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Interactive Effects of NaCl Levels and Zinc Sources and Levels on the Growth and Mineral Composition of Rice

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ABSTRACT

The effects of sodium chloride and Zn rates and sources on the growth and chemical composition of lowland rice (*Oryza sativa* L.) were studied using calcareous soil in a greenhouse experiment. The treatments comprised 5 levels of NaCl (0, 12.5, 25, 37.5 and 50 mmol kg^{-1} soil), three Zn rates (0, 5 and 10 mg kg^{-1} soil) and two Zn sources ($ZnSO_4$, $2H_2O$ and ZnEDTA). Applied salinity decreased shoot dry weight, leaf area and chlorophyll concentration, whereas Zn supply significantly increased these growth parameters. However, the enhancing effect of soil Zn fertilization was more pronounced at lower NaCl levels than under higher salt stress, irrespective of Zn sources. Concentrations of Zn, P and K were significantly decreased and those of Na and Cl increased in NaCl-treated plants. Zn application markedly increased Zn concentration and decreased Na and Cl and P accumulation in shoots. Moreover, there was a significant difference between the two Zn sources to affect rice growth. Free proline increased but reducing sugars decreased with an increase in the levels of substrate NaCl. However, Zn-untreated rice contained higher proline and reducing sugars than Zn-treated plants. Furthermore, an increase in proline was greater in the presence than in the absence of Zn and with $ZnSO_4$ than with ZnEDTA. It is concluded that a decrease in soil osmotic potential, nutrient imbalance and excessive plant accumulation of Na and Cl in NaCl-treated plants caused growth suppression, whilst Zn supply decreased the suppressing effects of excess salt on rice growth. Therefore, it is recommended that for growing rice in saline soils that are low in available Zn, Zn should be supplied in a adequate quantities.

Keywords: Calcareous soil, NaCl, Proline, Reducing sugars, Zinc.

INTRODUCTION

Soil salinity is one of the major constraints of arid and semiarid regions, where soluble salts are frequently high in the soil or in irrigation water. It adversely affects the growth of most agricultural crops through its influence on certain aspects of plant metabolism such as osmotic adjustment (Bernstein, 1963), the uptake of certain essential nutrients (Greenway *et al*., 1966), photosynthesis (Downton, 1977), and enzyme activity (Weimberg, 1970) as well as causing hormonal imbalance (Shah and Loomis, 1965).

In recent years, due attention has been paid to the potential use of saline soils for crop production in arid and semiarid regions. One approach to overcoming the suppressive influence of excess soluble salts is improvement in the nutritional status of such soil. Soil fertilization has sometimes offset the nutritional stress encountered in saline conditions. In this regard, the interaction between salinity and macronutrients (Cerda *et al*., 1977; Sameni *et al*., 1980; Satti *et al*., 1994; Shahdi, 1994) and micronutrients (El-Sherif *et al*., 1993; Hosseini *et al*., 2004; Keshavarz and Malakouti, 2005; Khoogar *et al*., 1999; Gupta and Gupta, 1984; Ravikovitch and Navrot,

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1976) has been noted. However, studies on soil salinity-Zn interaction in paddy fields are rather scarce for the calcareous soils of Iran. The present experiment was, therefore, initiated in order to study the main and combined effects of NaCl and soil Zn fertilization on the growth and chemical composition of lowland rice in an arid region with a highly calcareous soil.

MATERIALS AND METHODS

A surface 20 cm layer of an alluvial calcareous soil (Fine-loamy, hyperthermic Typic Ustorthents) with a pH of 7.5 (saturated paste), EC_e of 0.5 dS m^{-1}, cation exchange capacity (CEC) of 27.4 $cmol_c^+$ kg^{-1} soil, calcium carbonate equivalent (CCE) of 530 g kg^{-1}soil, organic matter (OM) of 25 g kg^{-1} soil, $NaHCO_3$-extractable P of 15.5 mg kg^{-1} soil, CH_3COONH_4-extractable K of 54 mmol kg^{-1} soil and DTPA-extractable Zn of 0.40 mg kg^{-1} soil was used in this experiment. There were five levels of NaCl (0, 12.5, 25, 37.5 and 50 mmol kg^{-1} soil), three levels of Zn (0, 5 and 10 mg kg^{-1} soil) and two Zn sources ($ZnSO_4$,$7H_2O$ and ZnEDTA), replicated three times in a factorial manner as a completely randomized design. N, P, Fe, Mn, and Cu were uniformly applied to each pot containing 2 kg air-dried soil at the rate 150, 25, 5, 5, and 2.5 mg kg^{-1} soil as $CO(NH_2)_2$, KH_2PO_4, FeEDDHA, $MnSO_4$, and $CuSO_4$, respectively.

Ten rice (*Oryza sativa* L.) seeds, Var. Ghasrdashty, were sown in each pot when the soil moisture was at field capacity. The rice seedlings were thinned to four uniform stands two weeks after planting and the soil was flooded to a height of 3 cm above the soil surface for the rest of the experiment. Prior to harvesting, the chlorophyll concentration was measured using a handy chlorophyllmeter (Model SPAD-502) in the most recently matured leaves and the leaf area per pot was determined using a planimeter. Free proline and reducing sugars were measured following the methods of Bates *et al*. (1973) and Nelson (1944), respectively.

After 56 days of growth in the greenhouse, the shoots were harvested, rinsed with distilled water, dried at 65°C for 48 h, weighed, ground and dry-ashed at 500°C. The sodium (Na) and potassium (K) concentrations were determined by flame photometry and Zn by atomic absorption (Model Varian 220 made in Australia). Chloride (Cl) concentration was determined by the procedure outlined by Chapman and Pratt (1961) and the phosphorus by colorimetry. Calcium (Ca) and magnesium (Mg) concentrations were determined by titration with EDTA. All data were subjected to the analysis of variance and mean comparisons were performed by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Increasing NaCl levels significantly reduced the shoot dry weight of rice while the application of either sources of Zn markedly enhanced it (Table 1). However, the enhancing effect of Zn supply on rice shoot yield was more pronounced at lower than higher NaCl levels. For instance, soil application of 10 mg Zn kg^{-1} increased shoot growth by 343 and 81% with 25 and 50 mmol NaCl kg^{-1} soil, respectively. With the same Zn level as ZnEDTA, those increases for the same NaCl rates were 225 and 118%, respectively.

The decline in rice growth as a result of salt stress has been reported by others (Fageria, 1985; Heenan *et al*., 1988; Shahdi Komole, 1994; Shannon *et al*., 1998; Zeng and Shannon, 2000). The rice growth suppression in saline media might be due to the depressing effect of excess soluble salts on photosynthesis, absorption of essential plant nutrients, respiration, protein and nucleic acid synthesis, enzyme activity and availability of soil water for plants. Several research workers have observed enhanced shoot growth of rice with Zn supply (Hosseini and Maftoun, 2005; Venkata and Mehta, 1974; Sajwan and Lindsay, 1988; Maftoun *et al*., 2003). Such an effect was anticipated due to the low level of DTPA-

Table 1. Effects of NaCl levels and Zn sources and levels on rice shoot dry weight (g pot $^{-1}$).

Zn source	Applied Zn (mg kg soil $^{-1}$)	NaCl levels (mmol kg^{-1} soil) 0	12.5	25	37.5	50	Mean
$ZnSO_4$	0	6.81 c [a]	4.04 c	3.51 c	3.28 c	3.23 b	4.17 c
	5	17.42 b	13.91 b	13.19 b	9.21 b	5.72 a	11.89 b
	10	19.12 a	16.04 a	15.54 a	10.89 a	5.86 a	13.43 a
	Mean	14.45 A	11.33 B	10.75 C	7.80 D	4.93 E	
ZnEDTA	0	7.66 c	4.85 c	3.85 b	3.41 b	2.84 b	4.52 c
	5	16.51 b	14.40 b	12.89 a	9.16 a	6.05 a	11.64 b
	10	19.40 a	16.14 a	12.53 a	8.37 a	6.20 a	12.53 a
	Mean	14.52 A	11.80 B	9.49 C	6.98 D	5.03 E	

[a] For each zinc source, values followed by the same small letter in each column or capital letter in each row, are not significantly different at $p \leq 0.05$.

extractable Zn in the soil used in our study (0.41 mg kg^{-1}). Zinc sulfate stimulated rice growth more than ZnEDTA. The addition of 10 mg Zn kg soil^{-1} as $ZnSO_4$ increased average shoot dry weight by 222% as compared to the control, while this increase with ZnEDTA was 177%.

One of the obvious morphological changes in the salt stressed rice plants was a reduction in leaf area, whereas Zn supply from either source significantly increased this growth parameter at any NaCl level (Table

Table 2. Effects of NaCl levels and Zn sources and levels on leaf area and chlorophyll content of rice.

Zn source	Applied Zn (mg kg $^{-1}$ soil)	NaCl level (mmol kg $^{-1}$ soil) 0	12.5	25	37.5	50	Mean
		Leaf area (cm^2 pot $^{-1}$)					
$ZnSO_4$	0	328 c [a]	265 c	253 b	124 c	85 b	211 c
	5	1183 b	647 b	605 a	341 b	226 a	600 b
	10	1211 a	696 a	606 a	370 a	229 a	622 a
	Mean	908 A	536 B	488 C	278 D	180 E	
ZnEDTA	0	360 c	277 b	244 b	122 b	78 b	216 c
	5	1192 b	653 a	552 a	318 a	213 a	586 b
	10	1214 a	668 a	571 a	331 a	224 a	602 a
	Mean	2089 A	533 B	456 C	257 D	172 E	
		Chlorophyll content (mg g $^{-1}$ leaf)					
$ZnSO_4$	0	1.97 b	1.84 b	1.51 c	1.17 b	1.04 b	1.51 b
	5	2.51 a	2.38 a	2.04 b	1.72 a	1.68 a	2.07 a
	10	2.52 a	2.35 a	2.18 a	1.75 a	1.69 a	2.10 a
	Mean	2.33 A	2.19 B	1.92 C	1.55 D	1.47 E	
ZnEDTA	0	1.93 b	1.76 b	1.49 c	1.19 b	1.08 b	1.52 b
	5	2.53 a	2.41 a	2.01 b	1.75 a	1.55 a	2.10 a
	10	2.52 a	2.34 a	2.14 a	1.75 a	1.67 a	2.14 a
	Mean	2.32 A	2.17 B	1.88 C	1.56 D	1.43 E	

[a] For each zinc source and each plant parameters, values followed by the same small letter in each column or capital letter in each row, are not significantly different at $p \leq 0.05$.

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2). However, the enhancing effect of Zn supply on leaf area became less evident at elevated levels of NaCl. For instance, a 269% increase in leaf area was observed with 10 mg Zn kg^{-1} in nonsaline soil, while the increase in 50 mmol NaCl treated soil was 169%. The smaller leaf area in NaCl-treated plants could be explained by a decline in protein synthesis in response to a water deficit in the expanding leaves (Zerbi *et al*., 1990). Chlorophyll concentration, taken as an indicator of salinity tolerance (Lee *et al*., 1992), decreased with increased NaCl levels. Whereas Zn-treated rice plants contained more chlorophyll than untreated ones regardless of the Zn source and/or NaCl rates (Table 2). The relationship between Cl and Na concentrations and chlorophyll content was computed by regression analysis which revealed a negative relationship between the chlorophyll and Cl (R^2= 0.99) and Na (R^2= 0.96) concentrations in the rice leaves. This indicated that as the Na and Cl concentrations increased, the chlorophyll concentration in leaves declined. Yeo and Flowers (1983) observed an inverse relationship between chlorophyll and Na concentrations in rice leaves.

The concentration of Zn in the rice shoots as a function of the Zn source and level and NaCl rate in the media is shown in Table 3. Zinc concentration was reduced greatly with an increasing NaCl concentration. These findings do not agree with those reported by Fageria (1985) in rice, Maas *et al*. (1972) in tomato and soybean, Nouri *et al*. (1970) in barley and Khoogar *et al*. (1999) in tomato. A plausible reason for such inconsistency is the difference in the experimental conditions. Ravikovitch and Navrot (1976) observed that soil salinity had little effect on Zn concentration in tomato tops in soil with high native Zn while, in Zn deficient soil, Zn concentration was increased by salinity in Zn-untreated as well as Zn-treated soil. Maas *et al*. (1972) found that NaCl treatment had little effect on Zn concentration in squash tops. NaCl appears to have had a specific inhibitory effect on Zn absorption by the rice cultivar used in this study. Zinc application significantly increased the Zn concentration in rice shoots in nonsaline as well as saline soil (Table 3).

The effects of NaCl levels and zinc sources and levels on Cl and Na concentration in the rice shoot, are shown in Tables 4 and 5. Although the concentration of Na was lower than that of Cl, changes in both were due to soil NaCl and were less affected by Zn addition. The plant Cl and Na concentrations were substantially increased by application of NaCl. The fact that the concentration of sodium was considerably lower than that of Cl, indicates that rice appears to have no regulatory control on Cl absorption. Gates *et al*. (1970) have noted that, although both Cl and Na ions are readily absorbed by plant roots, a greater portion of Cl is translo-

Table 3. Effects of NaCl levels and Zn sources and levels on Zn concentration in rice shoot (mg kg^{-1} dry wt.)

Zn source	Applied Zn (mg kg $soil^{-1}$)	NaCl levels (mmol kg^{-1} soil) 0	12.5	25	37.5	50	Mean
$ZnSO_4$	0	34.5 c [a]	28.7 c	25.6 c	22.5 c	20.2 c	26.3 c
	5	76.6 b	67.0 b	59.5 b	50.2 b	39.7 b	58.6 b
	10	102.3 a	86.2 a	70.9 a	55.8 a	41.1 a	71.2 a
	Mean	71.1 A	60.6 B	52.0 C	42.8 D	33.7 E	
ZnEDTA	0	35.0 c	28.9 c	26.0 c	25.3 c	21.5 c	27.3 c
	5	78.8 b	69.9 b	60.7 b	50.8 b	40.5 b	60.1 b
	10	98.3 a	89.9 a	68.2 a	59.7 a	42.3 a	71.7 a
	Mean	70.7 A	62.9 B	51.6 C	45.3 D	34.8 E	

[a] For each zinc source, the values followed by the same small letter in each column or capital letter in each row, are not significantly different at p≤ 0.05.

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Table 4. Effects of NaCl and $ZnSO_4$ levels on Cl and Na concentrations (%) in rice shoot.

NaCl level (mmol kg $^{-1}$ soil)	Applied Zn (mg kg $^{-1}$ soil) 0	5	10	Mean
	Cl concentration (%)			
0	0.643 e [a]	0.633 d	0.617 e	0.631 e
12.5	3.133 d	3.113 c	3.097 d	3.114 d
25	3.397 c	3.383 b	3.380 c	3.387 c
37.5	3.703 b	3.713 a	3.700 b	3.706 b
50	3.770 a	3.763 a	3.760 a	3.764 a
Mean	2.929 A	2.921 AB	2.911 B	
	Na concentration (%)			
0	0.200 e	0.183 c	0.183 c	0.189 e
12.5	0.880 d	0.867 b	0.857 b	0.868 d
25	0.933 c	0.920 b	0.917 b	0.923 c
37.5	1.230 b	1.217 a	1.197 a	1.214 b
50	1.283 a	1.270 a	1.263 a	1.272 a
Mean	0.905 A	0.891 B	0.883 C	

[a] For each plant parameter, values followed by the same small letter in each column or capital letter in each row, are not significantly different at $p\leq 0.05$.

cated to the shoots, whereas Na tends to remain in the root.

Regression equations describing the relationship between relative shoot growth and Cl and Na concentrations in the rice shoot were computed as below:

Y= –1.60Cl^2+0.23Cl+37.83
R2= 0.99 ** (Zn=0)
Y= –17.97Cl^2+62.95Cl+55.49
R2= 0.94 ** (Zn=5)
Y= –22.20Cl2+77.30Cl+60.52
R2= 0.96 ** (Zn=10)
Y= 8.75Na^2-32.73Na+43.72
R^2= 0.98 ** (Zn=0)
Y= –63.94Na^2+45.74Na+81.79
R^2= 0.96 ** (Zn=5)
Y= –80.10Na^2+57.21Na+92.01
R^2=0.98 ** (Zn=10)

Where Y= Relative shoot growth (%), Cl = Plant Cl concentration (%) and Na = Plant Na concentration (%). Based on these equations, the Cl and Na concentrations required

Table 5. Effects of NaCl and ZnEDTA levels on Cl and Na concentrations (%) in the rice shoot.

NaCl level (mmol kg $^{-1}$ soil)	Applied Zn (mg kg $^{-1}$ soil) 0	5	10	Mean
	Cl concentration (%)			
0	0.647 e [a]	0.627 d	0.623 e	0.632 e
12.5	3.120 d	3.103 c	3.090 d	3.104 d
25	3.410 c	3.387 b	3.370 c	3.389 c
37.5	3.693 b	3.707 a	3.683 b	3.694 b
50	3.770 a	3.750 a	3.743 a	3.754 a
Mean	2.928 A	2.915 AB	2.902 B	
	Na concentration (%)			
0	0.213 c	0.183 c	0.193 e	0.197 e
12.5	0.863 b	0.883 b	0.867 d	0.871 d
25	0.917 b	0.933 b	0.948 c	0.933 c
37.5	1.237 a	1.253 a	1.220 b	1.237 b
50	1.283 a	1.273 a	1.280 a	1.279 a
Mean	0.903 A	0.905 A	0.902 A	

[a] For each plant parameter, values followed by the same small letter in each column or capital letter in each row, are not significantly different at $p\leq 0.05$.

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Table 6. Shoot Cl and Na concentrations (%) required for 50% reduction in growth.

Applied Zn (mg kg $^{-1}$ soil)	50% growth reduction	
	Cl	Na
0	0.21	0.07
5	3.59	1.15
10	3.61	1.16

Table 7. Effects of NaCl levels and Zn sources and levels on the P concentration and K/Na ratio in rice shoots.

Zn source	applied Zn (mg kg $^{-1}$ soil)	NaCl level (mmol kg $^{-1}$ soil) 0	12.5	25	37.5	50	Mean
		P concentration (%)					
$ZnSO_4$	0	0.244 a [a]	0.219 a	0.203 a	0.186 a	0.163 a	0.203 a
	5	0.207 b	0.191 b	0.177 b	0.169 b	0.152 b	0.179 b
	10	0.192 c	0.161 c	0.155 c	0.155 c	0.117 c	0.156 c
	Mean	0.214 A	0.190 B	0.178 C	0.170 D	0.144 E	
ZnEDTA	0	0.241 a	0.208 a	0.198 a	0.185 a	0.166 a	0.200 a
	5	0.205 b	0.172 b	0.179 b	0.169 b	0.139 b	0.173 b
	10	0.180 c	0.163 c	0.159 c	0.136 c	0.114 c	0.151 c
	Mean	0.209 A	0.181 B	0.179 C	0.163 D	0.140 E	
		(K concentration /Na concentration) ratio					
$ZnSO_4$	0	12.10 c	1.70 a	1.14 b	0.67 b	0.52 b	3.23 c
	5	13.28 b	1.50 c	0.97 c	0.68 b	0.53 b	3.39 b
	10	13.88 a	1.61 b	1.21 a	0.94 a	0.61 a	3.65 a
	Mean	13.09 A	1.60 B	1.10 C	0.76 D	0.55 E	
ZnEDTA	0	11.36 c	1.73 a	1.18 a	0.68 b	0.53 b	3.09 c
	5	13.22 b	1.48 c	0.96 b	0.66 b	0.53 b	3.37 b
	10	13.37 a	1.63 b	1.19 a	0.97 a	0.63 a	3.56 a
	Mean	12.65 A	1.61 B	1.11 C	0.77 D	0.56 E	

[a] For each Zn source and growth parameter, values followed by the same small letter in each column or capital letter in each row, are not significantly different at p≤ 0.05.

for 50% growth decrement are shown in Table 6. These data indicate that Cl and Na concentrations associated with a 50% growth reduction are considerably higher in Zn-treated plants than in Zn-untreated plants implying that Zn supply increased the rice tolerance to the Cl and Na accumulation in the shoots.

Both forms of Zn application reduced P concentration in the rice shoot (Table 7), which conforms to the findings of Giordano and Mortvedt (1974) in rice, Parker (1997) for several crops, and Torun *et al*. (2001) in wheat. However, the (K concentration/Na concentration) ratio showed an increasing trend with Zn supply. Similar results have also been reported by Keshavarz and Malakouti (2005) in wheat. In the present study, increasing NaCl levels caused a significant decline in P and K/Na concentra-

Table 8. Effect of NaCl levels and Zn rates on the Ca and Mg concentration (%) in rice shoots.

NaCl level (mmol kg^{-1}soil)	Applied Zn (mg kg^{-1}soil)			
	0	5	10	Mean
		Mg concentration (%)		
0	0.53 a	0.47 a	0.41 a	0.47 a
12.5	0.42 b	0.36 b	0.29 b	0.36 b
25	0.39 c	0.31c	0.22 c	0.31 c
37.5	0.34 d	0.27 d	0.18 d	0.27 d
50	0.31 e	0.23 e	0.15 e	0.23 e
Mean	0.40 A	0.33 B	0.25 C	
		(Ca concentration/Na concentration) ratio		
0	5.86 a [a]	5.46 a	5.00 a	5.44 a
12.5	1.37 b	1.13 b	1.03 b	1.18 b
25	1.09 c	0.86 c	0.75 c	0.90 c
37.5	0.66 d	0.50 d	0.42 d	0.53 d
50	0.53 e	0.38 e	0.31 e	0.41 e
Mean	1.90 A	1.67 B	1.50 C	

[a] For each plant parameter, values followed by the small letter in each column or capital letter in each row, are not significantly different at $p \leq 0.05$.

tions. Shannon *et al*. (1998) reported that leaf concentration of K in rice was decreased by salinity. Hu *et al*. (1997) believe that an increase in Na and a decline in K concentration by soil salinity is caused by the apparent antagonism between K and Na. This antagonism may be due to the direct competition between Na and K at the site of ion uptake in the plasmalemma (Epstein, 1966). Sodium may also enhance the efflux of K into growth media due to the disturbed membrane integrity (Cramer *et al*., 1985).

Mg concentration and the (Ca concentration/Na concentration) ratio in shoots of rice declined with increasing NaCl levels and the addition of Zn (Table 8). A high Na concentration in the external medium might have reduced the activity of Ca and Mg in the soil solution, causing a decrease in Ca and Mg availability for plants (Adams, 1994). Kent and Lauchli (1985) believe that root growth and function might be impaired by a low Ca/Na ratio and, consequently, Ca transfer from root to the shoot may be inhibited. Since Zn addition increased the plants' shoot dry weight, the decline in plant Mg and Ca/Na concentration may be due to the dilution effect; Ca is a strong competitor of Mg. The binding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg than for Ca (Marschner, 1995).

Free proline accumulation was found to be increased in rice in response to NaCl, irrespective of Zn supply (Table 9). An increase in free proline concentration under salt stress has been established (Dubey and Rani, 1989; Lyer and Caplan, 1998; Lee *et al*., 1992; Lutts *et al*., 1996). Osmoregulation in many crops involves synthesis and the accumulation of organic solutes such as soluble sugars and free amino acids. Proline, a suitable index of rice salt tolerance (Lee *et al*., 1992) is a major constituent of free amino acids and has been reported to accumulate in the cytoplasm of cells (Pahlich *et al*., 1983) and thus lowers the cytosolic osmotic potential to balance the ionic build-up in the vacuole (Voetberg and Stewart 1989). Shannon (1978) observed that proline contributes to both osmotic adjustment and plant salt tolerance at high salinity levels.

There was a sharp decrease in the reducing sugar concentration with a rise in NaCl lev-

Table 9. Effects of NaCl levels and Zn sources and levels on proline concentration in rice shoots (µmole g $^{-1}$).

Zn source	Applied Zn (mg kg soil^{-1})	NaCl level (mmol kg $^{-1}$ soil) 0	12.5	25	37.5	50	Mean
ZnSO$_4$	0	0.157 a [a]	0.193 a	0.230 a	0.321 a	0.687 a	0.317 a
	5	0.143 b	0.190 a	0.227 a	0.315 a	0.653 b	0.305 b
	10	0.128 c	0.184 a	0.208 b	0.311 a	0.641 c	0.289 c
	Mean	0.140 E	0.189 D	0.221 C	0.315 B	0.660 A	
ZnEDTA	0	0.173 a	0.217 a	0.253 a	0.333 a	0.680 a	0.328 a
	5	0.163 ab	0.201 b	0.227 b	0.330 a	0.653 b	0.313 b
	10	0.157 b	0.207 ab	0.214 c	0.317 b	0.644 b	0.299 c
	Mean	0.164 E	0.206 D	0.232 C	0.327 B	0.658 A	

[a] For each zinc source, values followed by the same small letter in each column or capital letter in each row, are not significantly different at p≤ 0.05.

els (Table 10). A decline in reducing sugar content in plants subject to salt stress has been reported by others (Rush and Epstein, 1976; Maftoun *et al*., 2003) and might be due to the excessive Cl and Na ions affecting photosynthesis and sugar metabolism (Stewart and Lee, 1974) and/or the rise in plant respiration (Curtis *et al*., 1988).

In the present study, Zn addition lessened the accumulation of proline and reducing sugars. However, the depressing effect of Zn supply on proline was greater at lower than higher NaCl levels. For example, in NaCl-untreated rice, application of 10 mg Zn kg^{-1} (as ZnSO$_4$) decreased proline by 18.5%, whereas in plants treated with 50 mmol NaCl kg^{-1} and with the same Zn level, the increase was 6.7%. Because Zn addition increased the shoot dry weight of the plants, the decline in plant proline and reducing sugars concentration might be due to the dilution effect

In conclusion, these data suggest that provision of an optimum Zn supply is an important consideration whenever paddy rice is to be grown in saline soils. The relatively high concentrations of Cl and Na and/or limited water availability to plants caused by excess soluble salts were probably responsible for the rice growth suppression in saline media. Further research is imperative in different soils, with different genotypes and under different environmental conditions to substantiate these findings.

CONCLUSIONS

NaCl addition decreased the top dry weight, leaf area and chlorophyll content of rice. Zn addition alleviated the suppressing effect of NaCl. Zn sources caused a significant difference in top dry weight, leaf area and chlorophyll concentrations. Plant Zn concentration decreased and those of Na and Cl increased significantly in NaCl-treated

Table 10. Effects of NaCl levels and Zn rates and levels on reducing sugars concentration in rice (mg kg^{-1}).

applied Zn (mg kg $^{-1}$ soil)	NaCl level (mmol kg $^{-1}$ soil) 0	12.5	25	37.5	50	Mean
0	75.85 a [a]	48.93 a	36.58 a	33.63 a	27.71 a	44.54 a
5	61.52 b	39.59 b	30.07 b	27.49 b	25.08 b	36.75 b
10	61.96 b	37.40 c	29.28 b	26.07 b	25.43 b	36.03 b
Mean	66.44 A	41.97 B	31.98 C	29.07 D	26.08 E	

[a] Values followed by the same small letter in each column or capital letter in each row, are not significantly different at p≤ 0.05.

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plants. Zn application markedly increased Zn and decreased Na and Cl concentrations in rice. $ZnSO_4$ was more effective in changing the aforementioned parameters than ZnEDTA.

Rice amended with NaCl contained more proline and fewer reducing sugars than the control; the addition of Zn decreased proline as well as reducing sugar concentrations. $ZnSO_4$ was more effective than ZnEDTA in decreasing proline concentration in rice.

Phosphorus and potassium concentrations in rice decreased with increasing NaCl levels. Zn fertilization, regardless of Zn sources, reduced P concentration. Use of 5 and 10 mg Zn kg^{-1}soil, from each of two Zn sources, decreased and increased K concentration in rice, respectively. Rice growth decreased with an increase in shoot Na and Cl concentration.

In general, it is concluded that Zn addition markedly reduced the depressing effects of NaCl on top dry weight and other determined plant parameters. Therefore, it is strongly suggested that, in saline soils especially those low in plant available Zn, sufficient Zn should be added if rice has to be grown.

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آثار متقابل کلرید سدیم، سطوح و منبع روی بر رشد و ترکیب معدنی برنج

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چکیده

آثار کلرید سدیم و مقادیر و منبع روی بر رشد و ترکیب شیمیایی برنج (*Oryza sativa* L.) در یک خاک آهکی و در یک آزمایش گلخانه‌ای بررسی شد. تیمارها عبارت بودند از پنج سطح کلرید سدیم (۰، ۱۲/۵، ۲۵، ۳۷/۵ و ۵۰ میلی مول در کیلوگرم خاک)،سه سطح روی(۰ ، ۵ و ۱۰ میلی گرم در کیلوگرم خاک)و دو منبع روی (سولفات روی وکلات روی). آزمایش به‌صورت فاکتوریل در قالب یک طرح کاملاً تصادفی با سه تکرار انجام گرفت. سدیم‌کلرید باعث کاهش وزن خشک قسمت هوایی، سطح برگ و غلظت کلروفیل شد، در حالی که کاربرد روی به‌طور معنی داری، این پارامترها را افزایش داد. هر چند که این اثر افزایشی مصرف روی در خاک- بدون توجه به منبع روی- در سطوح پایین سدیم‌کلرید بیشتر بود تا سطوح بالاتر. در این بررسی و در گیاهان تیمارشده با سدیم کلرید، غلظت روی، فسفر و پتاسیم به‌طور معنی داری کاهش پیدا کرد، در حالی که مقادیر سدیم و کلر افزایش پیداکرد. کاربرد روی به‌طور مشخصی غلظت روی در اندام هوایی برنج را افزایش و تجمع سدیم و کلر و فسفر در این اندامها را کاهش داد. علاوه بر این، تفاوت معنی داری بین دو منبع روی از لحاظ تاثیر بر رشد برنج مشاهده شد. با افزایش سطوح سدیم کلرید در خاک، غلظت پرولین افزایش و میزان قندهای احیاکننده کاهش پیدا کرد.

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این در حالی است که برنج تیمار نشده با روی، مقادیر بالاتری پرولین و قندهای احیاکننده را نسبت به گیاه تیمار شده با روی نشان داد. بعلاوه میزان افزایش پرولین در حضور عنصر روی بیشتر بود و منبع سولفات روی نسبت به کلات روی، افزایش بیشتری در پرولین نشان داد. از نتایج به‌دست آمده چنین استنباط می‌شود که به‌طور احتمالی کاهش پتانسیل اسمزی خاک، عدم توازن عناصر غذایی و تجمع بیش از حد سدیم و کلر در گیاه در خاک تیمار شده با سدیم کلرید، سبب کاهش رشد شده و اضافه‌کردن روی، اثر سوء نمک بر رشد برنج را کاهش داده است. بنابراین توصیه می‌شود که در صورت کاشت برنج در خاکهای شور با کمبود روی قابل استفاده، مقادیر کافی روی به خاک اضافه شود.

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