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Full Length Article

Zinc Application Improves Maize Performance through Ionic Homeostasis and Ameliorating Devastating Effects of Brackish Water

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Abstract

Zinc application is required for optimum crop growth especially in calcareous soils located in semiarid to arid regions. The use of poor quality brackish water in arid zone agriculture further poses threat to soil productivity. Effect of Zn application (0, 3 and 9 mg kg^{-1}) and sodium absorption ratio of irrigation water (SAR_{iw}; distilled-water control, 8 and 16 ($mmol_c\ L^{-1})^{1/2}$) on plant growth and mineral concentration (Ca, Na, K and Zn) in shoots of two contrasting maize cultivars (hybrid, FHY-993 and synthetic variety, C-20) were evaluated in a pot study. Plant shoots showed a significant decrease (up to 31%, on average basis) due to increasing levels of SAR_{iw} and a significant increase (up to 13%, on average basis) in dry matter with the application of Zn to soil. Both cultivars varied significantly in response to Zn application and SAR_{iw}. Maximum increase in growth was observed in FHY-993 with application of Zn; while minimum decrease in plant growth due to increased level of SAR_{iw} was observed in C-20. The results indicated mitigation of sodicity effects by Zn application especially for FHY-993 with higher Zn requirement. Zinc application reduced shoot Na concentration while increased shoot Ca and K concentration; therefore, significantly increased Ca:Na and K:Na ratios in plant shoots. Conclusively, Zn application to maize improved growth by balancing K:Na and Ca:Na concentration ratios in shoots of stressed maize. However, the response may vary among cultivars depending upon their Zn requirement and Na susceptibility.

Keywords: Brackish water; Ionic ratios; Maize; SAR_{iw}; Zinc

Introduction

Scarcity of good quality irrigation water is limiting crop production especially in arid and semi-arid areas of the world. Farmers, therefore, are using recycled municipal or brackish underground water for irrigation (Qadir and Oster, 2004). In many parts of the world, use of brackish water for irrigation has been the main source of Na salts to agricultural lands. More than 0.8 billion hectares of world land surface is affected by high levels of salts in the soil, mainly due to secondary salt accumulation (FAO, 2008).

High sodium adsorption ratio of irrigation water (SAR_{iw}) results in several hazardous effects on soil quality and crop productivity. Sodicity reduces plant growth by altering ionic balances in the soil solution and within plant tissues (Zulfiqar *et al.,* 2012; Anil *et al*., 2005; Arzani, 2008) and influence physical properties of the soil (Qadir and Oster, 2004). Previous studies clearly indicated that the growth of most of the crop plants is hampered by high Na:Ca ratios in root medium; a characteristic of irrigation water of high SAR (Hu and Schmidhalter, 1997). Calcium is a structural component of plasma membrane and its deficiency disintegrate membranes causing leakage of electrolytes. Balanced Ca in plant tissues may prevent excessive Na uptake by roots (Pratiksha *et al*., 2010). Lack of good quality irrigation water impels to utilize the brackish water, but we must use some ameliorative strategies to cope with deleterious effects of sodic water for both economic and environmental concerns.

Worldwide soil Zn deficiency (White and Zasoski, 1999: Rafique *et al*., 2006) in arid and semi-arid areas is generally associated with salinity and calcareousness (Rashid and Rayan, 2004). Combination of sodicity and Zn deficiency can affect more than the single stress. Similar to Ca, structural and functional integrity of cell membrane is maintained by optimum Zn supply (Cakmak and Marschner, 1988). With limited Zn supply, decreased integrity and increased permeability of cell membranes are reported (Cakmak, 2000). This increases entry and accumulation of Na in plant tissues. Therefore, Zn application in sodic/saline sodic soils may be more beneficial as compared to normal soils (Alloway, 2008; Ahmad *et al.*, 2012a, b).

Maize (*Zea mays* L.) is sensitive to Zn deficiency and maize hybrids, in contrast to synthetic varieties, require

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greater rates of Zn application (Kanwal *et al*., 2009; Hussain *et al*., 2010a; 2011a). Though some work has been reported for differential Zn utilization efficiency of wheat genotypes under saline soils (Khoshgoftarmanesh *et al*., 2004), however the differential Zn requirement of maize hybrids and synthetic varieties has never been reported under irrigation with brackish water. The present study was conducted, therefore, to evaluate the effect of Zn application (0, 3 and 9 mg kg^{-1}) and SAR_{iw} (control, 8 and 16 ($mmol_c$ $L^{-1})^{1/2}$) on plant growth and mineral (Ca, Na, K and Zn) concentrations in shoots of two contrasting maize cultivars (hybrid, FHY-993 and synthetic variety, C-20).

Materials and Methods

Alkaline calcareous soil for the experiment was bulk sampled (0–15 cm depth). Air-dried soil was ground and sieved for larger particles by using a 2.0-mm sieve. Three homogeneous and representative subsamples of the sieved soil were used for soil characterization. Loam texture of the soil was determined by hydrometer method (Gee and Bauder, 1986). Soil had pH_s 7.93 and EC_e of 1.79 dS m^{-1} with 0.85% organic matter (Nelson and Sommers, 1982). Calcium carbonate ($CaCO_3$), 33 g kg^{-1} soil, was determined by acid dissolution (Allison and Moodie, 1965). Sodium adsorption ratio (SAR) of the soil was 7.2 ($mmol_c$ $L^{-1})^{1/2}$. Soil had 0.62 mg kg^{-1} DTPA-extractable Zn as measured on atomic absorption spectrophotometer (AAS) (Lindsay and Norvell, 1978).

Each pot was filled with 5 kg sieved soil. Various treatments comprising of three Zn rates (0, 3 and 9 mg Zn kg^{-1} soil), two maize cultivars (hybrid, FHY-993 and synthetic variety, C-20) and three levels of SAR_{iw} (distilled-water control, 8 and 16 ($mmol_c$ $L^{-1})^{1/2}$) were arranged in 3-factorial completely randomized design. Different SAR levels in the irrigation water were developed at a constant EC of 2 dS m^{-1} by using sodium chloride (NaCl), sodium sulphate (Na_2SO_4), calcium chloride ($CaCl_2$) and magnesium sulphate ($MgSO_4$) (Haider and Ghafoor, 1992). Uniform basal doses of 60 mg N, 45 mg P and 30 mg K kg^{-1} soil were applied to all the pots using urea, ammonium dihydrogen phosphate and potassium sulfate. Zinc sulfate ($ZnSO_4.7H_2O$) was used as a source of Zn and applied in solution form. After fertigation with NPK and Zn fertilizers, the soil in each pot was thoroughly mixed and equilibrated for one week before sowing.

Five pre-soaked seeds of maize cultivars were sown in each pot. After ten days, two seedlings per pot were maintained. For earlier ten days, pots were irrigated with distilled water. Soil was kept at field capacity for 40 more days with water of different SAR levels. Average temperature in the glasshouse was 30 ± 5°C at midday and 20 ± 3°C at midnight.

After fifty days of growth, plant shoots were harvested and oven dried at 70°C till a constant weight. The samples were then ground to 40-mesh. A homogenous portion of finely ground shoot samples was digested in a di-acid (HNO_3:$HClO_4$ ratio of 2:1) mixture (Jones and Case, 1990). Zinc and Ca concentration in the digest was estimated on AAS (PerkinElmer, 100 AAnalyst, Waltham, USA). Sodium and K in the digest were determined by flame photometer (Model 410, Thermo Electron Limited, Cambridge, UK).

Data of shoot dry matter and mineral content were statistically analyzed by using *Statistix 9*®. Means were separated by using least significance difference (LSD) test (Steel *et al*., 1997) at $\alpha = 0.05$.

Results

Shoot Growth

Main effects cultivar, SAR_{iw} and Zn application and interaction effect of cultivar each with Zn application and SAR_{iw} significantly ($P \leq 0.05$) influenced dry matter of maize cultivars (Table 1). Shoot dry matter of both FHY-993 and C-20 significantly decreased by increasing SAR_{iw} with minimum dry matter produced by FHY-993 at highest level of SAR_{iw} [16 ($mmol_c$ $L^{-1})^{1/2}$]. This decrease in shoot dry matter of C-20 was also similar (about 30%, over control) at the highest level of SAR_{iw} [16 (mmolc $L^{-1})^{1/2}$].

Incremental addition of Zn significantly increased shoot dry matter of both maize cultivars. Irrespective of SAR_{iw}, maximum shoot dry matter was found at 9 mg Zn kg^{-1} soil for FHY-993 and at 3 mg Zn kg^{-1} soil for C-20.

At 3 mg Zn kg^{-1} soil, 15% increase in shoot dry matter of C-20 was comparable to control with no Zn supply. A similar increase in shoot dry matter of C-20 was also observed at 8 SAR_{iw} and 16 SAR_{iw} ($mmol_c$ $L^{-1})^{1/2}$ (Table 1). For FHY-993, at different SARs, 13-35% increase in shoot dry matter was achieved at 9 mg Zn kg^{-1} soil than control.

Concentration and Content of Zn in Shoots

There were significant ($P \leq 0.05$) effect of cultivar, Zn application and SAR_{iw} on concentration of Zn in maize shoots (Fig. 1a). Zinc concentration in shoots of maize cultivars ranged from 15 to 59 mg Zn kg^{-1} at different levels of Zn and SAR_{iw}. At each level of SAR_{iw}, incremental Zn rates progressively increased shoot Zn concentration in both cultivars. On average, shoot Zn concentration was maximum at the highest SAR_{iw} [16 ($mmol_c$ $L^{-1})^{1/2}$].

Shoot Zn content was also significantly ($P \leq 0.05$) influenced by cultivar, SAR_{iw} and Zn application (Fig. 2b). On average, Zn application increased shoot Zn content by 1.2-folds at 3 mg kg^{-1} soil and 2.8-folds at 9 mg kg^{-1} soil.

Concentration of Na, Ca and K

Concentration of Na in shoots significantly ($P \leq 0.05$) increased in parallel to the incremental levels of SAR_{iw} and decreased with increasing Zn rates (Table 2). However,

Table 1: Shoot dry matter (g pot^{-1}) of two maize cultivars at different SAR_{iw} values and supplied with different Zn rates

Zn rates (mg kg^{-1})	FHY-993	C-20	FHY-993	C-20	FHY-993	C-20	Means
	Control		8 SAR_{iw}		16 SAR_{iw}		
0	15.00	15.90	11.50	11.17	9.17	10.96	12.28
3	16.00	18.23	12.21	12.88	11.10	12.63	13.84
9	16.89	16.50	13.03	12.33	12.35	12.03	13.85
Means	15.96	16.88	12.24	12.13	10.87	11.87	70.06
	16.42		12.18		11.37		

$LSD_{(0.05)}$ for shoot dry matter (cultivar = 0.34; Zn application = 0.41; SAR_{iw} = 0.41; cultivar × Zn application = 0.59; cultivar × SAR_{iw} = 0.59). Other interaction effects were non-significant α = 0.05

Table 2: Mineral concentration in shoots of two maize cultivars at different SAR_{iw} values and supplied with different Zn rates

Zn rates (mg kg^{-1})	FHY-993	C-20	FHY-993	C-20	FHY-993	C-20	Means
	Control SAR_{iw}		8 SAR_{iw}		16 SAR_{iw}		
Shoot Na concentration (mg Na g^{-1})							
0	8.93	6.69	15.62	14.73	19.19	18.97	14.02
3	5.36	4.24	11.83	12.27	15.17	15.62	10.75
9	3.57	3.12	9.15	9.37	12.94	14.50	8.78
Means	5.95	4.69	12.20	12.12	15.77	16.36	
	5.32		12.16		16.07		
Shoot Ca concentration (mg Ca g^{-1})							
0	3.21	3.37	4.05	3.69	4.53	4.65	4.59
3	3.65	3.77	4.33	4.45	4.73	4.77	4.75
9	4.09	4.45	4.53	4.65	4.85	5.01	4.93
Means	3.65	3.87	4.31	4.27	4.71	4.81	
	3.76		4.28		4.76		
Shoot K concentration (mg K g^{-1})							
0	48.5	44.5	45.5	40.2	39.3	36.3	42.4
3	45.8	49.8	41.6	44.2	37.6	40.2	43.2
9	50.5	46.5	46.5	42.6	40.6	37.3	44.0
Means	48.3	46.9	44.5	42.3	39.2	37.9	
	47.6		43.4		38.6		

$LSD_{(0.05)}$ for shoot Na concentration (Zn application = 0.88; SAR_{iw} = 0.88) shoot Ca concentration (Zn application = 0.20; SAR_{iw} = 0.20) and shoot K concentration (cultivar = 1.3; SAR_{iw} = 1.6; cultivar × Zn application = 2.3). Other main and interaction effects were non-significant α = 0.05

there was a significant ($P \leq 0.05$) increase in shoot Ca concentration with the application of Zn to root medium. Calcium concentration also increased significantly by increasing levels of SAR_{iw}. Nevertheless, Ca:Na concentration ratio decreased with increasing SAR_{iw} (Fig. 2a). At each rate of Zn, Ca:Na ratio was maximum for 0 SAR_{iw}. With no Zn application, however, Ca:Na ratios were similar for 8 and 16 SAR_{iw} levels ($mmol_c\ L^{-1})^{1/2}$.

Contrary to shoot Na concentration, concentration of K decreased significantly ($P \leq 0.05$) at higher levels of SAR_{iw} (Table 2). Compared to the 0 SAR_{iw}, decrease in K concentration was 9% at SAR_{iw} and 19% at SAR_{iw} level of 16 ($mmol_c\ L^{-1})^{1/2}$. The resultant K:Na concentration ratio was significantly ($P \leq 0.05$) affected by main and interaction effects of Zn application and SAR_{iw} along with cultivar × SAR_{iw} interaction (Fig. 2b). Increasing levels of SAR_{iw} significantly ($P \leq 0.05$) and progressively decreased K:Na concentration ratio in both cultivars. On average, application of 9 mg Zn kg^{-1} soil resulted in maximum K:Na concentration ratio in maize shoots.

Discussion

Plant biomass was decreased significantly as SAR_{iw} increased (Table 1). High Na in root medium disturbs uptake of both water and minerals from soil (Arzani, 2008) and causes osmotic effect (George *et al*., 2012). High Na in root zone affects shoot K concentration resulting in increased Na:K ratio (Tahir *et al*., 2011). Therefore, photosynthesis and other biochemical processes are disturbed resulting in reduction of plant growth (Parida and Das, 2005) as observed in present study. The imbalanced concentration of minerals in the root medium affects nutrient uptake from the soil and their utilization in the plant body (Katerji *et al*., 2004). Imbalanced nutrition may cause variations in nutritional requirements in stressed plants. Excesses Na in root medium reduces membrane permeability to Ca and Zn causing leakiness. In contrary, Zn and Ca play a key role in stability of cell membrane (Broadley *et al*., 2012; Hawkesford *et al*., 2012) and therefore, help the plants in selective uptake of required minerals.

Zinc deficiency is generally reported on soils affected by sodicity and Zn application in such situations increases plant growth by increasing shoot Zn concentration (Alloway, 2008). The soil used for the present study was Zn deficient containing 0.62 mg Zn kg^{-1} soil. Therefore, application of Zn significantly increased plant growth both in normal (0 SAR_{iw}) and Na stressed (8 and 16 SAR_{iw})

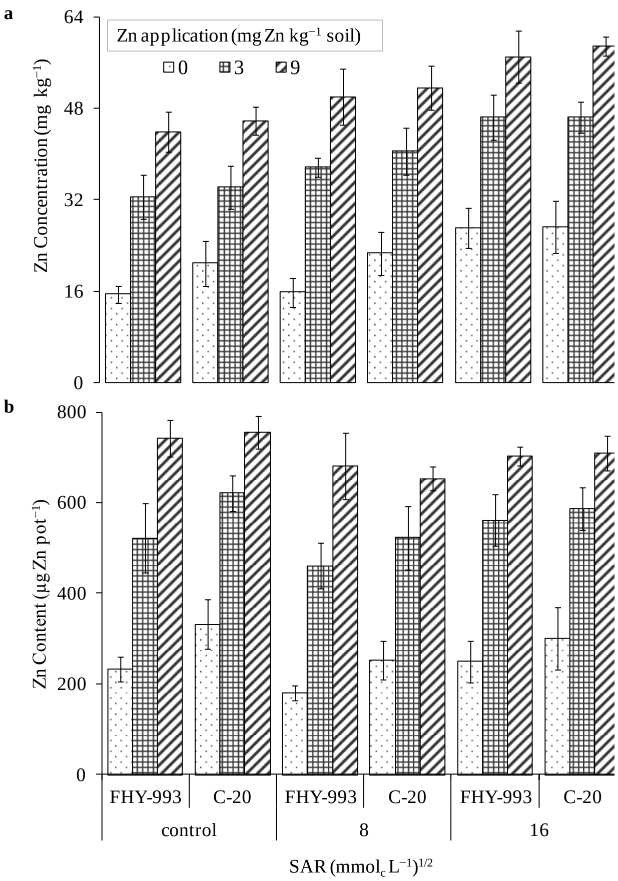

Fig. 1: Shoot Zn concentration (a) and content (b) in maize cultivars (FHY-993 and C-20) at SAR_{iw} levels. $LSD_{(0.05)}$ for shoot Zn concentration/content: cultivar 1.95/28; Zn application 2.39/34; SAR_{iw} 2.39/34. All interaction effects were non-significant at $\alpha = 0.05$

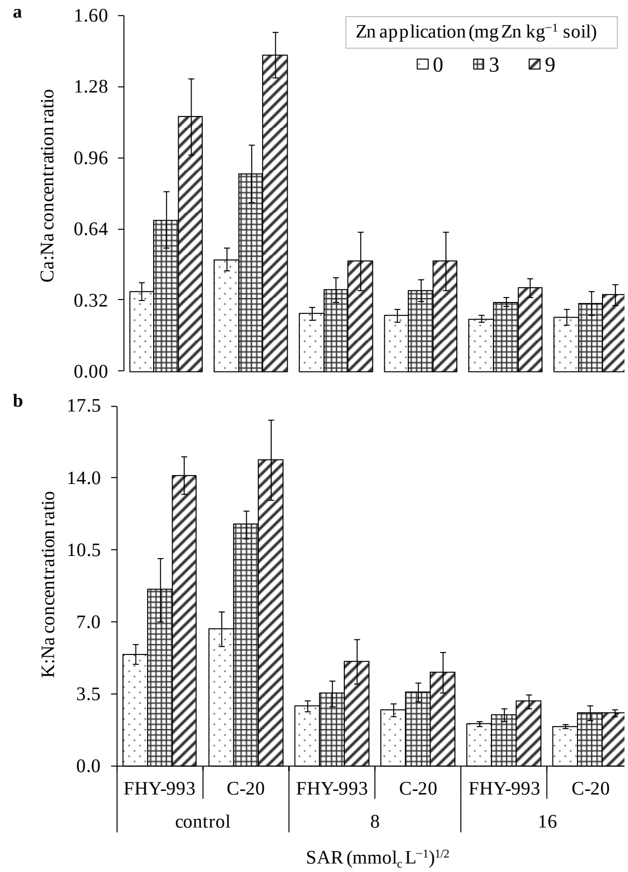

Fig. 2: Effect of Zn application on Ca:Na (a) and K:Na ratios (b) of maize cultivars at different SAR_{iw} levels. $LSD_{(0.05)}$ for shoot Ca:Na ratio/K:Na ratio: cultivar = 0.05/NS; Zn application = 0.06/0.55; SAR_{iw} = 0.06/0.55; cultivar × SAR_{iw} = 0.08/0.77; Zn application × SAR_{iw} = 0.10/0.95. Main and interactive effects without LSD values were non-significant $\alpha = 0.05$

plants (Table 1). However, shoot Zn concentration in maize plants also increased at higher SAR_{iw} (Fig. 1a). This is possibly due to negative growth dilution attributed to greater reduction of plant growth at higher levels of SAR_{iw} (Turan *et al*., 2010).

At higher levels SAR_{iw}, Na is responsible for reduced plant growth ($r = -0.89$) and imbalanced plant nutrition and it is accumulated in high concentration in plant tissues (Table 2). Any factor reducing Na uptake and/or accumulation within plant can improve salt tolerance. In present study, Zn application significantly reduced Na concentration in maize shoots (Table 2), thus improved salinity tolerance. This can be attributed to positive effects of Zn application on membrane stability and increased plant growth on Zn deficient and Na stressed plants (Genc *et al*., 2005). This also coincides with enhanced Na accumulation in barley plants under low Zn supply (Norvell and Welch, 1993), while a sufficient Zn supply reduced Na accumulation and contributed to salt tolerance in tomato plants (Alpaslan *et al*., 1999).

Similar to findings of the present study, differential Zn requirement of maize hybrids and synthetic varieties is previously reported (Kanwal *et al*., 2009; Hussain *et al*., 2010a) at 0 SAR_{iw}. Present investigation further indicated mitigation of sodicity effects by Zn application especially for the hybrid (FHY-993) as indicated by greater percent increase in shoot dry mater at 8 and 16 $(mmol_c\ L^{-1})^{1/2}$ SAR_{iw} (Table 1).

Higher SAR_{iw} and Zn application also significantly affected Ca concentration in plant shoots (Table 2). However, these are in contrast to other reports where only NaCl was used to develop salinity in the root medium (Lazof and Bernstein, 1999; Safavi and Khajehpour, 2007; Yildirim *et al*., 2009) or worked on natrophilic plants (Wakeel *et al*., 2009). This increase in Ca concentration may be due to negative growth dilution similar to Zn concentration. For present study, sodicity levels were imposed by mixture of various salts and Ca:Na concentration ratio seems to be interesting. These low

Ca:Na concentration ratios at higher levels of SAR_{iw} (Fig. 2a) indicated that uptake and transport of Ca was impaired by Na that resulted in reduced plant growth (Hussain *et al*., 2010b; 2011b). Moreover, application of Zn significantly increased Ca:Na concentration ratio in shoots and it indicates the importance of Zn in balanced ionic ratios in plant tissues.

Various researchers have demonstrated the antagonistic relationship between K and Na in maize and other plant species (Beck *et al*., 2004; Kronzucker *et al*., 2006) and higher K:Na concentration ratio is often reported as good indicator of high salt tolerance in plants (Maqsood *et al.*, 2008; Munnus *et al*., 2006). Excessive Na accumulation in plant body disturbs nutrient balances, osmotic regulation and causes specific ion deficiencies and toxicities (Katerji *et al*., 2004; Arzani, 2008; Tahir *et al*., 2011). Potassium concentration in shoots was greatly decreased at higher levels of $SAR_{iw.}$

In conclusion, shoot dry matter of both maize cultivars decreased by increasing levels of SAR_{iw} while increased with Zn application. At all levels of SAR_{iw}, incremental Zn progressively increased shoot Zn concentration and decreased Na concentration in both maize cultivars. The results indicated mitigation of sodicity effects by Zn application especially for hybrid FHY-993 with higher Zn requirement. Therefore, optimum Zn nutrition mitigates salt stress as indicated by improved growth and balanced K:Na and Ca:Na concentration ratios.

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