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# Maize response to water, salinity and nitrogen levels: soil and plant ions accumulation

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**ABSTRACT-** In the present study, some nutritional imbalances, specific ion toxicity and yield-ion concentration relationships in maize under water, nitrogen (N) and salinity stresses were assessed. Effect of different levels of irrigation water ($I1=1.0ET_c+0.25ET_c$ as leaching, I2 =0.75I1 and I3 =0.5I1) as main plot, salinity of irrigation water (S1=0.6, S2= 2.0 and S3=4.0 dS $m^{-1}$) as sub-plot and N fertilizer rates (N1=0, N2=150 and N3=300 kg N $ha^{-1}$) as sub-sub-plot on maize (cv SC 704) were investigated in a split-split-plot design with three replications during 2009 and 2010. Results showed that salts accumulated in soil were 28.4% higher in I2 compared with other irrigation treatments. Soil nitrate concentration was statistically higher under I3 and S1 treatments (83% and 10%, respectively) compared with other irrigation and salinity levels. There was no $K^+$ deficiency caused by salinity; however, salinity resulted in statistically lower $K^+/Na^+$ compared with no saline conditions. Plants took up 25% higher N in I2 compared with other irrigation levels. Furthermore, N uptake by plants decreased by an average of 18% under salinity condition indicating that higher N application rate above the required level under saline water application put the environment at the risk of groundwater N contamination. Results of this study confirmed the fact that $Na^+$ accumulation in soil was more detrimental than $Cl^-$ accumulation for maize irrigated with saline water. Besides, according to threshold values for soil ions, the optimum levels of irrigation and N fertilizer for maize might be lower under saline water application. Furthermore, based on the grain yield reduction coefficient, maize required a higher level of $K^+$ and $K^+/Na^+$ under deficit saline water irrigation for avoiding yield losses.

## INTRODUCTION

Famers have been forced to use saline water for irrigation in many regions of the world due to fresh water shortage. However, saline water application for irrigation may be exposed to problems including osmotic and specific-ion damage (particularly $Na^+$ and $Cl^-$) as well as nutritional disturbance that could lead to yield reduction (Bernstein and Francois, 1975). Nutrient disorders may be due to the effect of salinity on the availability, competition, transport or partitioning of nutrient within the plant or may be due to the physiological inactivation of a specific nutrient outcome of enhancing requirement of the plant for that essential element (Grattan and Grieve, 1999). Many crops, such as maize, are glycophytes (Greenway and Munns, 1980). They are compatible under low soil salinity conditions. The mechanisms they have developed for uptake, transferring and utilizing mineral elements from non-saline layer may not perform efficiently/effectively under saline situation. For example, salinity decreases phosphate absorption and accumulation in crops by diminishing phosphate availability in soil; however, in solution cultures ion disorders may be the outcome of competitive interactions (Sharpley et al., 1992). Sodium dominated salinity decreases $Ca^{2+}$ availability and also reduces $Ca^{2+}$ moving to growing parts of the plant, that influences the quality of vegetative and reproductive parts (Osawa, 1963). Salinity can directly affect nutrient absorption, for example $Na^+$ reducing $K^+$ uptake or $Cl^-$ reducing $NO_3^-$ uptake (Botella et al., 1997).

Regardless of numerous studies demonstrating that salinity decreases nutrient uptake and accumulation or influences their partitioning within the plant, little evidence exist that shows application of nutrients at higher levels than their optimum amounts in non-saline environments, upgrades crop yield in saline conditions. Nutrient additions, on the other hand, have been more successful for increasing crop growth and quality e.g. the modification of $Na^+$ induced $Ca^{2+}/K^+$ insufficiencies by supplemental calcium or potassium (Osawa, 1963; Botella et al., 1997).

Maize (*Zea mays* L.), one of the most important cereal crops, has been classified as moderately sensitive to the salinity (with threshold soil salinity, $EC_e$, of 1.7 dS $m^{-1}$, Mass and Hoffman, 1977). Water and nitrogen (N) are two important parameters influencing crop production. It has been shown that maize positively responds to an increase in water and N amount up to an optimum level (Zand-parsa and Sepaskhah, 2001). Hence, non-optimal levels of water and N cause yield reduction of maize. Growth and yield reduction of maize at over or under the optimum amounts of water and N under salinity conditions are highly complex, especially in nutritional disorders issues. The objectives of this work were to assess some nutritional imbalances and specific ion toxicity aspects in maize shoot under water, N and salinity stresses. Moreover, the potential relationships between relative grain yield *versus* soil and plant ion concentrations were assessed.

## MATERIALS AND METHODS

### Site Description

This study was performed at the Agricultural Experiment Station of Shiraz University (Bajgah) located at 1810 m above the mean sea level with 29°56' N latitude and 52°02' E longitude, in -southwestern Iran with semi-arid climate in 2009 and 2010. Long-term average air temperature, precipitation and relative humidity of the study area are 13.4 °C, 387 mm and 52.2%, respectively. Soil texture of the experimental site was clay loam up to depth of 0.60 m. Physico-chemical characteristics of the soil used in this study are shown in Table 1. Chemical analysis of the fresh water, as well saline irrigation water used in the experiments of this study is presented in Table 2.

**Table 1.** Physico-chemical characteristics of the soil used in the experiments of this study (average of two years)

| Characteristic | Amount | |
|---|---|---|
| Depth (cm) | 0-30 | 30-60 |
| Texture | CL* | CL |
| Caly (%) | 53.5 | 54.8 |
| Silt (%) | 33.0 | 34.5 |
| Field capacity (-0.03 MPa) (%, v/v) | 31 | 30 |
| Permanent wilting point (-1.5 MPa) (%, v/v) | 18 | 19 |
| Bulk density (kg $m^{-3}$) | 1460 | 1560 |
| $EC_e$ (dS $m^{-1}$) | 0.65 | 0.55 |
| pH (saturated past) | 7.50 | 7.45 |
| Organic matter (%) | 0.7 | 0.5 |
| Total nitrogen (%) | 0.021 | 0.009 |
| $NO_3$-N (mg $L^{-1}$) | 4.6 | 6.0 |
| Available P (mg $L^{-1}$) | 21.0 | 11.0 |
| Available K (mg $L^{-1}$) | 343.0 | 315.0 |

* Clay loam

Reference evapotranspiration ($ET_o$) in the study region is calculated using modified FAO-Penman-Monteith method (Razzaghi and Sepaskhah, 2012) using meteorological data. Mean daily air temperature ($T_{avg}$), relative humidity ($RH_{avg}$) and $ET_o$ during growing seasons in 2009 and 2010 are presented in Fig. 1. Potential evapotranspiration of maize ($ET_c$) is calculated by multiplying $ET_o$ and modified crop coefficient ($K_c$) in the study area (Shahrokhnia and Sepaskhah, 2013).

### Experimental Design and Treatments

Maize (cv SC704) was planted on May 21, 2009 and May 25, 2010 in a furrow irrigation system. There were five furrows in each plot with the length and spacing of 5 and 0.75 m, respectively. Final maize density was 88888 plants $ha^{-1}$ with spacing of 15 cm between plants. Phosphorus in the form of triple superphosphate was applied at a rate of 200 kg $ha^{-1}$ before planting.

**Table 2.** Chemical analysis of the fresh and saline irrigation waters used in the experiments of this study (average of two years)

| Characteristic | Fresh water | Saline waters | |
|---|---|---|---|
| EC (dS $m^{-1}$) | 0.60 | 2.00 | 4.00 |
| pH | 7.80 | 7.70 | 7.80 |
| $Cl^{-1}$ (meq $L^{-1}$) | 1.81 | 17.27 | 40.37 |
| $Na^+$ (meq $L^{-1}$) | 1.74 | 18.9 | 30.3 |
| $Ca^{2+}$ (meq $L^{-1}$) | 2.15 | 16.17 | 39.41 |
| $Mg^{2+}$ (meq $L^{-1}$) | 2.00 | 2.00 | 2.00 |
| $HCO_3^-$ (meq $L^{-1}$) | 1.97 | 4.99 | 4.64 |

The field was sufficiently irrigated (as 200 mm) in the 1th and 2nd irrigation (till three-leaf stage of plant). For measuring soil moisture using neutron probe, after 1th irrigation, a 1.5 m length aluminum access tube was emplaced at the center of each plot of two replications. Salinity and irrigation treatments began at 3rd irrigation (3-4 leaf stage of maize). The experimental treatments were three levels of amount and salinity of irrigation water and nitrogen fertilizer rate. Irrigation was done with seven-day intervals (Sepaskhah et al. 1993; Zand-Parsa and Sepaskhah, 2001) and actual evapotranspiration ($ET_c$) was considered as full plant water requirement for future seven days. Irrigation treatments were I1 ($1.0ET_c + 0.25ET_c$ as leaching fraction), I2 (0.75I1) and I3 (0.5I1). Nitrogen (as urea) levels were 300, 150 and 0 kg N $ha^{-1}$ as N3, N2 and N1, respectively. Seventy percent of the urea fertilizer was used at 3rd week and the remain was applied at10th week after sowing time in both years. Salinity treatments were referred to S3, S2 and S1, equivalent to 4, 2 and 0.6 (groundwater salinity) dS $m^{-1}$. The salinity treatments (S3 and S2) were obtained by adding the equal proportion of NaCl and $CaCl_2$ salts to the irrigation water. Cumulative applied water for different irrigation treatments are shown in Fig. 1. The layout of the experiment was a split-split plot with three replications. Water, salinity and nitrogen treatments were considered as the main-, sub- and sub-sub factors, respectively.

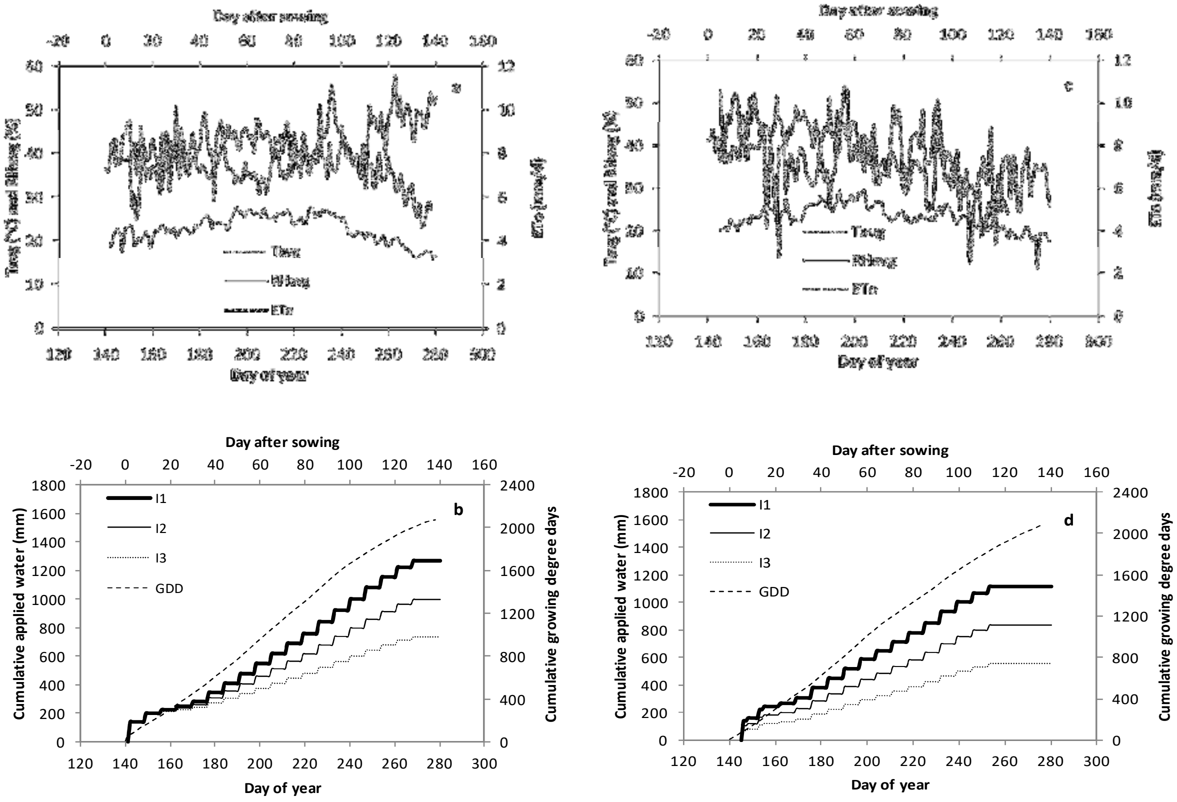

**Fig. 1.** Daily mean air temperature ($T_{avg}$), relative humidity ($RH_{avg}$) and reference evapotranspiration ($ET_o$) during the growing seasons in 2009 (a) and 2010 (c); cumulative applied water for different irrigation treatments ($1.25ET_c$: I1, 0.75I1: I2, 0.5I1: I3) and cumulative growing degree day (GDD) in 2009 (b) and 2010 (d).

Plots were watered using a volumetric measuring device. The field was leached using two heavy irrigations to reduce soil salinity during winter season after the 1st year. The arrangement of the experimental treatments in the field was the same in two years.

## Measurements and Calculations

Soil water content (v/v) in different irrigation treatments were monitored by neutron probe (neutron meter, Model CPN, 503DR) down to 1.5 m soil depth with 0.30 m intervals before each irrigation event. Dry matter (DM, oven dried at 70°C) was measured from three-six plants during the growing seasons with 30-day intervals. Concurrently, soil samples of each depth increment (0.3 m) down to 1.5 m depth, were collected, air dried and passed through 2 mm sieve for chemical analysis including electrical conductivity of soil saturation extract ($EC_e$, Richards, 1954), soluble $Na^+$ and $K^+$ (by flame photometer), soluble $Ca^{2+}$ and $Mg^{2+}$ by titrating the saturation extract by EDTA solution, $Cl^-$ by titration with $AgNO_3$ and $NO_3$-N (using the method presented by Chapman and Pratt, 1961). Sodium adsorption ratio (SAR) was determined as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (1)$$

where $Na^+$, $Ca^{2+}$, and $Mg^{2+}$ are the concentration of sodium, calcium, and magnesium, respectively, (meq $L^{-1}$).

Plants were harvested on October 11 in two years from three middle rows of each plot with 4 m length and oven dried at 70°C. Total DM and grain yield (GY, at 15 % moisture content) were measured. Nitrogen concentrations of grain and stover were determined by the Kjeldahl method [using the method presented by Chapman and Pratt (1961)]. Shoot-$Na^+$, -$Ca^{2+}$, -$Mg^{2+}$, -$Cl^-$ and $NO_3$-N were also determined using standard method for DM sampled during the growing seasons.

## Statistical Analysis

The statistical analysis including analysis of variance (ANOVA) and Duncan´s method for finding out the differences among means ($p \leq 0.05$) was carried out using MSTAT-C software. Mean values of the parameters between two years were considered in the analysis since, no significant effect of year on measured parameters was observed.

## RESULTS AND DISCUSSION

### Soil $EC_e$

Salinity of soil profile ($EC_e$) in I2 treatment was statiscally higher (28.4%) than that obtained in other irrigation levels (Table 3). The reason for this finding was higher leaching (Azizian and Sepaskhah, 2014b) and lower entered salt in I1 and I3 treatments, respectively. Soil solution salinity also increased significantly with increasing salinity levels, and its values in S2 and S3 were 3.3 and 3.9 times of that obtained in no saline condition, respectively. Furthermore, soil profile salinity insignificantly increased with increasing N application rate. This finding supported the results reported by Min et al. (2014) for cotton cultivation as they reported N fertilizer application had relatively little effect on soil salinity.

Variation of soil profile salinity under different irrigation and salinity levels during the growing seasons are presented in Fig. 2. The salts accumulated in the top layers of soil profile as they had higher $EC_e$ than the bottom layers. This was profound in higher saline water levels. Such distribution pattern of soil profile salinity was also reported by Noshadi et al. (2013) in tomato field under one-year drip irrigation. In fact, with short term saline water application a saline water-soil equilibrium conditions are not established and the salts had not enough opportunity to be transferred to deep layers. It is also shown in Fig. 2 that soil profile salinity increased during the growing seasons under different irrigation and salinity treatments. This pattern was also reported by Amer (2010) in soil profile of a maize field. The maximum salinity as 6.70 dS $m^{-1}$ was measured in top layer of the soil (0-30 cm) under I2S3 treatment on day 135 after sowing.

### Soil Ions

### Soil $Na^+$ and $Cl^-$

The soluble concentration of $Na^+$ and $Cl^-$ in saturation extract of soil was statistically higher in I2 than those values in other irrigation treatments (Table 3). The concentration of these two ions also increased significantly with increasing salinity levels as about 4 times in S3 compared with S1 treatment. These variations were in accordance with $EC_e$ variations. Soil $Na^+$ and $Cl^-$ concentrations in N2 and N3 treatment were also statistically higher than those obtained in N1 level. The reason for this finding is probably due to lower leaching in N2 and N3 treatments which accompanied higher water consumption by plant (Azizian and Sepaskhah, 2014b).

### Soil SAR

Relative content of $Na^+$ ion compared to sum of $Ca^{2+}$ and $Mg^{2+}$ is calculated by SAR index [Eq. (1)] and used for evaluating infiltration capacity of soil in companion with $EC_e$. In this study, the SAR value for S3 treatment was statistically higher than that value obtained in control (S1) treatment (Table 3). However, irrigation and N treatments had no significant effect on SAR. The values of this index in all treatments were still below than the critical value [SAR>3 for irrigation water salinity of >0.2 dS $m^{-1}$ that was nearly equal to soil exchangeable sodium percentage (ESP) under soil-water equilibrium conditions] which could reduce the infiltration rate of soil due to swelling and seal formation of clay particle (Ayers and Westcot, 1985). Reduction in soil infiltration was occurred due to saline water application; however, Suarez et al. (2008) and Amer (2010) mentioned that this phenomenon could be occurred at high soil SAR.

### Soil Nitrate

Mean values of soil profile $NO_3$-N content under different irrigation, salinity and N levels are shown in Table 3. The significant higher soil nitrate content in I3 compared with I2 (27%) and I1 (61%) treatments could be due to smaller amount of applied irrigation water and less leaching amount. Soil nitrate content under S1 was also statistically higher with an average of 10% than those obtained in other salinity levels. The $NO_3$-N content of soil in N2 and N3 treatments were significantly higher (as 0.6 and 1.3 times, respectively) than that obtained in N1 treatment due to higher N application rate.

**Table 3.** Mean values of soil salinity ($EC_e$) and ions concentration of saturation extract in different irrigation, salinity and nitrogen levels (two years average over root zone).

| Measured parameter | Irrigation levels | | | Salinity levels (dS $m^{-1}$) | | | Nitrogen levels (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | I1=1.25ETc | I2=0.75I1 | I3=0.50I1 | S1=0.6 | S2=2 | S3=4 | N1=0 | N2=150 | N3=300 |
| $EC_e$ (dS $m^{-1}$) | 1.45b* | 1.87a | 1.45b | 0.61c | 2.01b | 2.40a | 1.54a | 1.64a | 1.83a |
| $Na^+$ (meq $L^{-1}$) | 1.74b | 2.23a | 1.74b | 0.73b | 2.40a | 2.86a | 1.84b | 2.06a | 2.19a |
| $Cl^-$ (meq $L^{-1}$) | 9.89b | 10.97a | 8.54c | 3.47c | 11.83b | 14.11a | 9.02b | 10.11a | 10.77a |
| SAR | 0.68a | 0.71a | 0.63a | 0.43b | 0.76ab | 0.83a | 0.65a | 0.67a | 0.70a |
| $NO_3$-N (kg $ha^{-1}$) | 55.07c | 70.03b | 113.09a | 84.63a | 78.45b | 75.12b | 48.13c | 77.84b | 112.23a |

*Means in each row under irrigation, salinity and nitrogen levels for different traits followed by the same letter are not statistically different at $p \leq 0.05$ by Duncan multiple range test.

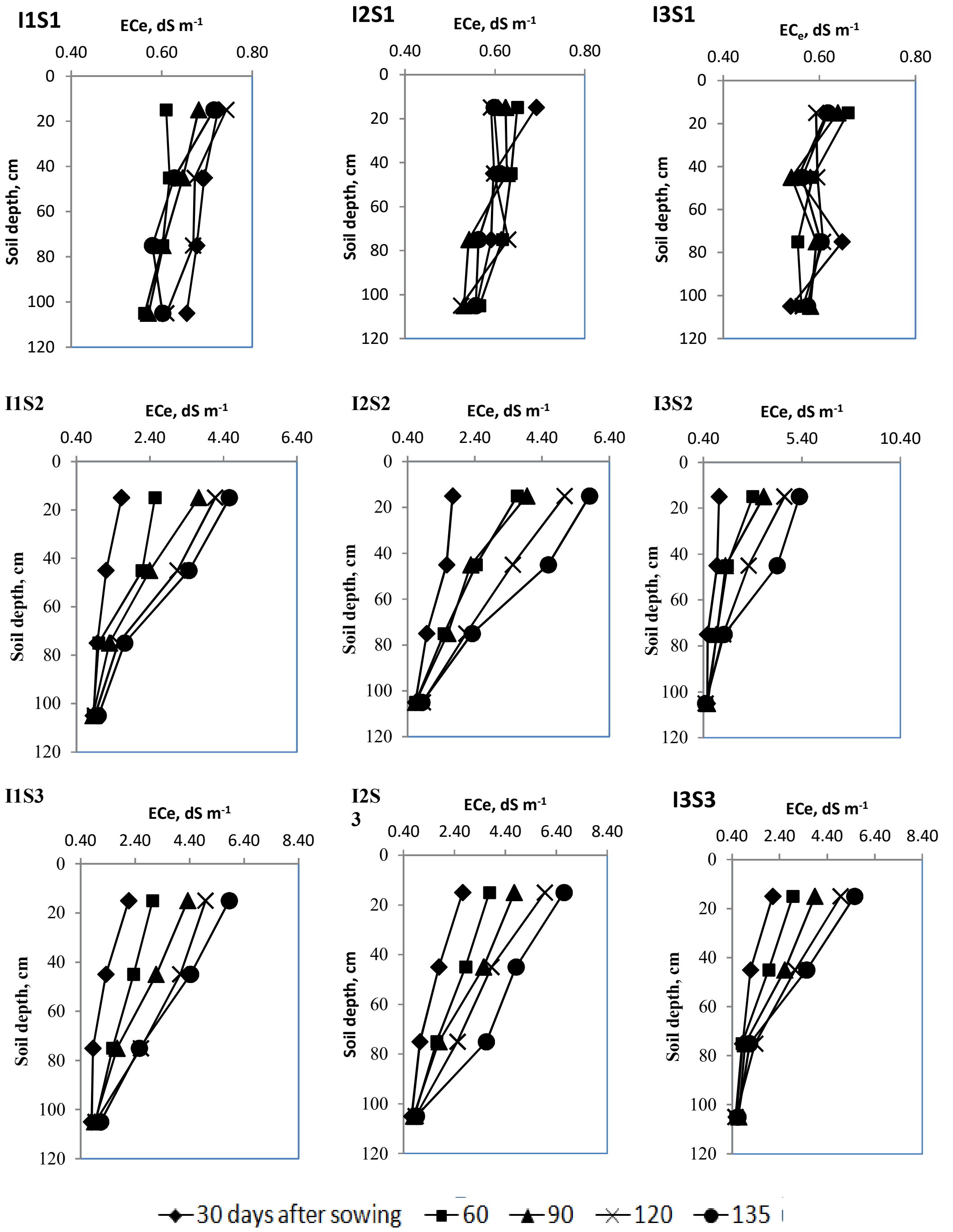

**Fig. 2.** Soil saturation extract salinity (ECe, dS m$^{-1}$) at different irrigation (I1=1.25ETc, I2=0.75I1 and I3=0.5I1) and salinity (S1=0.6, S2=2.0 and S3=4.0 dS m$^{-1}$) levels during the growing seasons

Seasonal variations of soil nitrate in depth of 0-30 and 30-60 cm are shown in Fig. 3. The substantial rapid increases in $NO_3$-N content of soil which were observed on days 30 after sowing time are due to N fertilizer application in 3rd week after planting. In general, the nitrate contents of soil in depth of 0-30 cm were higher than those of 30-60 cm depth in the early stages of the growing seasons; whereas, a reverse trend was observed after that, toward the end of the growing seasons. The reason for this finding was that the plant consumed residual and applied $NO_3$-N during the growing seasons. Besides, the rest of soil $NO_3$-N content in the soil surface layer might have been leached by irrigation water and accumulated in deeper layers of the soil profile. Furthermore, soil nitrate contents in both depths were lower or nearly equal to that obtained at the beginning of the growing seasons with the exception of 30-60 cm depth of I3 treatment in which $NO_3$-N accumulated in the soil during the growing seasons probably due to no leaching action. The soil nitrate content was generally higher at mid-season in different irrigation, salinity and N treatments compared with other times in the growing seasons. Moreover, the $NO_3$-N in 0-30 cm depth of the soil decreased after early rapid increase toward the end of the growing seasons.

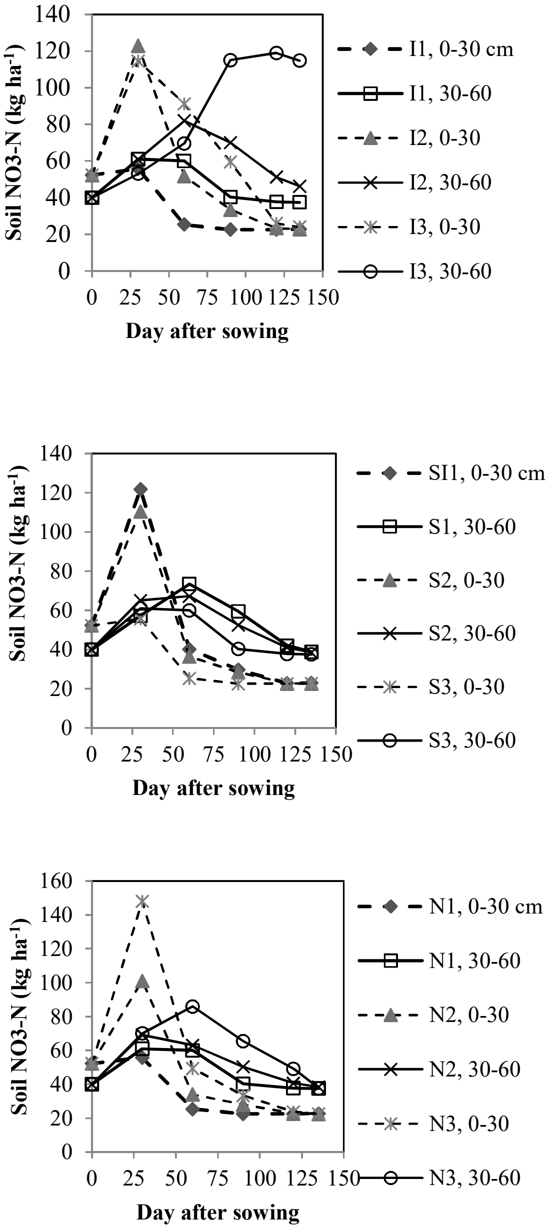

**Fig.3.** Variations of soil nitrate in depth of 0-30 and 30-60 cm under different irrigation (a, I1=1.25ET$_c$, I2=0.75I1 and I3=0.5I1), salinity (b, S1=0.6, S2=2.0 and S3=4.0 dS m$^{-1}$) and nitrogen (c, N1=0, N2=150 and N3=300 kg ha$^{-1}$) levels in growing seasons.

The nitrate content of soil in both depths under I1 treatment were clearly less than that obtained in I2 and I3 irrigation levels (Fig. 3a) mainly due to higher applied water (Fig. 1 b and d) and higher leaching occurred in this irrigation treatment [14.1% in I1 compared with 8.8 and 0.0% in I2 and I3 treatments, respectively (Azizin and Sepaskhah, 2014b)]. The soil nitrate content in depth of 30-60 cm at the end of the growing seasons under I3 treatment was 1.8-fold higher than that obtained at the beginning of the growing seasons. In other words, $NO_3$-N accumulated in deeper layer of the soil under lower applied water. The higher concentration of nitrate in soil may intensify the effect of salinity as it has been reported by Azizian and Sepaskhah (2014b).

According to Fig. 3b, soil nitrate contents of both depths in S3 treatment were clearly lower than those in S1 and S2 levels. This might be due to the fact that under highest salinity levels, plants absorbed lower soil nitrate content (Table 4) and then it leached by irrigation water from soil profile. This pattern was also observed in S2 treatment compared with S1 treatment. This is shown in Fig. 3b as the S2 curve was slightly lower than the S1 one.

Fig. 3c showed that soil nitrate contents of both 0-30 and 30-60 cm depths in N3 treatment were higher than those obtained in N2 treatment, and the values of $NO_3$-N obtained in N2 treatment were higher than those in N1 treatment. An increase in the soil nitrate contents in N1 treatment which was measured on day 30 after sowing time in both depths (approximately 7 and 53% in depth of 0-30 and 30-60 cm, respectively) might be due to mineralization of soil organic N.

## Plant Ions

### Plant $Na^+$ and $Cl^-$

Excess $Na^+$ and $Cl^-$ accumulation might have toxic effect on plants. In this study, no foliar injury symptoms were observed on maize leaves except than thegradually yellowing of the old leaves. Plant $Na^+$ and $Cl^-$ concentrations under different irrigation, salinity and nitrogen levels are presented in Table 4. Plant $Na^+$ concentration in S3 treatment was statistically higher than that obtained in other salinity levels (Table 4). Chloride ion accumulation was statistically higher in plant under S3 treatment compared with other salinity levels. However, there was no significant difference among $Na^+$ and $Cl^-$ concentrations in plants under different irrigation and nitrogen treatments. These trends were in accordance with the soil $Na^+$ and $Cl^-$ concentrations in the same plants (Table 3). According to the correlation analysis among all pairs of the soil and plant measured parameters, there was also a significant negative correlation ($r=-0.35$, $p<0.05$) between plant $Cl^-$ concentration and total N concentration (data not shown). Such negative correlation was also reported by Pérez-Alfocea et al. (1993) in tomato. Also, it has been reported in the literature that increased $NO_3$-N in the root zone decreased $Cl^-$ uptake and accumulation in numerous annual horticultural crops (Kafkafi et al., 1982; Feigin et al., 1987; Martinez and Cerdá, 1989).

Table 4. Mean values of maize top ions concentration in different irrigation, salinity and nitrogen levels (two years average).

| Measured parameter | Irrigation levels | | | Salinity levels (dS m$^{-1}$) | | | Nitrogen levels (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | I1=1.25ETc | I2=0.75I1 | I3=0.50I1 | S1=0.6 | S2=2 | S3=4 | N1=0 | N2=150 | N3=300 |
| Na$^+$ (%) | 0.54a$^*$ | 0.62a | 0.60a | 0.21b | 0.57b | 0.98a | 0.58a | 0.58a | 0.59a |
| Cl$^-$ (%) | 0.74a | 0.82a | 0.80a | 0.41b | 0.77ab | 1.18a | 0.79a | 0.78a | 0.79a |
| K$^+$ (%) | 2.27a | 1.49b | 1.05b | 1.81a | 1.57a | 1.42a | 1.61a | 1.59a | 1.60a |
| K$^+$/Na$^+$ | 2.62b | 4.01a | 2.62b | 9.10a | 2.95b | 1.47b | 4.51a | 4.49a | 4.51a |
| N (%) | 1.61b | 2.02a | 1.61b | 2.25a | 1.99ab | 1.70b | 1.27c | 1.98b | 2.69a |

$^*$Means in each row under irrigation, salinity and nitrogen levels for different traits followed by the same letter are not statistically different at $p \leq 0.05$ by by Duncan multiple range test.

## Plant K$^+$ and K$^+$/Na$^+$ Ratio

Adequate concentration of K$^+$ is essential for plant survival in saline habitats. Potassium makes a major contribution to lower osmotic potential in the roots that is a prerequisite for the water absorption and balance in plants (Marschner, 1995). Under saline-sodic or sodic conditions, high levels of external Na$^+$ not only interfere with K$^+$ acquisition by the roots, but also may disrupt the integrity of root membranes and alter their selectivity. The selectivity of the root system for K$^+$ over Na$^+$ must be sufficient to meet the concentration of K$^+$ required for metabolic processes to regulate ion transport and to adjust osmotic pressure. Furthermore, plant K$^+$/Na$^+$ ratio can be applied as selection criteria to assess salinity tolerance of different crop species. In this study, the plants under I1 and I2 treatments had statistically higher K$^+$ concentration and higher K$^+$/Na$^+$ ratio compared to those in other irrigation treatments, respectively (Table 4). Salinity had no significant effect on K$^+$ concentration of the studied plants. However, K$^+$/Na$^+$ ratio markedly decreased with application of saline irrigation water due to markedly increase in Na$^+$ concentration of the plants. When K$^+$ uptake is impaired by salinity, higher K$^+$ concentrations in tissue are required for shoot growth (Marschner, 1995). Although increases in plant Na$^+$ concentrations may help to maintain plant turgor pressure; however, Na$^+$ cannot completely substitute for K$^+$ which has been shown to be specifically required for protein synthesis and enzyme activation (Marschner, 1995). It has been reported that high K$^+$ concentrations in the stroma were necessary for the maintenance of optimum photosynthetic capacity in spinach under stress conditions (Chow et al., 1990). It seems that since K$^+$ uptake was not impaired by salinity (Table 4), shoot growth reduction due to salinity (Azizian and Sepaskhah, 2014a) could be attributed to some extent to the toxicity effect of Na$^+$ which was revealed in lower K$^+$/Na$^+$ ratio. Hence, under Na$^+$-induced salinity, application of potassium fertilizer might have improved the growth of maize and have provided the minimum concentration to avoid grain yield losses. Several studies with a wide variety of horticultural crops have shown that K$^+$ concentration and K$^+$/Na$^+$ ratio in plant tissue have been declined as the Na$^+$-salinity in the root media has been increased. For example, Botella et al. (1997) indicated that sodium-induced K$^+$ deficiency has been implicated in growth and yield reductions of maize. In this study, nitrogen treatments had no significant effect on plant K$^+$ concentration and K$^+$/Na$^+$ ratio.

## Plant Nitrogen

Top plant total N under different irrigation, salinity and N treatments are shown in Table 4. Plants took up 25% higher N in I2 (statistically significant) compared with other irrigation levels. Under I1 treatment, greater amount of leached water resulted in N leaching from root zone and hence its uptake decreased. On the other hand, in I3 treatment smaller amount of water uptake (ET and T, Azizian and Sepaskhah, 2014b) could be the reason for smaller amount of plant N concentration.

According to Table 4, N uptake in plant decreased by salinity and dropped significantly to the least amount in the highest salinity levels that was about 32% less than that obtained in no salinity treatments. The reduction in plant N with increased salinity was accompanied by the soil and plant Cl$^-$ content increase (Tables 3 and 4). Similar results were reported by Grattan and Grieve (1999) for some horticultural crops. The bulk results of the studies indicated that the N uptake or accumulation in the plant shoot may be reduced under saline conditions, although there are studies that found the opposite or no effect of salinity on N uptake by plants (Feigin, 1985). Some researchers attributed this reduction of N uptake to Cl$^-$ antagonism of NO$_3^-$ uptake (Bar et al., 1997; Feigin et al., 1987; Kafkafi et al., 1982): whereas, others attributed this response to the effect of salinity on reduced water uptake (Lea-Cox and Syvertsen, 1993). In our study, either reduction of water uptake (Azizian and Sepaskhah, 2014b) or antagonism effect of Cl$^-$ (as a main component of salinity in this study) might be the reasons for reduction in plant N. However, results of this study indicated that a higher application rate of N fertilizer above its required level under saline irrigation water put the environment at the risk of groundwater N contamination. In this study, plant N concentration also increased significantly under N2 and N3 treatments by 56 and 111% compared with that obtained under no N application rate.

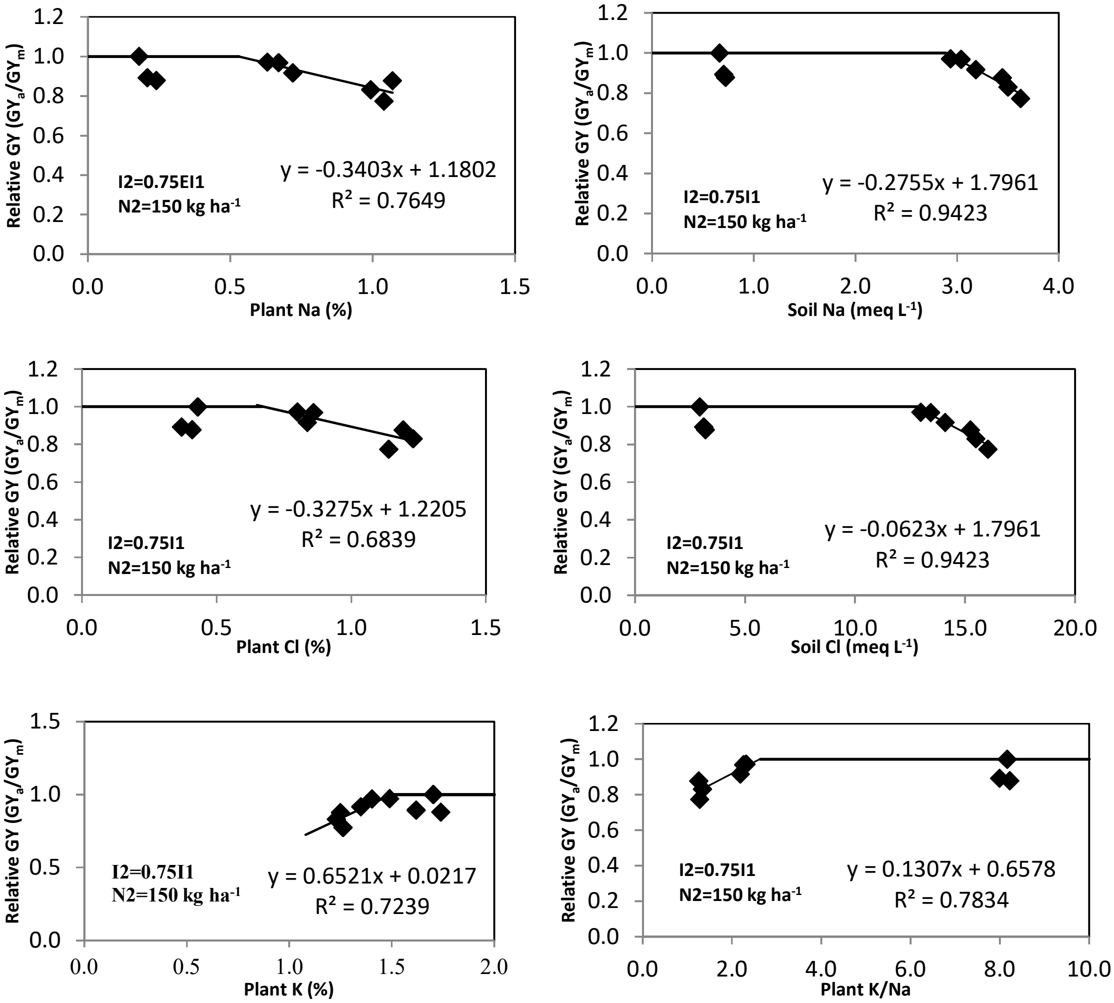

**Fig. 4.** Relationship between relative maize grain yield ($GY_a/GY_m$) and mean values of soil and plant ions concentrations (Na, Cl, K and plant K/Na ratio) under I2=0.75I1 irrigation regime and N2=150 kg ha$^{-1}$ N treatment.

**Table 5.** Threshold values of soil $Na^+$ and $Cl^-$ concentration in soil saturation extract and grain yield reduction coefficients for maize at different irrigation treatments and nitrogen application rates.

| Nitrogen application rate | Soil | Irrigation levels | | | | | |
|---|---|---|---|---|---|---|---|
| | | I1=1.25ETc | | I2=0.75I1 | | I3=0.5I1 | |
| (kg ha$^{-1}$) | ion | Threshold % | Slope %/meq L$^{-1}$ | Threshold % | Slope %/ meq L$^{-1}$ | Threshold % | Slope %/ meq L$^{-1}$ |
| 0 | $Na^+$ | 1.71 | 29.6 | 2.25 | 32.5 | 1.49 | 33.8 |
| 150 | | 1.45 | 10.9 | 2.89 | 27.5 | 2.19 | 40.0 |
| 300 | | 0.29 | 8.90 | 1.52 | 16.5 | 2.07 | 48.5 |
| 0 | $Cl^-$ | 7.57 | 6.7 | 10.01 | 7.3 | 6.55 | 7.7 |
| 150 | | 6.58 | 2.4 | 12.84 | 6.2 | 8.92 | 9.8 |
| 300 | | 1.30 | 2.0 | 6.76 | 3.7 | 9.21 | 10.9 |

## Grain Yield-Ion Relationships

Relationships between relative maize grain yield and mean values of soil and plant ion concentration were fitted through piecewise linear regression, where it was appropriate and shown in Fig. 4 as example for I2 and N2 treatments. The threshold values and also yield reduction coefficients (i.e. soil and plant indices) due to increase in ion concentration were calculated using these models. These soil/plant indices are presented in Tables 5 and 6 for soil and plant ions, respectively, for different irrigation and N application rates.

## Soil Indices

Maize GY and soil $Na^+$ and $Cl^-$ concentrations were negatively correlated (r=-0.21, $p<0.05$). Hence, the response of maize GY to increasing concentration of these two ions is expected to be a declining trend after a threshold value. It is shown in Table 5 that the threshold and slope values for $Cl^-$ were higher and lower than those values for $Na^+$, respectively.

Hence, $Na^+$ accumulation in soil was more detrimental than $Cl^-$ accumulation for maize irrigated with saline water. The lower values of grain yield reduction coefficient for these soil ions under higher N application rate in I1 and I2 treatments indicated that maize irrigated by saline water was less susceptible to soil $Na^+$ and $Cl^-$ with increasing N fertilizer rate. However, in I3 treatment, grain yield reduction coefficient for soil ions increased by increasing N application rate. In other words, application of N fertilizer as urea source could not improve maize tolerance to soil $Na^+$ and $Cl^-$ under deficit irrigation. This may be due to exacerbation of the salinity effect; however, it could improve maize tolerance to these ions at well-watered conditions (I1 and I2 treatments). With regard to the threshold values, maize had more complex behavior. It is shown in Table 5 that maize was more susceptible to soil $Na^+$ and $Cl^-$ under I1 and I2 treatments at the highest N application rate. The reason may be due to higher growth under higher available soil water and N and hence higher shoot $Na^+$ and $Cl^-$ absorption. However, maize was more sensitive to these soil ions with no N application under deficit irrigation. The plant with low root growth under this situation (lower soil N content) confronted with less available water and; therefore, higher soil $Na^+$ and $Cl^-$ concentration.

The slope of maize GY reduction in response to increase in soil $Na^+$ and $Cl^-$ became higher under deficit irrigation (I2 and I3 treatments). This indicated that maize was more sensitive to $Na^+$ and $Cl^-$ under deficit irrigation in the case of GY reduction coefficient. Furthermore, the threshold values for maize GY under I2 treatment by using 0 and 150 kg N $ha^{-1}$ were higher than those values obtained for other irrigation treatments. Whereas, with 300 kg N $ha^{-1}$ the threshold values became higher under deficit (I3) irrigation, as it means that maize is more tolerant to $Na^+$ and $Cl^-$ under high N application and deficit irrigation.

## Plant Indices

The negative correlation between maize GY and plant $Na^+$ and $Cl^-$ concentrations (r=-0.43, $p<0.05$) indicated that accumulation of these two ions in maize beyond a threshold value resulted in yield reduction. The smaller values of threshold and higher value of slope for $Na^+$ relative to $Cl^-$ indicated that maize was more sensitive to $Na^+$ accumulation in its shoot tissue than $Cl^-$ (Table 6) that is in accordance to the results reported by Isla and Aragüés (2010) for maize irrigated by saline water under sprinkle irrigation. The response of maize GY to shoot $Na^+$ and $Cl^-$ accumulation was more complex since in many cases no appropriate regression models could be fitted to the data. Besides, variation of the obtained plant indices was more complicated by increasing irrigation and N levels as they were calculated and are shown in Table 6.

Due to the $Na^+$-$K^+$ discrimination found in most plant species grown in saline conditions (Marschner, 1995), yield of maize were also positively correlated with plant $K^+$ concentration (r=0.83, $p<0.01$) and plant $K^+/Na^+$ ratio (r=0.67, $p<0.01$). Hence, maintenance of adequate concentrations of plant tissue $K^+$ and also $K^+/Na^+$ ratio are essential for full plant growth and yield production. In other words, with values lower than the threshold of these two plant parameters, growth was reduced (Fig. 4). According to threshold values presented in Table 6, maize generally became more sensitive to $K^+$ concentration and $K^+/Na^+$ ratio with increasing irrigation level and N application rate since the values of $K^+$ and $K^+/Na^+$ of which GY was reduced, were higher under higher levels of irrigation and N application rates as compared with the lower levels of these factors.

**Table 6.** Threshold values of plant $Na^+$, $Cl^-$, $K^+$, $K^+/Na^+$ concentration and grain yield reduction coefficient for maize at different irrigation treatments and nitrogen application rates.

| Nitrogen application rate (kg $ha^{-1}$) | Plant Ion | Irrigation levels<br>I1=1.25ETc<br>Threshold % | <br>I1=1.25ETc<br>Slope %/% | <br>I2=0.75I1<br>Threshold % | <br>I2=0.75I1<br>Slope %/% | <br>I3=0.5I1<br>Threshold % | <br>I3=0.5I1<br>Slope %/% |
|---|---|---|---|---|---|---|---|
| 0 | $Na^+$ | -[*] | - | - | - | 0.03 | 39.0 |
| 150 | | - | - | 0.53 | 34.0 | 0.07 | 31.4 |
| 300 | | - | - | - | - | - | - |
| 0 | $Cl^-$ | - | - | 0.07 | 3.27 | 0.30 | 44.2 |
| 150 | | - | - | 0.67 | 32.7 | 0.28 | 32.3 |
| 300 | | - | - | - | - | - | - |
| 0 | $K^+$ | 2.54 | 61.4 | 1.74 | 85.4 | 1.35 | 85.8 |
| 150 | | 2.74 | 22.7 | 1.5 | 65.2 | 1.39 | 59.4 |
| 300 | | 2.81 | 43.6 | 2.14 | 43.3 | 1.07 | 81.4 |

[*] In these cases, there were no appropriate relationships between relative grain yield and ion concentration in plant top

Hence, the optimum level of irrigation and N application rate might be lower under saline water application. However, based on yield reduction coefficient (e.g. slope of the regression lines) maize was more sensitive to $K^+$ deficiency and $K^+/Na^+$ ratio under water stress conditions, since at a given reduction in the $K^+$ concentration or $K^+/Na^+$ ratio in plant it resulted in a higher decrease in relative maize GY. In other words, under deficit irrigation with saline water, a higher concentration of $K^+$ and $K^+/Na^+$ ratio in plant was required to avoide yield losses. Furthermore, yield reduction coefficient with regard to $K^+$ concentration and $K^+/Na^+$ ratio in plant are more complicated with increasing N application rate.

## CONCLUSION

Results of this study showed that soil profile became 1.2 times more saline under I2=0.75I1 treatment compared with other irrigation levels. Application of saline irrigation water also led to salts accumulation twice higher than the no saline water application. Similar pattern (like to soil $EC_e$) was observed for soil $Na^+$ and $Cl^-$ concentrations by application of saline water. Furthermore, soil salinity increased during growing seasons and it was higher in the top layers of soil profile. The values of SAR in all treatments remained lower than the critical value that can reduce the infiltration rate of soil. Soil nitrate content was higher under I3 and S1 as 83% and 10% compared with other irrigation and salinity levels, respectively. In general, the nitrate content of soil in depth of 0-30 cm was also higher than that of 30-60 cm depth during early growing season; however, the reverse trend was observed at the end of the growing seasons. Results also showed that $Na^+$ and $Cl^-$ accumulated about 1.5 and 3.5 times more in plant tissue under S3 compared with no salinity conditions, respectively. Plant $K^+$ was higher in well-watered condition (I1) compared with other irrigation treatments. Besides, salinity resulted in lower $K^+/Na^+$ compared with no salinity treatment. Plants took up 25% higher N in I2 compared with other irrigation levels. Furthermore, N uptake by plants was decreased by an average of 18% under saline irrigation water application. Results of this study confirm the fact that $Na^+$ accumulation in soil was more detrimental than $Cl^-$ accumulation for maize irrigated with saline water. Besides, according to threshold value of $K^+$ and $K^+/Na^+$ in plant, maize generally was more sensitive to deficiency of these parameters with increasing irrigation and N levels. Furthermore, based on GY reduction coefficient, maize was more sensitive to $K^+$ and $K^+/Na^+$ deficient under water stress conditions.

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# واکنش ذرت به سطوح آب، شوری و ازت: تجمع یون ها در خاک و گیاه

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***واژه های کلیدی:***
تجمع یون ها
تنش شوری و نیتروژن
غلظت آستانه
تنش آبی
کاهش عملکرد

**چکیده-** در این مطالعه برخی جنبه های عدم تعادل عناصر غذایی، سمیت ویژه یونی و ارتباط محصول با غلظت یون‌ها برای گیاه ذرت تحت تیمارهای آب، ازت و شوری بررسی شد. اثر سطوح آب آبیاری ( I1=0.25ETc+1.0ETc بعنوان آبشویی، I2=0.75I1 و I3=0.5I1) بعنوان فاکتور اصلی، شوری آب آبیاری (S1=0.6، S2=2.0 و S3=4.0 dS/m) بعنوان فاکتور فرعی اول و ازت (N1=0، N2=150 و $N3=300\ kg\ N\ ha^{-1}$) بعنوان فاکتور فرعی دوم روی ذرت (رقم SC704) تحت یک آزمایش کرت‌های دوبار خرد شده  در سه تکرار در سال-های ۱۳۸۸ و ۱۳۸۹ بررسی شد. نتایج نشان داد که تجمع املاح در خاک در تیمار I2 نسبت به دیگر تیمارهای آبیاری ۲۸/۴٪ بیشتر بود. غلظت نیترات خاک نیز در تیمارهای I3 و S1 نسبت به دیگر تیمارهای آب و شوری به ترتیب ۸۳ و ۱۰٪ بیشتر بود. هیچ‌گونه کمبود $K^+$ ناشی از شوری مشاهده نشد درحالی‌که شوری منجر به کاهش معنی‌دار نسبت $K^+/Na^+$ در مقایسه به بقیه تیمارها گردید. گیاه در تیمار I2 نسبت به دیگر تیمارهای آبی ۲۵٪ بیشتر ازت جذب کرد. بعلاوه جذب ازت توسط گیاه در شرایط کاربرد آب شور کاهش یافت که حاکی از خطر آلودگی آب زیرزمینی با نیترات آبشویی شده می‌باشد. نتایج مؤید این واقعیت بود که تجمع $Na^+$ در خاک نسبت به $Cl^-$ برای ذرت مضرتر است. همچنین حدود آستانه یونی در خاک حاکی از این بود که سطوح بهینه آب و ازت برای ذرت در شرایط شور ممکن است کمتر باشد. بعلاوه بر اساس شیب کاهش عملکرد، ذرت به مقادیر بیشتری از $K^+$ و $K^+/Na^+$ برای عدم کاهش عملکرد ناشی در شرایط شور نیاز دارد.