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Response of rice genotypes to sodic waters and Zn rates

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Abstract

Identification of rice genotypes that are tolerant to both sodicity and Zn deficiency is necessary before any rice genotype is cultivated in these stressed environments. We conducted anopen field pot trial to evaluate the response of three rice genotypes (Shandar, NIA-19/A, and NIA-102) to various levels of $NaHCO_3$ (0, 40 and 80 *mM*) and Zn application rates (0 and 15 kg Zn ha^{-1}).The rice plants were harvested at maturity (110 days after transplantation) and analyzed for various growth and yield components, and ions content. Sodic waters (40 and 80 *mM* $NaHCO_3$) significantly reduced most of the growth and yield traits of rice genotypes. Rice plants irrigated with 40 and 80 *mM* $NaHCO_3$ had 15% and 35%, respectively, less grain yield when compared with the plants irrigated with non-sodic water. This adverse effect on growth and yield components may be associated to high Na^+ content in rice tissues (straw and grain), which was two-to-three fold higher in rice plants irrigated with sodic waters (40 and 80 *mM* $NaHCO_3$) than the plants irrigated with nonsodic water. Zinc application at the rate of 15 kg Zn ha^{-1} was not always effective in improving the growth and yield components; the effect was variable with sodic water levels and rice genotypes. Relatively Shandar was tolerant to sodic waters and responsive to Zn application, hence may be grown in sodic environments, provided the Zn is included in rice cropping.

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Introduction

Salt-affected soils are a common feature of arid and semi-arid zones of the world. These soils are mainly developed in these areas because of natural (e.g. weathering of rocks and minerals) and human activities (e.g. irrigation water). Salt-affected soils are divided into three groups: saline soils, saline-sodic soils and sodic soils (Brady and Weil, 2002; Muhammad, 1996). Globally, 1128 Mha land is salt-affected, out of which 60% soils are saline, 26% soils are sodic and 14% soils are saline-sodic in nature (Wicke *et al.* 2011). The situation is different in Pakistan, where the soils are majorly saline-sodic and sodic. It has been estimated that, out of total salt-affected lands, 60% are saline-sodic and sodic while 40% are saline in nature (Qureshi *et al.* 2008). A high number of saline-sodic and sodic soils in Pakistan may be attributed to many factors including the use of poor quality groundwater for irrigation purpose. According to Qureshi *et al.* (2008), about 70% of the tube wells in the Indus Basin area (where country's 90% of the food is produced, (Qureshi, 2011)) are uplifting sodic water that contains excessive amounts of sodium (Na^+), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions.

Sodic soils are characterized by high amount of Na^+ on the exchange complex that adversely affects the suitability of these soils for agriculture. Some of the problems associated with sodic soils include high pH, deteriorated soil structure, dispersed organic matter, poor water holding capacity, limited aeration, and increased risk of runoff and erosion (Qadir *et al.* 2007; Qadir and Schubert, 2002; Sumner, 1993). Plant essential nutrients are generally limited in these soils (Pandey *et al.* 2013). Among many essential nutrients, Zn (an essential micro nutrient) is deficient in sodic soils (Qadar and Azam, 2007). This deficiency of Zn may be associated to high pH, low organic matter, and excessive amounts of Na^+, CO_3^{2-} and HCO_3^- ions in sodic soils that affect the Zn availability to crop plants (Rao *et al.* 2013; Alloway, 2009). Despite a number of problems associated with these soils, they still produce a large proportion of cereal crops globally (Sumner, 1993).

Rice (*Oryza sativa L.*) has been reported to be sensitive to both the stresses viz. sodicity and Zn deficiency (Alloway, 2009; Qadar, 2002). However, considerable difference exists among rice genotypes as a function of sodicity and Zn deficiency. Qadar (2002) investigated the performance of thirty rice genotypes to Zn deficiency and sodicity stresses. The researcher found ten genotypes tolerant to both the stresses, sixteen genotypes were found susceptible to Zn deficiency and four genotypes were found susceptible to sodicity. Hence identification of rice genotypes that perform better insodicity and Zn deficiency is an effective technique and a practical solution for utilization of sodic and Zn-deficient soils. However, the studies, where the collective impact of sodicity and Zn deficiency on rice crop growth, yield and ions content is investigated, are lacking in the literature. Furthermore, the reported studies are mainly conducted in hydroponic culture (Hajiboland *et al.* 2005; *Yang et al.* 2003) which do not consider the factors that may affect plants when they are grown in field conditions. In addition, studies are missing where the sodic irrigation water is used in soil environment to evaluate the performance of rice genotypes with or without Zn application. Such studies are mainly lacking in Pakistan where a considerable portion of sodic water is used for crop cultivation. The research reported in this manuscript is an effort to screen out the rice genotypes that are tolerant to sodic waters and Zn deficiency. The specific objectives of this work include (i) to determine the growth and yield of rice genotypes as a function of sodic waters and Zn levels, and (ii) to analyze the concentration of Na^+ and Zn^{2+} in rice tissues with the application of sodic waters and Zn levels.

Materials and methods

A three factorial pot trial was carried out at the Centre for Bio-saline Agriculture, Department of Soil Science, Sindh Agriculture University, Tandojam Pakistan in a Complete Randomized Design (CRD) with three replications. The three factors were: two Zn levels (0 and 15 kg Zn ha^{-1}), three sodic water levels (0, 40 and 80*mM* $NaHCO_3$) and three rice cultivars (Shandar, NIA-19/A and NIA-102).

Large round cemented pots with a capacity of 60 kg soil per pot were used for rice cultivation. These cemented pots were placed on a flat ground in an open environment and filled with an arable clay loam soil. Inorganic fertilizers viz. urea (N46%), diammonium phosphate (DAP: N18% and $P_2O_5$46%) and sulphate of potash (SOP:K_2O50%) fertilizers were applied as per local recommendations (120 kg N, 90 kg P_2O_5, and 60 kg K_2O ha^{-1}).Full dose of potassium was applied before transplantation of rice cultivars. At the same time, DAP was applied to provide full dose of phosphorus and basal amount of N. The remaining amount of N was given in two equal splits through urea at 25 days after transplantation and at booting stage of rice cultivars.

Five weeks old seedlings of rice cultivars (Shandar, NIA-19/A and NIA-102) were planted in cemented pots at a distance of 10 cm plant to plant and 15 cm row to row. The defined rates of Zinc (0 and 15 kg Znha^{-1}) were applied to each treatment pot as Zinc Sulphate (33% Zn^{2+}). These Zn rates were applied to the pots after 15 days of transplanting.

The defined sodic water levels (40 and 80*mM*) wereprepared from $NaHCO_3$ salt (analytical grade) in the laboratory. Canal water was also included in the experiment as control (0 *mM* $NaHCO_3$). Rice cultivars were irrigated with these waters twice and/or thrice in a week, and the level of the water was maintained to a submerged condition (2-3 inches head). Rice plants were harvested at maturity by cutting at soil level with sharp sickle.

Agronomic observations and plant analysis

Various agronomic observations viz. plant height (cm) at maturity, number of tillers per hill (at maturity), panicle length (cm), grains per panicle, 1000 grain weight (g), spikelet sterility (%), and grain yield (kg ha^{-1}) were recorded. The contents of Na^+ and Zn^{2+} were determined in rice plant tissues (grains and straw) by dry ashing of these tissues. The $Na^+$was analyzed by flame photometer and Zn^{2+} was analyzed by Atomic Absorption Spectrometer (AAS).

Statistical analysis

The agronomic and ionic data was analyzed for ANOVA using Minitab 16 software. The significant difference among treatments was computed using Tukey's test at a *P* value of 0.05.

Soil Analysis

Before rice cultivation, the experimental soil was analyzed for some basic physico-chemical characteristics. These characteristics include: soil texture by hydrometer method (Bouyoucos, 1962), organic matter content using Walkley-Black method (Walkley and Black, 1934), electrical conductivity (EC dS m^{-1}) and pH in 1:2 soil water extracts using digital meters, and lime content by acid neutralization method (Ryan *et al.* 2001). Available Zn^{2+} was extracted by AB-DTPA method (Soltanpour and Schwab, 1977) and analyzed by AAS.

The findings of these analyses are given in Table 1. Accordingly, the experimental soil was clay loam in texture (33.7% sand, 28.3% silt and 38% clay), slightly alkaline in reaction (pH 7.7), non-saline (EC 0.6 dS m^{-1}), low in organic matter content (0.71%) and lime content (8.7%), and deficient in available Zn (1.27 mg kg^{-1}).

Table 1. Physico-chemical properties of experimental soil before rice transplantation.

Properties	Values
pH(1:2 soil water extract)	7.7
Electrical conductivity (ECdS m^{-1} in 1:2 soil water extract)	0.6
Lime ($CaCO_3$, %)	8.7
Soil organic matter (%)	0.71
Available Zn^{2+} (mg kg^{-1})	1.27
Textural class	Clay loam (33.7% sand, 28.3% silt and 38% clay)

Results

The results are described here by first considering the effect of main factors (sodic water, Zn rates and genotypes) individually and then describing their interactive effect on the growth and yield components, and ions content.

Response of rice genotypes for growth and yield parameters as a function of sodic waters and Zn rates

Effect of sodic waters

The growth (plant height, number of tillers per hill, number of grains per hill) and yield (1000 grain weight, spikelet sterility and grain yield) parameters of rice genotypes were significantly affected by sodic waters (*P* < 0.05; Table 2 to 8). There was a continual decrease in plant height, number of tillers per hill, panicle length, number of grains per hill, 1000 grain weight and grain yield with an increase in sodic water levels. These parameters were significantly least when the rice genotypes were irrigated with 80 *mM* $NaHCO_3$ water. There was a significant increase in spikelet sterility with increasing levels of $NaHCO_3$.

A 52% more spikelet sterility was observed in rice plants that were irrigated with 80 *mM* $NaHCO_3$ than the plants that were irrigated with non-sodic water (canal water).

Effect of Zn rates

The application of Zn had positive effect on the growth and yield parameters of rice genotypes. When the plants were fertilized with 15 kg Znha^{-1}, they produced taller plants, more number of tillers per hill, longer panicles, more number of grains per hill, heavier grains and higher grain yield than the plants where no Zn was applied. Significantly less spikelet sterility was observed in plants when they were fertilized with 15 kg Znha^{-1}.

Genotypes Response

Rice genotypes differed significantly as a function of sodic waters and Zn rates. The genotype, Shandar produced significantly taller plants, more number of tillers per hill, lengthy panicles, more number of grains per hill, heavier grains, less spikelet sterility and higher grain yield than other genotypes (NIA-19/A and NIA-102).

Table 2. Plant height (cm) of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	97.0	105.0	88.8	93.6	82.7	88.0	92.5 A
40	91.3	96.4	82.8	87.8	87.2	82.4	86.5 B
80	84.2	89.5	78.9	84.7	72.6	77.5	81.2 C
Mean of Znrates	90.8 B	97.0 A	83.5 C	88.7 B	77.8 D	82.7 C	
Mean of Genotypes	93.9 A		86.1 B		80.2 C		

*Zn levels represent kg Znha^{-1} values; each value is a mean of three replicates; Means followed by different letters are significantly different at *P*<0.05.

Table 3. Number of tillers per hillof rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	15.8bcd	19.4 a	13.5ef	16.5bc	11.2gh	14.0 de	15.1 A
40	13.7def	16.8 b	11.0gh	14.5cde	9.3 hi	12.9efg	13.0 B
80	11.0gh	14.5cde	9.3 hi	12.3efg	8.2i	11.7fg	11.2 C
Mean of Znrates	13.5 BC	16.9 A	11.3 D	14.4 B	10.0 E	12.9 C	
Mean of Genotypes	15.2 A		12.9 B		11.2 C		

*Zn levels represent kg Znha^{-1} values; each value is a mean of three replicates; Means followed by different letters are significantly different at *P*< 0.05.

Table 4. Panicle length (cm) of rice genotypes as affected by Zn rates and sodic water level.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	23.9 ab	25.6 a	18.8 e	20.7cde	18.9 e	20.2cde	21.3
40	22.7abcd	24.6 ab	20.1cde	21.7bcde	18.4 e	19.8cde	21.1
80	21.7bcde	23.0abc	19.8cde	21.3bcde	19.4de	20.8cde	20.1
Mean of Znrates	22.8 B	24.3 A	19.5 BC	21.4 B	18.9 C	20.2 B	
Mean of Genotypes	23.6 A		20.3 B		19.6 B		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at *P*< 0.05.

Table 5. Number of grains per hill of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	77.8bc	100.5 a	53.4defg	72.2bcd	36.5ghij	51.6efgh	65.4 A
40	62.9cdef	83.5 ab	40.2ghij	60.0cdef	31.5ij	49.3fghi	54.6 B
80	48.8fghi	68.8bcd	33.5hij	46.5fghi	25.3 j	39.6ghij	43.8 C
Mean of Znrates	63.2 B	84.3 A	42.5 C	59.6 B	31.1 D	46.9 C	
Mean of Genotypes	73.7 A		51.0 B		39.0 C		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at *P*< *0.05*.

Table 6. The 1000 grain weight (g) of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	21.0	22.5	18.7	20.3	18.7	19.7	20.1 A
40	19.0	20.2	17.8	19.3	18.7	20.3	19.2 A
80	18.0	18.3	16.7	18.0	15.5	17.7	17.4 B
Mean of Znrates	19.3 AB	20.3 A	17.7 B	19.2 AB	17.6 B	19.2 AB	
Mean of Genotypes	19.8 A		18.5 B		18.4 B		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates;Means followed by different letters are significantly different at *P*< *0.05*.

Table 7. Spikelet sterility (%) of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	37.4	20.3	48.2	35.6	60.0	44.0	41.0 C
40	51.2	32.4	60.5	47.4	70.7	53.2	53.0 B
80	56.5	42.1	72.2	57.6	83.1	63.7	62.5 A
Mean of Znrates	48.3 C	31.6 D	60.3 B	46.9 C	71.3 A	53.6 BC	
Mean of Genotypes	40.0 C		53.6 B		62.5 A		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at *P*< *0.05*.

Table 8. Grain yield (kg ha^{-1}) of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	6670.0c	7794.7a	4984.7fg	5774.7d	3484.7 j	5390.0 e	5683.1 A
40	5610.0d	7280.0b	4664.0 h	5348.0 e	2962.7 l	3098.0 kl	4827.1 B
80	4804.7gh	5094.7 f	3176.0 k	3740.0i	2584.7 m	2744.7 m	3690.8 C
Mean of Znrates	5694.9 B	6723.1A	4274.9 D	4954.2 C	3010.7 F	3744.2 E	
Mean of Genotypes	6209.0 A		4614.6 B		3377.4 C		

*Zn levels represent kg Znha^{-1} values; each value is a mean of three replicates; Means followed by different letters are significantly different at $P< 0.05$.

Interactive Effect

The interaction of factors was only significant for number of tillers per hill, panicle length, number of grains per hill and grain yield. Maximum number of tillers per hill, longer panicles, maximum number of grains per hill and highest grain yield was produced by Shandar, when this cultivar was irrigated with non-sodic water and fertilized with 15 kg Znha^{-1} (Table 3, 4, 5 and 8). However, considering only the grain yield and sodic waters (40 and 80 *mM* $NaHCO_3$), the maximum grain yield was recorded in Shandar when irrigated with 40 *mM* $NaHCO_3$ and fertilized with 15 kg Zn ha^{-1}. This indicates that Shandar may be irrigated with sodic waters, if Zn is included in the rice farming.

Response of rice genotypes for ions content as a function of sodic waters and Zn rates

Effect of Sodic waters

The effect of sodic waters on Na^+ content in grains and straw of rice genotypes remained significant ($P<$ 0.05; Table 9 and 10). Sodium content in rice grains and straw was increased with an increase in $NaHCO_3$ levels of irrigation water. The increase in Na^+ content in grains and straw was two-to-three fold higher in the rice plants irrigated with 40 and 80 *mM*$NaHCO_3$ when compared with rice plants that were irrigated with non-sodic water (0 *mM* $NaHCO_3$).

The effect of sodic waters on Zn^{2+} content in grains and straw of rice genotypes was found significant ($P<$ 0.05; Table 11 and 12). An inverse effect of sodic waters was observed on Zn^{2+} content in grains of rice genotypes, where a continual decrease was observed with increasing levels of $NaHCO_3$.

The Zn content in rice grains was nearly 20% less in sodic waters (40 and 80 *mM* $NaHCO_3$) than the plants irrigated with non-sodic water. The effect of sodic waters on Zn content in straw was variable, where a decrease at 40 *mM* $NaHCO_3$ and an increase at 80 *mM* $NaHCO_3$ water were observed with respect to non-sodic water.

Effect of Zn rates

The impact of Zn rates on Na^+ content in grains and straw of rice genotypes was found significant ($P <$ 0.05). However, the application of Zn did not have any positive effect in reducing Na^+ content in grains of rice genotypes. When the Zn was applied at the rate of 15 kg Zn ha^{-1}, there was a constant increase in the Na^+ content in the grains of rice genotypes. In straw, the effect of Zn on Na^+ content was variable and genotype specific. There was significantly less Na^+ content in straw of Shandar when this genotype was fertilized with 15 kg Znha^{-1}. In other two genotypes (NIA-19/A and NIA-102), Zn application (15 kg Znha^{-1}) increased the Na^+ content in straw in comparison to the straw of the plants where no Zn was applied.

The application of Zn at the rate of 15 kg Znha^{-1} significantly increased the Zn content in grains of rice genotypes. The Zn content in rice grains was 1.2 to 2 folds higher than the plants where no Zn was applied. In straw, the Zn content was 1.1 to 1.6 times higher than the plants where Zn was not applied.

Genotypes Response

Rice genotypes differed significantly for Na^+ content in rice grains and straw. There was significantly higher Na^+ content in grains and straw of Shandar and NIA-102 than the NIA-19/A as a function of sodic waters and Zn rates. For Zn content, NIA-102 significantly accumulated more Zn in grains and straw when compared with NIA-19/A and Shandar as a function of sodic waters and Zn rates.

Table 9. Na^+ content (%) in grains of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	0.139 f	0.149 f	0.128 f	0.188ef	0.138 f	0.192ef	0.156 B
40	0.275cde	0.262 de	0.199ef	0.360bc	0.358bc	0.434 ab	0.315 A
80	0.450 ab	0.466 a	0.249 de	0.294 cd	0.255 de	0.310 cd	0.338 A
Mean of Znrates	0.290 AB	0.292 AB	0.192 C	0.280 AB	0.250 B	0.312 A	
Mean of Genotypes	0.290 A		0.237 B		0.281 A		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at $P< 0.05$.

Table 10. Na^+ content (%) in straw of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	1.44 f	1.26 f	1.80 f	1.29 f	1.48 f	1.67 f	1.49 C
40	3.69 d	2.69 e	1.63 f	2.89 e	2.80 e	4.48bc	3.03 B
80	5.37 a	5.05 ab	4.02 cd	3.62 d	4.93 ab	5.10 ab	4.68 A
Mean of Znrates	3.50 A	2.30 B	2.48 C	2.60 C	3.07 B	3.75 A	
Mean of Genotypes	3.25 A		2.54 B		3.41 A		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at $P< 0.05$.

Table 11. Zn^{2+} content (µg g^{-1}) in grains of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	14.27fg	23.31 c	17.24 e	24.50bc	20.08 d	27.85 a	21.21A
40	11.56 hi	16.50ef	12.84gh	25.98 ab	14.90efg	16.87 e	17.20 B
80	10.47i	12.87gh	13.78gh	22.99 c	17.18 e	25.91 ab	16.44 C
Mean of Znrates	12.10 D	17.56 B	14.62 C	24.50 A	17.39 B	23.54 A	
Mean of Genotypes	14.83 C		19.56 B		20.47 A		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at $P< 0.05$.

Table 12. Zn^{2+} content (µg g^{-1}) in straw of rice genotypes as affected by Zn rates and sodic water levels.

$NaHCO_3$ Levels (*mM*)	Shandar		NIA-19/A		NIA-102		Mean of Sodic waters
	*Zn-0	Zn-15	Zn-0	Zn-15	Zn-0	Zn-15	
0	14.65 g	27.70bc	18.54efg	34.90a	24.20 cd	28.40bc	24.73 B
40	18.17efg	30.71 ab	16.69fg	22.28 de	16.81fg	20.05def	20.78 C
80	20.17def	28.02bc	22.18 de	29.52 b	28.91bc	35.07 a	27.31 A
Mean of Znrates	17.66 C	28.81 A	19.14 C	28.90 A	23.30 B	27.84 A	
Mean of Genotypes	23.24 C		24.02 B		25.56 A		

*Zn levels represent kg $Znha^{-1}$ values; each value is a mean of three replicates; Means followed by different letters are significantly different at $P< 0.05$.

Interactive Effect

Relatively more Na^+ in grains and straw was observed in Shandar and NIA-102 when these genotypes were irrigated with 80 *mM* $NaHCO_3$ water and fertilized with 0 and 15 kg $Znha^{-1}$. More Zn was found in the tissues of rice genotypes when they were fertilized with 15 kg $Znha^{-1}$, however, the maximum accumulation was variable with rice tissue, genotype and sodic water level. For example, maximum Zn in grains was found in NIA-102 when irrigated with 0 and 80 *mM* $NaHCO_3$ water, and in NIA-19/A when irrigated with 40 *mM* $NaHCO_3$ water. In straw, maximum Zn was found in NIA-102 and NIA-19/A when irrigated with 80 *mM* $NaHCO_3$and non-sodic water respectively, and in Shandar when irrigated with 40 *mM* $NaHCO_3$ water.

Discussion

The current study describes the adverse effects of sodic waters on growth and yield parameters of rice genotypes. These adverse effects may be associated to high Na^+ content in rice tissues (Table 9 and 10). Sodium is not an essential element for plants and its high concentration has been recorded to reduce growth and yield in rice crop (Saleh and Maftoun, 2008; Ali *et al.* 2004; Zeng and Shannon, 2000; Shannon *et al.* 1998). In addition, the high Na^+ concentration in growth media interferes in K^+ uptake, and reduces Ca^{2+} availability, transport and mobility within plant tissues (Grattan and Grieve, 1999). The negative effects of Na^+ on plants' growth and yield are further accelerated by the adverse effect of this element on soil physical conditions. The soils dominated in sodium ions have deteriorated structure, slow water permeability, poor aeration, and dispersed organic matter content (Brady and Weil, 2002).

The adverse effects of sodic water on growth and yield components in present study may also be related to the presence of bicarbonate ions (HCO_3^-) in irrigation water. In a hydroponic study, Alhendawi *et al.* (1997) studied the effect of bicarbonate levels on growth, organic acids accumulation and Fe uptake by barley, sorghum and maize. These researchers observed a decrease in root and shoot growth, an increase in the organic acids in plant roots, and a decrease in Fe uptake and mobility in tested crop species with bicarbonate supply. Yang *et al.* (2003) reported decline in shoot dry matter yield, root dry weight, root length in Zn-inefficient rice genotype (IR26) with bicarbonate application. These researchers further observed excessive accumulation of organic acids (malate, citrate, and fumarate) in the roots of Zn efficient rice genotype (IR36) and Zn-inefficient rice genotype (IR26). Meng *et al.* (2004) determined the effects of bicarbonate and high pH on macro-and-micro nutrients accumulation by rice genotypes. The findings of their study revealed reduction of K, Ca, Mg, Fe, Cu, Mn and Zn in tissues of Zn-inefficient genotype with bicarbonate level ($NaHCO_3$ at 10 mmol L^{-1}).

In the present study, Zn application (15 kg Zn ha^{-1}) significantly increased the growth and yield components of rice genotypes when compared with plants where no Zn was applied. Zinc is an essential plant nutrient and plays important role in plant metabolism. In plants, Zn works as a functional, structural and regulatory cofactor of enzymes (Alloway, 2008). It is involved in carbohydrate, protein and auxin metabolism, membrane integrity and plant reproduction (Alloway, 2008). An increased plant growth and grain yield of rice genotypes as a function of Zn application under salt stress condition has been reported (Ahmad *et al.* 2012; Saleh and Maftoun, 2008; Iqbal and Aslam, 1999).

Rice genotypes responded differently to sodic water levels and Zn rates. The genotype, Shandar exhibited better crop growth and yield than other genotypes. Overall the trend of higher growth and yield was: Shandar > NIA-19/A >NIA-102. These results indicate that Shandar is relatively a salt-tolerant and Zn-efficient genotype (this is further confirmed by interaction effect, reported in Table 3, 4, 5 and 8). Hence, this genotype is suitable for cultivation in the areas where soil is sodic or where sodic water is used for irrigation, provided the soil is not Zn deficient.

A difference in genotypes for growth and yield parameters as a function of sodic waters and Zn rates may be attributed to difference in their genetic makeup. A varietal difference in rice genotypes with respect to sodicity and Zn use efficiency has also been documented (Hafeez *et al.* 2012; Qadar, 2002).

In the present study, a high Na^+ content in straw and grains of rice genotypes was found with an increase in Na^+ levels in irrigation water. Interestingly, Zn application (15 kg Zn ha^{-1}) was unable to restrict the Na^+ content in rice tissues; instead the Zn application further increased Na^+ content in rice tissues. In contrast, Na^+ levels reduced the Zn content in rice grains of rice genotypes. This indicates the adverse effects of Na^+ on accumulation and uptake of essential elements (Zn in this case). It has been reported that sodicity decreased soil available Zn and its concentration in plant tissues of maize (Mehrotra *et al.* 1986).

Among rice genotypes, NIA-102 accumulated more Na^+ and Zn^{2+} in its tissues. However, this cultivar had lowest growth and yield, indicating the sensitivity of this cultivar to sodic water and less efficiency to applied Zn. Hence, NIA-102 appears to be unsuitable for sodic conditions. The genotype, Shandar accumulated more Na^+ (equal to NIA-102) and less Zn^{2+} in its tissues. Despite a high Na^+ content in tissues of Shandar, this genotype produced the highest growth and yield than other cultivars. This suggests that Shandar has a well-developed compartmentalization mechanism by which the genotype has possibly retained Na^+ in its cell organelles where the element was not able to affect growth and yield attributes. Munns and Tester (2008) summarized that plants adopt three different strategies to control salinity; (i) increase osmotic adjustments to tolerate osmotic stress, (ii) exclude Na^+ accumulation in aerial tissues, and (iii) tolerate Na^+ by its compartmentalization at the cellular and intracellular levels.

Conclusion

The present study affirms the toxic effects of $NaHCO_3$ enriched sodic water on the growth and yield of tested rice genotypes. The application of Zn at the rate of 15 kg Zn ha^{-1} enhanced the growth and yield attributes of rice genotypes.

The genotype, Shandar, exhibited healthy growth and yield under sodic environment by tolerating high amount of Na^+ in its tissues. This confirms that Shandar is a salt-tolerant and Zn-efficient genotype and may be grown in the areas where the soil is sodic and/or where sodic water is used for rice cultivation, provided the Zn is included in cropping system.

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