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Full Length Research Paper

Effect of salt stress on growth and ion distribution and accumulation in shoot and root of maize plant

Murat Ali Turan[1]*, Abdelkarim Hassan Awad Elkarim[2], Nilgün Taban[3] and Suleyman Taban[4]

[1]Department of Soil Science, Faculty of Agriculture, Uludag University, 16059 Bursa, Turkey.
[2]Department of Soil Science, Faculty of Agriculture, Khartoum University, 13314 Shambat-Khartoum, Sudan.
[3]Agricultural Engineer, Kastamonu, Turkey.
[4]Faculty of Arts and Sciences, Kastamonu University, 37100 Kastamonu, Turkey.

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In this study, effect of applied NaCl on shoot and root growth and distribution and accumulation of Na, Cl, N, P, K, Ca, Fe, Zn and Mn in shoot and root of the maize plant (*Zea mays* L. cv: RX 947) was investigated. The experiment was arranged in a completely randomized design (CRD) under the greenhouse condition. Sodium chloride was applied at the rates of 0, 25, 50, 75 and 100 mM NaCl. Shoot and root growth of the maize plants was inhibited by salinity and NaCl significantly decreased shoot and root dry mass of maize plants. Sodium chloride caused to increase Na, Cl, P, Zn and Mn concentrations in the shoot and root. Applied NaCl decreased N, Ca and Fe concentrations in the shoot, increased N, Ca and Fe concentrations in the root. Sodium, Cl, N, P, Ca, Fe, Zn and Mn accumulated in the root in according to applied NaCl.

Key words: Maize, salt stress, shoots and root growth, sodium, chlorine.

INTRODUCTION

Salinity, due to over-accumulation of NaCl, is usually of great concern and the most injurious factor in arid and semi arid regions. Saline soils are widespread on Earth, and their genesis may be natural or accelerated by the extension of irrigated agriculture, the intensive use of water resources combined with high evaporation rates and human activity (Lambers, 2003; Arzani, 2008). Despite the essentiality of chloride as a micronutrient for all higher plants and of sodium as mineral nutrient for many halophytes and some C_4 species, salt accumulation may convert agricultural areas in unfavorable environments, reduce local biodiversity, limit growth and reproduction of plants, and may lead to toxicity in non-salt-tolerant plants, known as glycophytes (Marschner, 1995). Most of the cultivated plants are sensitive to salt-stress, in which NaCl - salinity causes reduction in vegetative growth, the rate of photosynthesis (Erdal et al., 2000, Neto et al., 2004) and also water availability and imbalance in nutrient uptake by plants (Pessarakli and Tucker, 1988) with inhibition in seed germination due to ionic disturbance, osmotic and toxic effects (Dell'aquilla, 2000, Türkmen et al., 2002).

Soil salinity is shown to increase P, Mn and Zn and decrease K and Fe (Turan et al., 2007a) concentrations of plants. Shoots are generally more sensitive to cation disturbances than roots and there are great differences among plant species in the ability to prevent or tolerate the excess salt concentrations (Jeschke, 1982; Munns, 1993). In the current study, effect of NaCl on shoot and root growth, distribution and accumulation of Na, Cl, N, P, K, Ca, Fe, Zn and Mn in shoot and root of the maize plant was studied.

MATERIALS AND METHODS

Soil material

The experimental soil taken from Aridisol great soil group was non-calcareous (0.58 % $CaCO_3$), clay in texture, slightly alkaline (pH: 7.42 and EC: 0.148 dS m^{-1}; both in 1:2.5 water extract). The soil sample had 82.9 mg kg^{-1} exchangeable Na and water extractable Cl was 9.37 mg kg^{-1}.

*Corresponding author. E-mail: maturan@uludag.edu.tr.

Table 1. Effect of NaCl treatments on dry weights (g pot^{-1}) of shoot and root of the maize plants.

NaCl, mM	Shoot	Root	Shoot/Root
0	26.18 ± 2.15a	12.18 ± 1.65a	2.15
25	24.23 ± 1.98a	10.33 ± 1.32ab	2.35
50	20.12 ± 1.76b	10.01 ± 0.95b	2.01
75	15.19 ± 1.12c	8.75 ± 0.78c	1.74
100	12.12 ± 0.98d	6.48 ± 0.34d	1.87
Treatments	**	**	

** Significant at P<0.01 level. Means followed by the same letter in column are not significantly different (Duncan's multiple range test, P<0.01).

Pot experiment

The experiment was conducted under greenhouse conditions (humidity 65 - 75%, air temperature 25 - 30°C and neutral light intensity 340 - 450 µmol m^{-2} s^{-1}) in Ankara-Turkey. The soil (3000 g) was placed into pots and was salinised with NaCl at the rates of 0, 25, 50, 75 and 100 mM NaCl. For basal fertilizers, 100 mg N kg^{-1} as ammonium nitrate and 80 mg P kg^{-1} as triple super phosphate were applied to the pots. Five maize (*Zea mays* L. CV: RX947) seeds were sown into each pot which were thinned to three after emergence. Plants were harvested six weeks after germination and divided into shoot and root. Dry weight measurements of all plant samples were taken after being washed with distilled water. The shoot:root ratio was estimated.

Chemical analysis

After grinding, all plant samples were digested with HNO_3:$HClO_4$ acid mixture (4:1) in order to determine P, K, Ca, Na, Fe, Zn and Mn in the shoots and roots (Celik and Katkat, 2009). Nitrogen was determined by Kjeldahl digestion method according to Bremner (1965). Phosphorus was determined by the vanadomolybdate-phosphoric method with Shimadzu UV 1208 model spectro photometry describing by Kacar and İnal (2008). Na, K and Ca were determined by using Eppendorf Elex 6361 model flame photometry describing by Miller (1998). Chloride was analyzed by precipitation as AgCl and titration according to Johnson and Ulrich (1959). Fe, Zn and Mn were determined by atomic absorption spectrometry (Hanlon, 1998) (Philips model 9200x, Pye Unicam Ltd. GB).

Statistical analysis

The pot experiment was arranged in a completely randomized design with five salt concentrations and four replicates. Analysis of variance of data for all parameters was computed using MINITAB computer package (Minitab Release 10.51). MSTAT-C package program (Version 3.00) was used to compare treatment means by Duncan's Multiple Range Test.

RESULTS

Shoot and root dry weights of maize plants

Applied NaCl inhibited the growth of maize plant and caused to decrease both shoot and root dry weights (Table 1). Shoot and root growth of maize were negatively correlated to the concentration of NaCl (p<0.01). Maize plants grown at the low levels of NaCl (0 and 25 mM) reached relatively higher dry weights and did not imply toxicity symptoms, however, the growth was significantly reduced at higher levels of salinity (50, 75 and 100 mM) indicating the symptoms of salt toxicity as growth depression.

The concentrations of NaCl that significantly reduced shoot and root dry weights were 50, 75 and 100 mM by 23.14, 41.97 and 53.71% for shoots and by 17.81, 28.16 and 46.79% for roots, respectively, in comparison to the control. The shoot: root ratio was found to decline with increasing salinity (Table 1).

Ion concentrations and distribution

Concentrations of Na and Cl ions significantly increased in parallel to amount of NaCl (p<0.01) (Table 2). NaCl treatments caused to decrease K concentrations and K/Na ratio in shoot and root of maize plants (Table 2). The increasing salinity significantly decreased nitrogen and iron concentrations in the shoots (p<0.05) while displaying an increase in the roots (p<0.01) (Tables 3 and 4). The amount of phosphorus, zinc and manganese concentrations in the shoots and roots increased with salinity (Tables 3 and 4). On the contrary potassium concentrations in maize plant shoots and roots were significantly decreased with increasing salinity (p<0.01) (Table 2). The Ca con-centration in the roots increased with NaCl application whilst Ca declined in the shoots (p<0.01) (Table 3).

DISCUSSION

Shoot and root dry weights of maize plants

Data analyses showed a significant reduction on growth of maize plants with increasing NaCl. Salinity affects both water absorption and biochemical processes resulting in reduction of plant growth (Parida and Das, 2005) and a decline in the rates of net photosynthesis significantly

Table 2. Effects of NaCl treatments on sodium, chloride and potassium concentrations and K/Na ratio in shoot and root of the maize plants.

NaCl mM	Na, g kg^{-1}		Cl, g kg^{-1}		K, g kg^{-1}		K/Na ratio	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
0	0.32±0.02a	1.03±0.09a	1.86±0.96a	2.53±0.23a	27.17±2.62a	19.03±1.69a	84.91	18.48
25	0.88±0.03b	4.76±1.13b	12.61±2.65b	20.96±2.93b	21.03±2.96b	17.29±2.36b	23.90	3.63
50	1.13±0.12c	6.43±1.65b	22.56±3.23c	28.25±3.32c	18.66±1.56c	16.33±1.89b	16.51	2.54
75	2.96±0.16d	9.15±1.95c	35.53±4.13d	39.63±4.34d	18.27±1.87c	14.15±1.37c	6.17	1.55
100	4.46±1.03e	11.86±2.35c	44.16±5.75e	48.26±6.76e	17.93±1.35c	11.15±1.06d	4.02	0.94
Treat	**	**	**	**	**	**		

** Significant at P<0.01 level. Means followed by the same letter in column are not significantly different (Duncan's multiple range test, P<0.01).

Table 3. Effects of NaCl treatments on nitrogen, phosphorus and calcium concentrations in shoot and root of the maize plants.

NaCl, mM	N, g kg^{-1}		P, g kg^{-1}		Ca, g kg^{-1}	
	Shoot	Root	Shoot	Root	Shoot	Root
0	15.63±1.26a	9.16±0.68a	2.24±0.36a	1.66±0.79a	12.43±1.26a	3.23±0.96a
25	15.55±1.89a	10.83±1.98b	2.56±0.86a	2.67±0.96b	9.55±1.68b	3.96±0.46a
50	15.27±2.15a	11.77±2.09b	3.09±1.12b	4.09±1.58c	7.82±1.06c	5.96±1.03b
75	13.37±2.98b	13.13±2.16c	3.53±1.35b	5.93±1.79d	6.47±2.15d	7.67±1.26c
100	12.83±2.48b	14.96±3.75d	4.27±2.06c	6.87±2.02e	4.86±2.43e	9.33±1.35d
Treat.	**	**	**	**	**	**

** Significant at P<0.01 level. Means followed by the same letter in column are not significantly different (Duncan's multiple range test, P<0.01).

Table 4. Effects of NaCl treatments on iron, zinc and manganese concentrations in shoot and root of the maize plants.

NaCl mM	Fe, mg kg^{-1}		Zn, mg kg^{-1}		Mn, mg kg^{-1}	
	Shoot	Root	Shoot	Root	Shoot	Root
0	96.27±3.68a	77.21±2.34a	7.62±0.76a	16.71±0.56a	73.22±2.48a	71.34±1.06a
25	88.33±4.26b	120.83±3.56b	9.55±0.83b	21.05±0.48b	76.66±2.15a	91.34±0.98b
50	83.76±4.19bc	193.55±4.49c	10.89±1.06bc	27.63±1.12c	85.42±3.56b	166.67±1.13c
75	80.88±5.02c	231.48±5.13d	11.63±1.54c	32.85±1.34d	102.54±4.88c	168.15±1.78c
100	63.59±4.83d	243.69±6.10d	14.15±1.67d	37.46±1.88e	109.82±5.06c	248.49±4.35d
Treat	**	**	**	**	**	**

** Significant at P<0.01 level. Means followed by the same letter in column are not significantly different (Duncan's multiple range test P<0.01).

significantly by negatively affecting CO_2 assimilation and leads to decrease largely nutrient uptake, and finally growth of plants is getting reduce (Lauchli, 1984; Seeman and Sharkey, 1986; Cha-Um and Kirdmanee, 2009).

Although many researchers (Al-Karaki, 1997; Taban et al., 1999; Turan et al., 2007b) reported that low levels of applied NaCl reduced the dry weight of experimental plants, the results obtained from our study showed that but the high levels of NaCl (50, 75 and 100 mM) inhibited shoot and root growth of the maize plants.

The suppression of plant growth under saline conditions may either be due to osmotic reduction in water availability or to excessive ion levels which is known by the specific ion effect (Marschner, 1995). As findings of this study, the shoot growth was much more affected by salinity than was the root growth. These findings are in agreement with Huck and Schroeder (1995), and Esechie et al. (2002), who reported that roots seemed to be more resistant to salinity than were plant foliage. It may be explained that in the higher levels of NaCl, the osmotic effect could be inhibited by the growth of the shoot.

Ion concentrations and distribution

Increasing levels of NaCl induced a progressive absorption of Na and Cl in both shoot and root agreeing with the result of Chavan and Karadge (1986), and Turan et al. (2007a). Excessive Na concentration in the plant tissue hinders nutrient balance, osmotic regulation and causes specific ion toxicity (Katerji et al., 2004; Arzani, 2008). Accumulation of Cl in the root tissue is disruptive to membrane uptake mechanisms, and these results in increased translocation of Cl to the shoots (Yousif et al., 1972). As reported by Cordovilla et al. (1995), NaCl decreased N concentration in the shoot tissues. Salinity has a negative interference on the nitrogen acquisition and utilization (Lewis, 1986). The negative effect of NaCl on the nitrogen concentration of plants could be explained by the antagonism between Cl^{-1} and NO_3^{-1} as reported by Wehrmann and Hahndel (1984). On the contrary the results of Award et al. (1990), and Al-Karaki (1997), in this study NaCl treatments increased P concentrations in the shoot and root even at the higher levels of salinity. On the other hand this result is in agreement with the reports of Yahya (1998) and Turan et al. (2007a). The increased shoot P concentration by applying NaCl may be due to the increased availability of P in the soil or synergistic effect of Na, which is involved in P uptake and/or transport to the shoot (Grattan and Maas, 1988).

When NaCl was applied to the soil, NaCl decreased K concentrations in the Shoot and root in according with an antagonism between Na and K (Erdal et al., 2000; Beck et al., 2004; Karmoker et al., 2008). Cramer et al. (1985) showed that excess NaCl leads to the loss of potassium due to membrane depolarization by sodium ions. As a result of salinity, therefore, potassium accumulated in shoot rather than in root by salinity effect. K accumulated in the shoot as also reported by Siegel et al. (1980) and Karmoker et al. (2008). High Na concentration in the substrate or soil inhibits uptake and transport of Ca^{2+} and may therefore; induce calcium deficiency in plants (Lynch and Lauchli, 1985). Unlike the results of Maas et al. (1972), Bhivare and Nimbalkar (1984), the results of this research showed that NaCl decreased iron concen-tration in the shoot. These results are in agreement with Shrivastava et al. (1993), and Alpaslan et al. (1998). Applied NaCl caused to increase iron concentration and accumulation in the root. Applying NaCl increased zinc and manganese concentrations in the shoot and root.

Similar results were reported by Chavan and Karadge (1980), Martinez et al. (1987) and Alpaslan et al. (1998). The present study showed that low levels of NaCl did not affect the growth of maize plants. But high levels of NaCl inhibited the growth and caused to decreased dry weight both organs. NaCl caused to decrease nitrogen, potassium, calcium and iron in the shoot tissue. Na, P, Fe, Zn and Mn accumulated in the root tissue in accordance with applied NaCl.

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