leaves of maize plant using the SPAD – 502 meter (Dwyer *et al*., 1991.). Plant height and root length were measured in centimeter using meter rod and the means were averaged. Fresh weight of shoot and root (g) after the harvest of crop was determined using the electrical balance. While the dry weight of shoot and root in gram was calculated after drying of plants in oven at 70ºC for 48 hours.

Statistical analysis was carried out using the statistical package Statistix 8.1. using the procedure given by Steel *et al*., (1997). The treatment means were compared using the least significance difference (LSD) at 5% level of significance.

Results

a. Soil pH: Soil reaction is an important chemical property which has great influence on other soil characteristics and plant parameters. Different potassium levels and NaCl concentrations significantly affected soil pH. The soil pH determined after the harvest of crop showed significant rise in soil pH due to application of salt, the maximum pH was recorded 10.5 where 180 mM NaCl was applied but no potassium was added. While it was evident that the use of potassium in the soil tend to buffer the rise in soil pH. The lowest soil pH was observed 6.9 at 75 and 90 kg K ha^{-1} for 60 mM NaCl (Table 3).

b. Soil EC: Soil electrical conductivity is an important parameter indicating the accumulation of salts in soil. By the applied concentration of salts, soil EC was increased significantly, however the use of potassium in conjugation with the salts have lowered the effect of induced salts. The highest soil EC was recorded 12.6 dS m^{-1} in the pots recieving 180 mM salt concentration without any potassium was applied. The EC was reduced with increasing the level of Potassium in the three salt levels. The lowest EC was showed 2.9 dS m^{-1} at 75 kg K ha^{-1} for 60 mM NaCl (Table 3).

c. Sodium adsorption ratio (SAR): Exchangeable sodium in the soil is measured through the Sodium adsorption ratio, which describes the relation between exchangeable and soluble salts. Potassium fertilizer have shown significant effect on SAR due to interaction between potassium and sodium in soil. Maximum SAR was observed for 180 mM at control level of potassium as 18.5. Lowest sodium adsorption ratio was found 8.3 at 90 kg K ha^{-1} for 60 mM NaCl (Table 3). The variation in the SAR value may be due induced salt stress by adding NaCl.

d. Soil potassium: Potassium retention in soil was affected positively by different potassium levels and NaCl concentrations. Maximum potassium in soil was measured 212.6 mg kg^{-1} where 90 kg K ha^{-1} was applied and the induced salt stress was 60Mm. The potassium content varied due to release of non – exchangeable K by the addition of NaCl. The least potassium in soil was found 95.1 mg kg^{-1} in control treatment, where maximum NaCl salts was applied (Table 3).

e. Potassium uptake by shoot and root: The uptake of potassium by plants under high external Na mostly face strong competition and the uptake of K is hindered. This usually result in deficiency of K in plants under high saline sodic conditions, which ultimately result in impairment of plant growth. In the current study the uptake by shoot was comparatively higher than the roots of maize crop. However the application of potassium fertilizers showed great influence on both root and shoot of maize. Maximum and potassium uptake by shoot was observed 83.3 mg kg^{-1} at 105 kg K ha^{-1} for 60 mM while lowest uptake of potassium in shoot was observed 42 mg kg^{-1} at control level of potassium for 180 mM NaCl (Fig. 1). However, the differences between different potassium levels and NaCl concentrations could not reach to a level of significance in respect of potassium uptake by root. Maximum uptake of potassium was recorded 26.4 mg kg^{-1} at 90 kg K ha^{-1} for 60 mM. Lowest uptake of potassium in root was found 17.1 mg kg^{-1} in control level of potassium for 180 mM NaCl (Fig. 1).

f. Chlorophyll contents: Chlorophyll content was determined by SPAD showing significant decline in its value due to increasing salt concentration. The addition of potassium at an increasing level showed different chlorophyll content of maize leaves. Maximum SPAD value of chlorophyll was noticed 38 µg m^2 by the unite use of 75 kg K ha^{-1} and 60 mM NaCl while lowest SPAD value of chlorophyll was found 13.2 µg m^2 at 105 kg K ha^{-1} for 180 mM NaCl (Table 4).

g. Plant height: The application of salt concentrations and potassium levels showed significant effect on the plant stature of maize. But, as plant height was the genetic trait of a veriety so it become difficult to draw the conclusion that it was adversely affected by the salt stress or increased by the potassium levels from the result of current study. The results however showed maximum plant height 131.9 cm at 90 kg K ha^{-1} for 180 mM NaCl while lowest plant height was recorded 89.3 cm at 75 kg K $ha^{-1}$for 120 mM NaCl (Table 4).

h. Root length: Study of nutrients and effect of salts on the plant may be determined from the growth of its root in the rhizosphere. In the current study, induced salt conditions hindered the root length. The stunted growth of root may be due to reduced water uptake by the plants under higher salt levels. However, by the addition of potassium levels the increase in the root length may be attributed to support in water uptake and had resulted in significant elongation of roots. The maximum root length was 27.2 cm at 105 kg K ha^{-1} for 60 mM while lowest root length was recorded 10.4 cm where highest salinity concentration of 180 mM NaCl was applied without potassium fertilizer (Table 4).

i. Fresh weight of shoot: The fresh weight of shoot wasalso significantly influenced through potassium levels and NaCl concentrations. Maximum fresh weight of shoot was observed 145.9 gm at 105 kg K ha^{-1} for 60 mM. Lowest weight of shoot was observed 55.3 gm at 45 kg K ha^{-1} with stress of 60 mM NaCl (Table 5).

j. Dry shoot weight: The results pertaining to the weight of dried shoots revealed significant corelation between the potassium levels and NaCl concentrations. The results showed highest dry weight of 60.9 g by the application of the highest potassium level i.e. 105 kg K ha^{-1} under the applied salt concentration of 120 mM, while lowest dry weight of shoot was observed at higher concentration of NaCl 180 mM at 45 kg K ha^{-1} which was 18 g (Table 5).

k. Root fresh weight: The data of root fresh weight was also significant through the addition of potassium under salt stress condition. The fresh weight of root was recorded maximum 19.1 g at maximum concentration of K, which was 105 kg K ha^{-1} with the salt concentration of 60 mM NaCl and the minimum root fresh weight was found 6.6 g at 45 kg K ha^{-1} for 180 mM (Table 5).

l. Root dry weight: Significant effect was found on dry weight of root through different potassium levels and NaCl concentration. Maximum dry weight of root was observed 9.9 gm at 105 kg K ha^{-1} for 60 mM NaCl while minimum root dry weight was found 1.9 gm at 45 kg K ha^{-1} for higher level of NaCl 180 mM (Table 5).

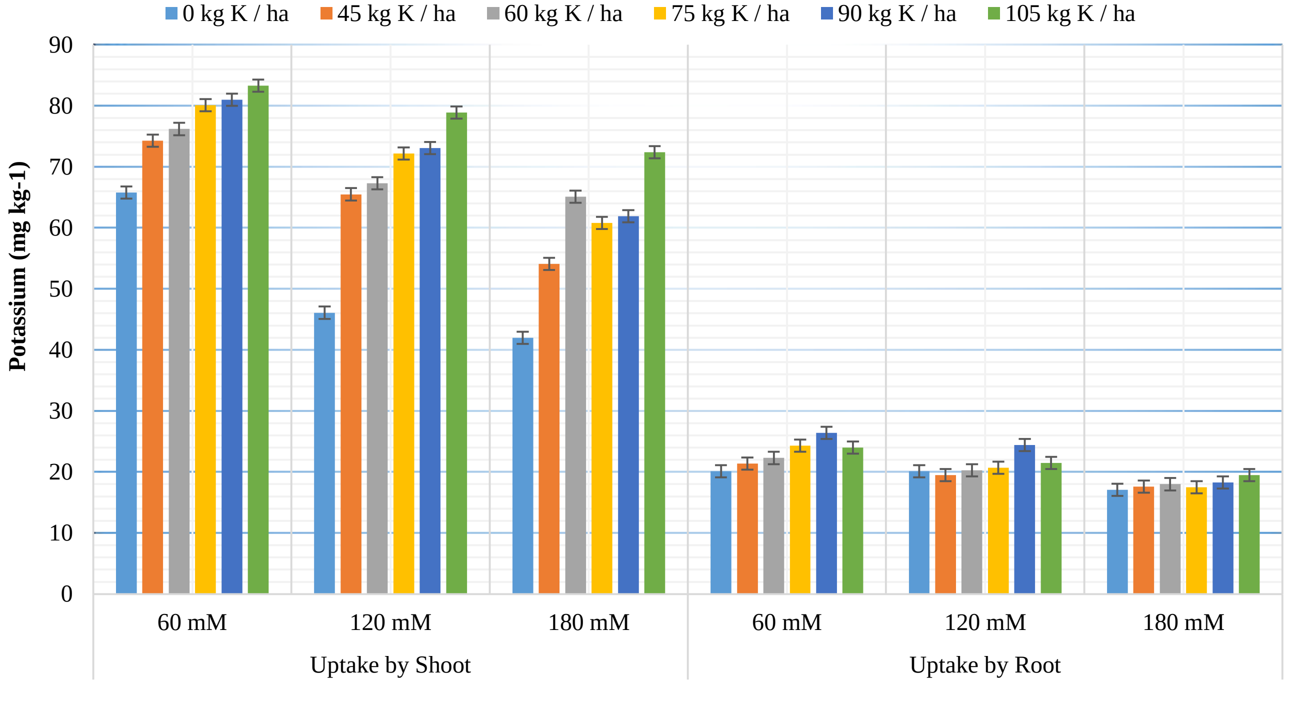

Fig. 1. Potassium uptake by shoot and root of crop as influenced by potassium level under induced salt concentration.

Table 3. Soil properties as affected by different levels of potassium under saline-sodic condition.

Variables	Treatments (K kg ha^{-1})	60 mM NaCl	120 mM NaCl	180 mM NaCl
Soil pH	Control	7.7 efgh	9.7 b	10.5a
	45	8.0 efg	8.3 de	10.5 a
	60	7.7 efgh	8.8 cd	9.0c
	75	6.9 j	7.0 ij	9.2 bc
	90	6.9 j	7.1 hij	7.6 fghi
	105	7.2 hij	7.4 ghij	8.2 def
Soil EC (dS m^{-1})	Control	4.9 def	10.1 b	12.6 a
	45	6.0 cde	7.6 c	10.1 b
	60	3.7 fg	7.4 c	10.2 b
	75	2.9 g	4.5 efg	6.7 cd
	90	4.1 fg	5.4 def	7.3 c
	105	4.1 fg	5.2 def	7.8 c
SAR	Control	14.4 bc	18.1 a	18.5 a
	45	10.0 ghi	13.5 cde	18.0 a
	60	10.1 ghi	11.5 efg	15.7 b
	75	9.1 hi	10.2 ghi	12.3 def
	90	8.3 i	11.6 efg	13.9 bcd
	105	8.8 hi	10.4 fgh	14.1 bcd
Potassium (mg kg^{-1})	Control	100.6 klm	95.1 lm	77.2 m
	45	116.4 jkl	112.4 jkl	125.6 hijk
	60	145.5 fghi	132.6 ghij	119.9 ijkl
	75	175.8 bcde	150.3 efgh	154.6 defg
	90	212.6a	188.8 abc	177.5 bcd
	105	173.6 bcde	197.6 ab	162.6 cdef

Table 4. Growth parameters as affected by different levels of potassium under saline-sodic condition.

Variables	Treatments (K kg ha^{-1})	60 mM NaCl	120 mM NaCl	180 mM NaCl
Chlorophyll Contents	Control	26.3 cd	22.3 e	16.2 gh
	45	23.4 de	20.3 ef	16.9 fg
	60	30.9 b	28.0 bc	20.3 ef
	75	38.0 a	30.2 b	26.3 cd
	90	22.4 e	18.2 fg	15.2 gh
	105	17.2 fg	15.5 gh	13.2 h
Plant height (cm)	Control	103.5 bcde	93.3 de	98.7 cde
	45	110.4 abcde	103.3 bcde	101.6 bcde
	60	120.4 abc	122.1 abc	111.2 abcde
	75	124.6 abc	89.3 e	120.4 abc
	90	127.5 ab	122.5 abc	131.9 a
	105	118.2 abcd	121.8 abc	110.8 abcde
Root length (cm)	Control	15.2 efghi	10.7 i	10.4 i
	45	20.2 cd	19.0 cdef	13.3 ghi
	60	26.3 a	19.7 cdef	14.6 fghi
	75	25.3 ab	15.7 defgh	12.6 hi
	90	22.7 abc	20.8 bc	18.3 cdef
	105	27.2 a	20.0 cde	18.0 cdefg

Table 5. Fresh and dry weight of shoot and root as affected by different levels of potassium under saline-sodic condition.

Variables	Treatments (K kg ha^{-1})	60 mM NaCl	120 mM NaCl	180 mM NaCl
Fresh weight of shoot (gm)	Control	69.5 hi	79.2 gh	90.7 efg
	45	55.3 i	82.5 gh	88.4 fgh
	60	101.5 def	81.3 gh	91.0 efg
	75	88.9 fgh	108.6 cde	84.0 fgh
	90	102.8 def	88.9 fg	123.9 bc
	105	145.9 a	115.4 bcd	128.8 ab
Dry weight of shoot (gm)	Control	18.8 h	20.6 h	23.8 fgh
	45	25.9 fgh	22.1 gh	18.0 h
	60	29.4 efgh	35.4 def	33.9 defg
	75	35.1 def	24.3 fgh	34.5 def
	90	49.4 abc	40.3 cde	46.1 bcd
	105	55.4 ab	60.9 a	48.9 bc
Fresh weight of root (gm)	Control	12.7 def	10.6 fgh	8.8 hij
	45	9.7 ghi	8.0 ij	6.6 j
	60	15.9 bc	13.4 cde	9.4 hi
	75	13.3 de	12.7 def	8.2 hij
	90	18.0 ab	14.8 cd	11.9 efg
	105	19.1 a	17.6 ab	13.4 cde
Dry weight of root (gm)	Control	5.9 def	4.3 gh	4.2 gh
	45	4.3 gh	3.1 hi	1.9 i
	60	7.1 cd	6.6 cde	4.0 gh
	75	6.5 cde	6.0 def	4.6 fgh
	90	8.9 ab	7.3 cd	5.1 efg
	105	9.9 a	7.8 bc	6.9 cd

Discussion

The soil properties including pH, EC and SAR were significantly increased with the increase in the concentration NaCl to develop salt stress conditions. Different levels of potassium have shown to reduce the pH, EC and SAR. This may be attributed to antagonistic effect of K^+ on Na^+ and dominance effect of Na^+ which was responsible for increasing pH, EC and SAR at higher NaCl concentration. Our result of study were in accordance with Mostafizur *et al*., (2018) who found that NaCl showed toxic effect on the physicochemical properties of pot soil. Increase in soil pH by increase salinity levels have been reported by Fontes & Ronchi (2002). The increase in EC of normal soil by the addition of salinity levels was reported by (Saleem *et al*., 1993, Abid, 2000) and considered that due to non – leaching of salts from the pots resulted in buildup of salts and greater EC value. Abid *et al*., (2001) stated that SAR increased with increase in the salt stress and the water intake rate was decreased due to clog of soil pores. In high salinity condition, the application of K fertilizer decreased Na^+ and resulted lower SAR value. Higher salinity levels the Na^+ suppressed K^+ uptake from saline soil and resulted high concentration of K^+ in saline soil (Sajid *et al*., 2014). Gul *et al*., (2015) demonstrated that inducing the salt stress by the application of NaCl might increase the potassium in soil solution as the non-exchangeable K, released from the soil minerals. Abbasi *et al*., (2014) reported that the unfavourable effect of salt stress is reduced by the application of Potassium fertilizer.

Maximum uptake of K by shoot and root was observed by higher rate of K applied under lowest concentration of NaCl due to the presence of less Na^+ ions, K^+ ions remain dominant which improved uptake by shoot and root. Higher NaCl concentration in solution resulted in decreased K uptake and translocation from root to shoot, regardless of K level. The toxic and higher NaCl was suppressed by high level of K in solution and K uptake and translocation from root to shoot was increased (Ghazi, 2000). Reduction of potassium concentration in whole plant or in tissue under salt stress condition was reported by many researchers (Abbasi *et al*., 2015; Wang & Han, 2007; Wu *et al*., 2009).

Chlorophyll is considered as the most important parameter because of plant growth and development depends upon photosynthesis and easily affected by environmental stresses (Salisbary & Rose, 1992; Dubey, 1997; Taiz & Zeiger, 1998). In this study the chlorophyll contents in maize leaf was reduced under higher NaCl concentrations. Heidari (2012) reported that the chlorophyll content in salt sensitive plants was reduced, while in the salt tolerant was enhanced.

The agronomic parameters including plant height and root length were significantly influenced by salt stress. Werner & Finkelstein (1995) recorded inhibited growth of root and the elongation of shoot due to toxic effect and restrained water uptake by plants. Also, the nutrients uptake is restricted (Neumann, 1995).

The applied salt concentration showed greater influence on the fresh and dry weight of both shoot and root of plant. It was noticed by the addition of higher levels of potassium under salt concentration of 60 mM NaCl, the ion toxicity was enhanced and due to greater Na^+ ions metabolic and nutritional characteristics were imbalanced and resulted in reduction of both shoot and root of maize. Fresh weights and osmotic effects were effected by salt stress leading to growth reduction (Shannon *et al*., 2000). The dry weight of plant was reduced through high salt concentration and this effect might be due to the specific ion effect of Na^+ and Cl^- together with osmotic effect (Turan *et al*., 2007; Tafouo *et al*., 2010). Usman *et al*., (2012) reported a reduction in root fresh weight for 20 mM to 40 mM compared to the control. Root dry weight of plant was decreased due to the reduction in nutrients uptake and plant water absorption under high salt stress condition (Kaya *et al*., 2001), this reduction in morphological parameters was due to the plant suffering in it metabolic activities which clearly indicated the stress in plants.

Conclusion

It may be concluded from result of this study that applied concentration of 60 mM salts along with higher level of potassium reduced toxic effect on soil and agronomic parameters as compared the lower level of potassium and control (without potassium). Increasing soil pH, EC and SAR was measured where 180 mM NaCl was applied, which had developed higher Na^+ ions and resulted in reduced nutrient uptake and water availability to plants by clogging pores. The increasing concentration of potassium fertilizer mitigated the antagonistic effect of higher salinity concentrations imposed on maize plant and resulted in better response in term of nutrients uptake and agronomic parameters.

References

Abbasi, G.H., J. Akhtar, R. Ahmad, M. Jamil, M. Anwar-Ul-Haq, S. Ali and M. Ijaz. 2015. Potassium application mitigates salt stress differentially at different growth stages in tolerant and sensitive maize hybrids. *Plant Growth Reg.,* 76(1): 111-125.

Abbasi, G.H., J. Akhtar, M. Anwar-ul-Haq, S. Ali, Z. Chen and W. Malik. 2014. Exogenous Potassium differentially mitigates salt stress in tolerant and sensitive maize hybrids. *Pak. J. Bot*., 46(1): 135-146.

Abid, M. 2000. Response of soils and crops to brackish irrigation waters, Ph.D. Thesis, University of Agriculture, Faisalabald, Pakistan.

Abid, M., Q. Abdul, A.D. Altaf and A.W. Rana. 2001. Effect of salinity and SAR Of irrigation water on yield, physiological growth parameters of Maize (*Zea Mays* L.) and properties of the soil. *J. Res. Sci.*, 12(1): 26-33.

Alam, S.M., A. Ansari and M.A. Khan. 2000. Nuclear Institute of Agriculture, Tando Jam, available at http://www. pakistaneconomist.com/issue2000/ issue19&20/i&e3.htm.

Apse, M.P. and E. Blumwald. 2002. Engineering salt tolerance in plants. *Curr. Opin. Biotech.,* 2: 146-150.

Bayraklı, F. 1987. Soil and Plant Analysis. The Publications Agricultural, Faculty of Ondokuz Mayıs University. No.17. Samsun, Turkey.

Dawood, M.T., Abdelhamid and U. Schmidhalter. 2014. Potassium fertilizer enhances the salt tolerance of common bean (*Phaseolus vulgaris* L.) Mona G. *J. Hort. Sci. Biotech.,* 89(2): 185-192.

Dubey, R.S. 1997. Photosynthesis in plants under stressful conditions. In: *Handbook of photosynthesis,* (Ed.: M. Pessarakli). Marcel Dekker, New York. pp. 859-975.

Dwyer, L.M., M. Tollenaar and L. Houwing, 1991. Anon-destructive method to monitor leaf greenness Amin corn. *Can. J. Plant Sci*., 71: 505-509.

Fisarakis, I., K. Chartzoulakis and D. Stavrakas. 2001. Response of sultana vines (*V. vinifera* L.) on six rootstocks to NaCl salinity exposure and recovery. *Agric. Water Manag.,* 51: 13-27.

Fontes P.C.R. and C.P. Ronchi. 2002. Critical values of nitrogen indices in tomato plants grown in soil and nutrient solution determined by different statistical procedures. *Pesquisa Agropec. Brasil*., 37: 1421-1429.

Ghazi N.A.K. 2000. Growth, sodium, and potassium uptake and translocation in salt stressed tomato. *J. Plant Nutr.,* 23(3): 369-379.

Gul, M., A. Wakeel, M. Saqib and A. Wahid. 2015. Effect of NaCl-induced saline sodicity on the interpretation of soil potassium dynamics. *Arch. Agron Soil Sci.,* 62(4): 523-532.

Heidari, M. 2012. Effects of salinity stress on growth, chlorophyll content and osmotic components of two basil (*Ocimum basilicum* L.) genotypes. *Afr. J. Biotech*., 11(2): 379-384.

Hussain, Z., R. Khattak, M. Irshad and A. Eneji. 2013. Ameliorative effect of potassium sulphate on the growth and chemical composition of wheat (*Triticum aestivum* L.) in salt affected soils. *J. Soil Sci. Plant Nutr.,* 13: 401-415.

Katerji, N., J.W. Van Hoorn, A. Hamdy and M. Mastrorilli. 2000. Salt tolerance classification of crops according to soil salinity and to water stress day index. *Agric. Water Manag.,* 43: 99-109.

Kavitha, P.G., A.J. Miller, M.K. Mathew and F.J.M. Maathuis. 2012. Rice cultivars with differing salt tolerance contains similar cation channels in their rot cells. *J. Exp. Bot.,* 63: 3289 -3296.

Kaya, C., H. Kirnak and H. Higgs. 2001. Enhancement of growth and normal growth parameters by foliar application of potassium and phosphorus in tomato cultivars grown at high (NaCl) salinity. *J. Plant Nutr.,* 24: 357-367.

Khatoon, T., K. Hussain, A. Majeed, K. Nawaz and M.F. Nisar. 2010. Morphological variations in maize (*Zea mays* L.) under different levels of NaCl at germinating stage. *World Appl. Sci. J.,* 8(10): 1294-1297.

Mostafizur, M.R., H. Mobarok, F.B.H. Kaniz, M.S. Tajuddin, S. Mashura, M. Rasheduzzaman, M. H. Anwar, A.K.M. Mahbubul and M. Khabir Uddin. 2018. Effects of NaCl-salinity on tomato (*Lycopersicon, esculentum* Mill.) plants in a pot experiment, *Open Agric.,* 3: 578-585.

Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell Environ.,* 25: 239-250.

Neumann, P.M. 1995. Inhibition of root growth by salinity stress: Toxicity or an adaptive biophysical response. In: (Eds.): Baluska, F., M. Ciamporova, O. Gasparikova, P.W. Barlow. Structure and Function of Roots. The Netherlands: Kluwer Academic Publishers. pp. 299-304.

Parida, A.K., A.B. Das and B. Mittra. 2004. Effects of salt on growth, ion accumulation, photosynthesis and leaf anatomy of the mangrove (*Bruguiera parviflora*. *Trees*. 18: 167-174. DOI:10.1007/s00468-003-0293-8.

Qureshi, A.S., P.G. McCornick, M. Qadir and Z. Aslam. 2008. Managing salinity and waterlogging in the Indus Basin of Pakistan. *Agric. Water Manag.,* 95: 1-10.

Richards, L.A. 1954 Diagnosis and Improvement of Saline and Alkaline soils. USDA Agric. Handbook 60. Washington DC: 158.

Ryan, J., G. Estefan and A. Rashid. 2001. Soil and Plant Analysis. Laboratory Manual. Int. Centre Agric. Res. Dry Areas. Aleppo, Syria.

Sajid, H., M. Anwar-ul-Haq, A. Zeeshan, M. Afzal, S. Imran and H. Shahbaz. 2014. Physiological and ionic expressions of different hybrids of maize (*Zea mays* L.) under different salinity levels. *Uni. J. Agric. Res.,* 2(5): 168-173.

Saleem, Z., M. Rashid and M. Ishaq. 1993. Growing crops with brackish water without affecting the soil health, *Pak. J. Soil Sci.,* 9: 41-46.

Salisbury, F.B. and C.W. Ross. 1992. *Plant Physiology,* (fourth edition ed.), Wadsworth, Belmont CA.

Shannon, M.C., C.M. Grieve, S.M. Lesch and J.H. Draper. 2000. Analysis of salt tolerance in nine leafy vegetables irrigated with saline drainage water. *J. Amer. Soc. Hort. Sci*., 125: 658-664.

Steel, R.G.D., J.H. Torrie and D. Dickey. 1997. *Principles and Procedure of Statistics. A Biometrical Approach* 3rd Ed. McGraw Hill Book Co. Inc., New York. pp. 352-358.

Taiz, L. and E. Zeiger. 1998. *Plant Physiology,* 2nd edn, Sinauer Associates Publishers, Sunderland, Massachusetts.

Tafouo, V.D., O.F. Wamba, E. Youmbi G.V. Nono and A. Akoa. 2010. Growth, yield, water status, and ionic distribution response of three bambara groundnut landraces (*Vigna subterranean* (L.) Verdic.) grown under saline conditions. *Int. J. Bot*., 6: 53-58.

Tester, M. and R. Devenport. 2003. Na^+ Tolerance and Na^+ Transport in Higher Plants. *Annals Bot.*, 91(5): 503-527.

Turan, M.A., N. Turkmen and N. Taban. 2007. Effect of NaCl on stomatal resistance and proline, chlorophyll, Na, Cl, and K concentrations of lentil plants. *J. Agron*., 6: 378-381.

Usman, M., A.U. Haq, T. Ahsan, S. Amjad, Z. Riast and M. Umar 2012. Effect of NaCl on morphological attributes of maize (*Zea mays* L.). *Word J. Agric. Sci.,* 8(4): 381-384.

Wang, W., B. Vinocur and A. Altman. 2003. Plant responses to drought, salinity and extreme temperature: towards genetic engineering for stress tolerance. *Planta,* 218: 1-14.

Wang, X.S. and J.G. Han. 2007. Effects of NaCl and silicon on ion distribution in the roots, shoots and leaves of two alfalfa cultivars with different slat tolerance. *Soil Sci. Plant Nutr*., 53: 278-285.

Werner, J.E. and R.R. Finkelstein. 1995. Arabidopsis mutants with reduced response to NaCl and osmotic stress. *Physiol Plant.,* 93(4): 659-666.

Wu, Y.S., Y.B. Hu and G.H. Xu. 2009. Interactive effects of potassium and sodium on root growth and expression of K/Na transporter genes in rice. *Plant Growth Reg.,* 57(3): 271-280.

(Received for publication 23 May 2020)