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Effect of salinity, nitrogen sources and inter-specific competition on nutrient composition of corn and red root pigweed

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ABSTRACT

Sodium accumulation due to salinity stress is one of the most critical factors that seriously affect plant nutrient uptake and limits crop growth and production. Application of different sources of nitrogen not only affects crop nutrition through interference between nitrogen sources and sodium ion, but also changes crop and weed competition patterns and alters crop nutrient absorption. The current study was carried out in order to investigate the effect of salinity stress (0, 100 and 200 mM NaCl) and different sources of nitrogen (calcium nitrate, ammonium sulphate and ammonium nitrate) on sodium, potassium and nitrogen content of corn (*Zea mays* L.) and red root pigweed (*Amaranthus retroflexus* L.) in roots and shoots under competitive conditions. Consider to obtained results, competition between corn and pigweed decreased potassium and nitrogen content in roots and shoots in both species. Salinity stress showed similar results and significantly decreased nitrogen content in root and shoot of corn. In treated corn plants with 200 mM NaCl, nitrogen content decreased by 47% and 56% in roots and shoots, respectively while sodium content dramatically increased. Under conditions of salinity stress and competition, there was more reduction in potassium content of roots and shoots in corn. Root and shoot nitrogen content showed similar responses to salinity stress either under competitive conditions or lack of competition. In this study, the lowest potassium to sodium ratio was obtained from 200 mM NaCl treatment. Therefore, it can be concluded that salinity stress and competition have synergistic effect on potassium absorption. In addition, the highest potassium content in corn roots was related to calcium nitrate treatment. The highest potassium to sodium ratio in corn shoots was obtained from calcium nitrate and ammonium nitrate treatments; however there was no significant difference between these treatments. By contrast, the lowest potassium to sodium ratio in corn roots was observed in ammonium nitrate treatment. The highest sodium content in pigweed root was obtained when ammonium sulphate was applied. There was no significant difference between nitrogen sources as regards sodium content in roots of corn.

KEYWORDS: Corn, Salinity, Nitrogen sources, Competition, Red root pigweed

INTRODUCTION

Corn is one of the most important cereals in human and animal diet. Increase of corn production is one of the global purposes to supply human and animal needs. Based on cultivated area and seed production, corn is ranked as third important cereal after wheat and rice (Azizian and Sepaskhah, 2014; Ghazal et al., 2013). In corn farms, weeds cause remarkable reduction in growth and seed yield because of weak competitiveness of corn against weeds. This weakness is due to slow growth during the first stages of growth and even it has been reported that low weed densities decrease corn seed yield (Simic et al., 2012). Omovbude and Udensi (2012) stated that weeds are the most important factor in corn yield reduction and lead to 35 to 80% yield loss. Primary stages of corn growth are the most sensitive stages. Competitiveness of weed plants depends on time of appearance, type of crop and weeding time (Hussain et al., 2012). Among different species of weeds, red root pigweed is one of the most important and noxious weeds in corn farms which decrease seed yield because of its high competitiveness for sunlight and nutrients (Cagáň et al., 2010).

The level of micro and macro nutrients in the soil is a crucial factor in competition between crop and weed. Therefore, spatial and temporal fertilizers management is suitable tools in weed control management. Most of weeds are more efficient in nutrient uptake from soil than the crops so sometimes fertilizing might decrease crop yield through increase in weed competitiveness. On the other hand, under certain conditions, crops are able to uptake nutrients more efficiently than weeds and increase biomass production and prevent seed yield loss. In a study the effects of red root pigweed densities (5, 10 and 20 plant per m^2) and different levels of nitrogen (100, 160 and 22 $kg.ha^{-1}$) on corn and pigweed growth was investigated by Kristensen's team (2008). Their results indicated that the highest growth was found when 160 kg ha^{-1} nitrogen was applied while increase of nitrogen in presence of pigweed led to decrease in growth and development. Increase in nitrogen application led to increase in corn stem length during flowering stage and increase in seed number in corn and pigweed plants; however these traits in pigweed in all nitrogen levels decreased due to inter-specific

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competition. Increase in weed density increased pigweed stem length while decreased specific leaf area. The highest dry matter and seed yield was obtained when 160 and 200 kg ha^{-1} nitrogen was applied and when farm was completely free of weeds. It is worth to mention that, weed interference significantly decreased corn biomass and yield.

Salinity is one of the most important problems in agriculture which limits crop growth rate and production. Using salt tolerant species and improved soil management is needed to reduce adverse effects of salinity on crop growth and yield. Salinity has negative effect on plant transpiration, leaf water potential, stomatal conductance, leaf expansion and finally seed yield. Decrease in seed yield on account of salinity is due to decrease in seed number and weight (Azizian, and Sepaskhah, 2014). Moreover, salinity decreases corn seed germination, germination pace and seedling establishment which cause low root and shoot dry weight. It has been reported that one unit increase in salinity (more than threshold) could decrease corn yield by 14% (Zadehbagheri, 2014). Nitrogen fertilizers improve crop growth and yield under normal salinity conditions but under salinity conditions, increase in nitrogen application make crops more sensitive to salinity (Azizian, and Sepaskhah, 2014). The high levels of nitrate decrease salinity negative effects through increase in photosystem II efficiency and carbon dioxide assimilation. Although, ammonium is toxic for plants, conjugate application of nitrate and ammonium decreases negative effects of salinity (Miranda et al., 2014).

Consider to above mentioned rationales, this study was aimed to investigate the effects of salinity and different sources of nitrogen on sodium, potassium and nitrogen content of corn and red root pigweed in roots and shoots under competitive conditions.

MATERIAL AND METHODS

The current study was carried out in East Azerbaijan Agriculture and Natural Resource Research Center, Tabriz Iran under controlled conditions during 2014. The experimental design consisted of a 27 treatments were arranged factorial based on a randomized complete blocks design with three replicates, giving a total of 81 pots. Salinity (0 mM, 100 mM and 200 mM NaCl), nitrogen sources (calcium nitrate, ammonium sulphate and ammonium nitrate) and weed and crop interference (weed free, crop free and weed and crop) were experimental treatments. The corn (N.S 640) and pigweed seeds were surface sterilized for 5 min in sodium hypochlorite solution and then in 96% ethanol for 30 s and then rinsed with distilled water. Then sterilized seeds were sown in plastic pots (30cm height and 28cm diameter) filled with perlite (3-5 mm diameter) and kept under controlled conditions, maintained at 24/18±2 °C day/night (16/8 h) temperature cycles, 60% relative humidity. Watering was done immediately after seed sowing with fresh half strength Hoagland solution on alternate days. Each pot was supplied with 1 liter Hoagland nutrient solution, until 4-6 leafy stages of corn or 3-5 leafy stage of pigweed. Salt stress and nitrogen treatments were applied at 6-6 leafy stages of corn. Salinity was induced by adding NaCl to Hoagland's nutrient solution to reach 100 (EC = 8.6) and 200 mM (EC = 16.2) salinity. Electrical conductivity of Hoagland's nutrient solution was considered as control. Nitrogen treatment was applied at 10 mM concentrations from each source of nitrogen. At tasseling stage, pigweed plants were at maturity stages so crop and weed were harvested and root and shoots were separated. After drying, root and shoot samples were collected to measure sodium, potassium and nitrogen content. Sodium and potassium content in tissues were measure using flame photometer method (Flame Photometer, JenWay PFP7) and nitrogen was measured by titration method using Kjeltec Auto 1030 Analyzer, Tecator.

The results were submitted to statistical analysis using the software SAS System for Windows 9.1. The analysis of variance (ANOVA) was carried out, and based on the level of significance in the F test ($p < 0.05$). Mean values were compared using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Analysis of variance showed that inter-specific competition had significant effect on all traits of corn except for sodium content in shoots and roots and potassium to sodium ratio in shoots (Table 1). The effect of nitrogen sources was significant on potassium content in roots and potassium to sodium ratio in roots and shoots (Table 1). Salinity had significant effect on all studied traits. Interaction between competition and salinity was significant on potassium content of shoots and roots and potassium to sodium ratio in roots (Table 1). In case of red root pigweed, competition had significant effect on nitrogen content of roots and shoots, potassium content of roots and potassium to sodium ratio in roots (Table 2). The effect of nitrogen sources was significant just on sodium content in roots and potassium to sodium ratio in roots (Table 2) while effect of salinity was significant on all traits of pigweed. In addition, interaction between competition and nitrogen sources was significant on potassium to sodium ratio in roots and shoots (Table 2). Interaction between competition and salinity was significant on nitrogen content of shoots, sodium content of roots and potassium to sodium ratio in roots (Table 2). Potassium to sodium ratio in roots was affected by interaction between salinity and nitrogen sources (Table 2).

Corn's root nitrogen content

The results indicated that, inter-specific competition decreased nitrogen content in roots of corn by 11.3% (Table 3). It has been reported that weed interference decreases nitrogen uptake in corn (Azeez, and Adetunji, 2007). In addition, Lindquist and co-workers (2010) indicated that, corn nitrogen content decreased due to competition between weed and crop. Comparison of means showed that salinity decreased nitrogen content in roots of corn and this decrease was parallel with increasing salinity level. In other words, 100 and 200 mM NaCl decreased nitrogen content by 18.7 and 47.4%, respectively (Table 5).

Corn's shoot nitrogen content

Weed interference decreased nitrogen content in shoot of corn. This reduction was registered about 15.3% (Table 3). According to comparison of means, 100 and 200 mM NaCl decreased nitrogen content by 29.4 and 55.8%, respectively (Table 3).

Corn's shoot sodium content

The results reveled that, salinity significantly increased shoot sodium content in corn. 100 and 200 mM NaCl increased sodium content by 2.8 and 5.6%, respectively (Table 5). Increase of 5.5 % in sodium content in corn grown under 100 mM NaCl has been reported previously (Akram et al., 2007).

Corn's root potassium content

Under conditions of weed interference and weed free conditions, increase in salinity levels led to decrease in potassium content compared with control, however, this reduction was more in weed interference conditions. Under weed free conditions, 200 mM NaCl decreased root potassium content by 57% compared with control while this reduction was 63% when corn plants were cultivated along with pigweed (Table 7).

Głowacka (2011) has found that competition decreases potassium availability in soil and decreases potassium uptake by plants. On the other hand, sodium decrease potassium uptake twice because of its ionic characteristics. In addition, salinity suppresses root capability for nutrient uptake (Eker et al., 2006; Maqsood, 2009). In this study the highest potassium content in roots was observed when calcium nitrate was applied (Table 4).

Corn's shoot potassium content

Salinity decreased potassium content whether under weed interference or weed free conditions; however this reduction was more pronounced under weed interference conditions. Under weed free conditions, 100 and 200 mM NaCl showed similar reduction in corn shoot potassium content (Table 7). Since potassium uptake occur with help of water and salinity decreased water adsorption so salinity decreases potassium uptake (Maqsood, 2009). Therefore, it seems that competition and salinity have synergistic effect on potassium uptake inhibition. Anyways salinity decreases potassium uptake either under competitive conditions or weed free conditions. Akram and co-researchers (2007) have reported a significant decrease in potassium uptake because of salinity stress.

Corn's root potassium to sodium ratio

Salinity decreased potassium to sodium ratio in roots grown under both weedy and weed free conditions. 200 mM NaCl decreased potassium to sodium ratio by 89 and 90% in weed free and weedy conditions, respectively (Table 7). Decrease of this ratio was reported by Kaya and co-workers in 2013. According to the results under control conditions and 100 mM NaCl, competition decreased potassium to sodium ratio while under 200 mM NaCl, competition had no effect on potassium to sodium ratio. High level of salinity decreases root and shoot growth so the effect of competition is negligible. Researches believe that under strong abiotic stress conditions, competition between species dramatically decreases (Bayala et al., 2013). In this study, potassium to sodium ratio in ammonium nitrate treatment was less than calcium nitrate treatment.

Corn's shoot potassium to sodium ratio

The potassium to sodium ratio in calcium nitrate and ammonium nitrate treatments was more than ammonium sulphate treatment. There was no significant difference between calcium nitrate and ammonium nitrate in terms of potassium to sodium ratio (Table 4). Akram et al (2007) stated that 100 mM NaCl decreases potassium to sodium ration in corn. Comparison of means demonstrated that salinity decreases this ratio. 100 mM and 200 mM NaCl decreases potassium to sodium ratio 82.9 and 91.4 %, respectively (Table 5). Similar results were obtained by Turan and co-workers (2009).

Pigweed's root nitrogen content

Weed and crop competition decreased pigweed root nitrogen content by 10% (Table 3). In addition, both salinity stress levels decreased root nitrogen content so that 100 mM and 200 mM NaCl decreased root nitrogen content by 39.5 and 52%, respectively (Table 5). Decrease in root nitrogen content in pigweed has been reported by Abdel-Aziz et al in 2011.

Pigweed's shoot nitrogen content

The results showed that salinity decreased pigweed shoot nitrogen content, especially when 200 mM NaCl was applied. Interestingly, this reduction was more pronounced when pigweed plants were grown independently. In other words, under competitive conditions, pigweed shoot nitrogen content decreased by 47% due to 200 mM salinity stress while this reduction was 64% when pigweed and corn were cultivated together (Table 7). Similar results were obtained by Abdel-Aziz and co-workers (2011).

Pigweed's root sodium content

There was significant increase in root sodium content due to salinity stress so that increase in salinity levels was in parallel with increase in sodium content; however sodium accumulation in pigweed roots was more under competitive conditions. Sodium content increased three times in full pigweed pots but this increase was more than six times under competitive conditions (Table 7). We concluded that under competitive conditions sodium accumulation would increase because of allelopathic interactions. It has been reported that sodium uptake increased in wheat plants under competitive conditions (Alam et al., 2007). Alam and co-workers (2007) have studied the effect of lamb's quarters (*Chenopodium album* L.) water extract and salinity stress on wheat seed germination and observed that radicle length, shoot length and dry weight decreased. They have reported that mixture of water extract and salinity was more effective. In addition, this treatment increased calcium, potassium and sodium in shoots and roots compared with control (Alam et al., 2007). In physiological point of view, increase in sodium uptake by pigweed roots under competitive conditions, might be due to decrease in accessibility to growth sources or any disturbance in physiological processes and root weakness. For instance, Aktash and co-workers (2006) suggested that zinc decreases sodium uptake, therefore, zinc deficiency due to competition, increases sodium uptake. On the other hand, potassium deficiency increases sodium uptake (Botrini et al., 2000). In this study, ammonium sulphate increased sodium uptake compared with calcium nitrate and ammonium nitrate. There was no significant difference between calcium nitrate and ammonium nitrate fertilizers. So we concluded that nitrates decrease sodium uptake by root plants (Table 4).

Pigweed's shoot sodium content

Nitrogen sources and competition had no effect on shoot sodium content while salinity stress significantly increased sodium content compared with control. Sodium content increased by 3.4 and 5.2% due to 100 and 200 mM NaCl, respectively (Table 5). Similar results were obtained by (Abdel-Aziz et al., 2011).

Pigweed's root potassium content

Competition decreased potassium content by 16.6% in pigweed roots (Table 3). Decrease in potassium content due to competition has been reported by Tilman and co-workers (1999). In addition, salinity decreased potassium content in pigweed roots. Potassium content decreased by 53.3 and 70.6% due to 100 and 200 mM NaCl, respectively (Table 5). In a similar research, salinity decreased potassium content in pigweed plants (Abdel-Aziz et al., 2011; Omami et al., 2005).

Pigweed's shoot potassium content

Nitrogen sources and competition had no significant effect on potassium content in pigweed shoots while salinity stress decreased potassium content. Potassium content in shoots decreased by 26.6 and 44.7% due to 100 and 200 mM NaCl, respectively (Table 5). Similarly, decrease in potassium content of pigweed plants was reported by Abdel-Aziz and colleagues (2011).

Pigweed's root potassium to sodium ratio

There was no significant difference between nitrogen sources under competitive conditions. Pigweed's root potassium to sodium ratio increased when ammonium nitrate or calcium nitrate were applied (Table 6), in other words, nitrates increase potassium to sodium ratio. Similar results have been reported by Holzschuh and colleagues (2011). In both conditions, salinity decreased potassium to sodium ratio and there was nosignificant difference between salinity levels in terms of potassium to sodium ratio. In addition, there was no significant difference between competitive conditions under salinity stress (Table 7). It has been reported that pigweed plants are sensitive to salinity and accumulate sodium in tissues under salinity stress conditions (Bilalis et al., 2014).

Pigweed's shoot potassium to sodium ratio

When calcium nitrate or ammonium sulphate were applied, competition had no effect on pigweed's shoot potassium to sodium ratio, while when ammonium nitrate was applied competition between corn and pigweed decreased pigweed's shoot potassium to sodium ratio (Table 6). Salinity stress decreased pigweed's shoot potassium to sodium ratio. Potassium to sodium ratio decreased by 82.8 and 90.7% due to 100 and 200 mM NaCl, respectively (Table 5).

Table 1: Analysis of variance on nitrogen, sodium and potassium content of corn affected by competition, nitrogen sources and salinity.

S.O.V	d.f	Shoot N content	Root N content	Shoot Na content	Root Na content	Shoot K content	Root K content	K/Na in shoots	K/Na in roots
C	1	2.200**	0.214**	0.015 ns	0.167 ns	1.070**	1.450**	2.081 ns	0.864**
N	2	0.051ns	0.024 ns	0.18 ns	0.067 ns	0.111 ns	0.064**	2.802*	0.021*
C×N	2	0.048 ns	0 ns	0.022 ns	0.062 ns	0.162 ns	0.011 ns	0.45 ns	0.004 ns
S	2	16.654**	2.001**	18.911**	20.156**	7.082**	0.757**	306.302**	2.941**
C×S	2	0.27 ns	0.034 ns	0.057 ns	0.021 ns	0.435*	0.065**	0.94 ns	0.181**
N×S	4	0.161 ns	0.008 ns	0.037 ns	0.039 ns	0.114 ns	0.003 ns	1.559 ns	0.002 ns
C×N×S	4	0.055 ns	0.008 ns	0.013 ns	0.037 ns	0.134 ns	0.008 ns	0.869 ns	0.006 ns
Error	36	0.093	0.016	0.075	0.051	0.126	0.005	0.739	0.007
C.V (%)		12.41	11.45	19.77	13.05	15.9	14.74	24.63	19.69

C: Competition; N: Nitrogen sources; S: salinity. *, ** and ns: significant at 0.05, 0.01 probability level and no significant, respectively.

Table 2: Analysis of variance on nitrogen, sodium and potassium content of pigweed affected by competition, nitrogen sources and salinity.

S.O.V	d.f	Shoot N content	Root N content	Shoot Na content	Root Na content	Shoot K content	Root K content	K/Na in shoots	K/Na in roots
C	1	0.342*	0.060**	0.227 ns	0.067 ns	0 ns	0.098**	0.667 ns	0.028*
N	2	0.014 ns	0.001 ns	0.09 ns	0.869**	0.099 ns	0.002 ns	0.061 ns	0.028**
C×N	2	0.142 ns	0.001 ns	0.172 ns	0.204 ns	0.316 ns	0.007 ns	1.685*	0.020*
S	2	8.859**	1.252**	43.307**	69.727**	18.379**	1.396**	268.546**	3.470**
C×S	2	0.436**	0.007 ns	0.131 ns	0.857**	0.151 ns	0.007 ns	1.101 ns	0.068**
N×S	4	0.045 ns	0.001 ns	0.08 ns	0.079 ns	0.27 ns	0.003 ns	0.31 ns	0.015*
C×N×S	4	0.025 ns	0.008 ns	0.119 ns	0.109 ns	0.267 ns	0.007 ns	1.022 ns	0.009 ns
Error	36	0.061	0.005	0.081	0.067	0.233	0.005	0.423	0.004
C.V (%)		12.74	10.93	12.59	8.45	13.93	16.56	19.99	19.18

C: Competition; N: Nitrogen sources; S: salinity. *, ** and ns: significant at 0.05, 0.01 probability level and no significant, respectively.

Table 3: Effect of competition on nitrogen content of roots and shoots in corn and pigweed

	Shoot N content (corn)	Root N content (corn)	Shoot N content (pigweed)	Root N content (pigweed)
No competition	2.6	1.15	0.70	0.48
Competition	2.2	1.02	0.63	0.40

Values within the same column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Table 4: Effect of nitrogen sources on potassium and sodium content of roots and shoots in corn and pigweed

Nitrogen sources	Root K content (corn)	K/Na in shoot (corn)	K/Na in root (corn)	Root Na content (pigweed)
Calcium nitrate	0.5272 a	3.711 a	0.4583 a	2.994 b
Ammonium sulphate	0.4778 b	3.033 b	0.4106 ab	3.311 a
Ammonium nitrate	0.4089 c	3.722 a	0.3917 b	2.889 b

Values within the same column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Table 5: Effect of salinity on nitrogen, potassium and sodium content of roots and shoots in corn and pigweed

Salinity	Shoot N content (corn)	Root N content (corn)	Shoot Na content (corn)	K/Na in shoot (corn)	Root N content (pigweed)	Shoot Na content (pigweed)	Shoot K content (pigweed)	Root K content (pigweed)	K/Na in shoot (pigweed)
0 mM	3.444 a	1.394 a	0.3611 c	8.233 a	0.9667 a	0.5889 c	4.511 a	0.7556 a	7.694 a
100 mM	2.417 b	1.139 b	1.389 b	1.483 b	0.5833 b	2.528 b	3.389 b	0.3500 b	1.372 b
200 mM	1.522 c	0.7333 c	2.411 a	0.7500 c	0.4611 c	3.656 a	2.494 c	0.2222 c	0.6889 c

Values within the same column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Table 6: Effect of competition and nitrogen sources on potassium to sodium ratio of shoot and roots in pigweed

Competition	Nitrogen sources	K/Na in shoots	K/Na in roots
No competition	Calcium nitrate	2.956 ab	0.3389 a
	Ammonium sulphate	3.556 a	0.2233 b
	Ammonium nitrate	3.578 a	0.3556 a
Competition	Calcium nitrate	3.433 ab	0.3633 a
	Ammonium sulphate	3.067 ab	0.3433 a
	Ammonium nitrate	2.922 b	0.3467 a

Values within the same column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Table 7: Effect of competition and salinity on nitrogen, sodium and potassium of shoots and roots in corn and pigweed

Competition	Salinity	Shoot K content (corn)	Root K content (corn)	K/Na in roots (corn)	Shoot N content (pigweed)	root Na content (pigweed)	K/Na in roots (pigweed)
No competition	0 mM	3.022 a	0.8778 a	1.104 a	2.822 a	1.111 d	0.7411 b
	100 mM	2.044 b	0.6567 b	0.4067 c	2.133 bc	3.411 c	0.1189 c
	200 mM	2.056 b	0.3711 d	0.1289 de	1.122 d	4.567 b	0.05778 cd
Competition	0 mM	2.856 a	0.4922 c	0.6433 b	2.344 b	0.7778 e	0.9278 a
	100 mM	2.000 b	0.2489 e	0.1700 d	1.989 c	3.422 c	0.08889 cd
	200 mM	1.422 c	0.1811 f	0.06778 e	1.267 d	5.100 a	0.03667 d

Values within the same column and followed by the same letter are not different at P < 0.05 by an ANOVA protected Duncan's Multiple Range Test.

Conclusion

In general, results indicted that, competition affect element content either in shoots or roots of both species; however sodium content was not affected by competition between corn and pigweed. The effect of nitrogen sources was significant on root potassium content and potassium to sodium ratio in shoots and roots of corn, while this effect was significant on root sodium content and potassium to sodium ratio in roots of pigweed. Salinity affected all studied traits in both species. From the results, it can be concluded that competition decreased nutrient uptake by plants. On the other hand, salinity and competition had synergistic effect on nutrient uptake. Among nitrogen sources, calcium nitrate was known as the best nitrogen source for better nitrogen and potassium uptake in corn plants.

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