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Zinc-enriched Farm Yard Manure Improves Grain Yield and Grain Zinc Concentration in Rice Grown on a Saline-sodic Soil

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ABSTRACT

Zinc is widespread deficient in calcareous soils and its management is more complex in reduced root-zone conditions of rice grown on saline-sodic soils. Present pot study was conducted in a wire house, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan during 2010 to compare Zn enriched farm yard manure (FYM) with chelated (Zn-EDTA) and non chelated (zinc sulphate, $ZnSO_4$) Zn sources for optimum grain yield and higher Zn concentration in grains of rice (cv. Shaheen Basmati) grown in a salt-affected soil. Treatments comprised of 1.5, 3 or 6 mg Zn kg^{-1} soil in the form of both $ZnSO_4$ and Zn-EDTA, and Zn-enriched farm yard manure 5% of soil (w/w). Zn enrichment was done with same three levels of Zn using $ZnSO_4$. Application of Zn increased plant growth, grain yield and Zn concentration in various tissues, irrespective of the Zn source. The increase in plant growth and Zn concentration was higher when plants were grown with Zn-enriched FYM compared to $ZnSO_4$ or Zn-EDTA application alone. The maximum Zn concentration in rice grains (13.9 mg kg^{-1}) and straw (19.1 mg kg^{-1}) were obtained with the same treatment. It was concluded that application of $ZnSO_4$ enriched FYM proved better over application of alone $ZnSO_4$ or Zn-EDTA indicating the positive role of organic matter in increasing grain yield and grain Zn concentration on soils affected with salts and depleted in organic matter.

Key Words: Farm yard manure; Rice; Saline-sodic soil; Zinc sulphate; Zinc-EDTA

INTRODUCTION

Soil salinity and sodicity are important factors hampering crop productivity in many areas of the world. Rice, a major staple food of the world, also suffers from soil salinity and sodicty hazards (Mavi *et al*., 2012). The saline-sodic soils are characterized by high concentration of soluble salts and Na domination on cation exchange complex. Such soils also have low organic matter and crops grown on these soils suffer from specific ionic toxicities (Na, Cl & B) and deficiencies (Ca, K & Zn) causing substantial yield decline (Grattan & Grieve, 1999; Nasim *et al*., 2008; Tahir *et al.,* 2010, 2012).

Widespread soil Zn deficiency is also one of the important factors responsible for yield reduction in rice (Fageria *et al*., 2002; Quijano-Guerta *et al*., 2002) and it is also positively correlates with widespread human Zn deficiency (Alloway, 2009). The greater Zn concentration in cereals grains is an important strategy to fight with human Zn deficiency in a situation where about half of the world's total population is living under the risk of Zn deficiency (Hotz, 2009). However, the frequency of soil Zn deficiency is greater in rice than other crops, with more than 50% of the crop worldwide prone to this nutritional disorder (Hacisalihoglu & Kochian, 2003; Rehman *et al*., 2012). Therefore, Zn deficiency is considered as one of the most important nutritional stresses limiting rice production in Asia (Cakmak *et al*., 2001; Quijano-Guerta *et al*., 2002; Luo *et al*., 2010; Rehman *et al*., 2012). Low Zn contents in soil, calcareousness and prolonged submergence of soil are the factors responsible for low Zn phytoavailability (Alloway, 2009; Ghaffar *et al*., 2011). Most of the soils in these areas are also saline/sodic because of arid to semi-arid climates, artificial irrigation with tubewell water and salty parent material (Ghafoor *et al*., 2004). As more than 90% of rice is grown under flooded conditions, use of brackish tubewell water is increasing the problem of salinity and sodicity in Pakistan and other countries. Hence, Zn deficiency and soil salinity/sodicity are common features of rice fields in the arid to semi-arid climates.

Application of $ZnSO_4$ is the general strategy to improve grain yield and grain Zn concentration in cereals grown on Zn deficient soils. Cakmak (2008) and Rehman *et al.* (2012) have reviewed several studies where Zn application to Zn-deficient calcareous soils significantly and

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remarkably increased plant growth and grain yield, grain Zn concentration. However effectiveness of applied Zn is a question in soils with high pH and $CaCO_3$ content where Zn gets bound with soil constituents and/or precipitated rendering its availability to crop plants (Hussain *et al*., 2011; Rehman *et al*., 2012).

Several chelated Zn sources are available and generally it is accepted that Zn chelates are more effective than inorganic salts under the soils conditions discussed above. However, because of high solubility, low cost and ease of availability in the market, $ZnSO_4$ is the most widely used Zn fertilizer. In addition, Zn oxide (ZnO) and Zn-EDTA are also being used by farmers. In a field experiment, Naik and Das (2007) found that Zn-EDTA was better for growth and paddy yield of rice than $ZnSO_4$. Also, Zn uptake and utilization was higher with chelated Zn sources than inorganic salts of Zn. The chelated forms of Zn also maintained a higher concentration of Zn in the soil solution and for longer periods than $ZnSO_4$ (Chand *et al*., 1981). In contrary, a number of reports indicated better results with $ZnSO_4$ compared to other sources particularly for Zn uptake in grains (Giordano, 1977; Rehman *et al*. 2012).

Addition of organic matter may improve efficiency of applied Zn through its direct and indirect effects on physiological properties of soil including changes in rhizosphere pH and formation of organic complexes with Zn (Rehman *et al*., 2012). Several reports are available emphasizing the role of organic matter in improving Zn efficiency. For instance, Karlen and Stott (1994) reported an increased Zn availability due to FYM addition in the rice-wheat system compared with application of inorganic fertilizers alone. Srivastava *et al*. (2008) used Zn enriched bio-sludge in rice and reported that it improved Zn phytoavailability in soil compared to $ZnSO_4$ alone.

Most of the studies in the past were focused with special emphasis to increase in grain yield only. Due to identification of widespread human Zn deficiency, research has recently been switched towards increasing grain Zn concentration in cereals (Cakmak, 2009). A number of studies are available on the comparative efficiencies of Zn sources in rice (Naik & Das, 2007; Srivastava *et al*., 2008; also see Rehman *et al*., 2012) however, studies are lacking emphasizing the beneficial effects of addition of FYM on Zn availability in the root-zone, uptake by plants and its translocation towards rice grain. Moreover, most of the comparative studies were conducted in hydroponics, or on normal soils and studies on Zn efficiency under saline-sodic soil conditions are rare. We hypothesized that application of $ZnSO_4$ enriched FYM to a saline-sodic soil may improve paddy yield and Zn concentration in rice grains to improve human nutrition. The objective of this study was to compare zinc (Zn) enriched FYM with chelated Zn (Zn-EDTA) and non- chelated ($ZnSO_4$) Zn sources on the availability and retention of Zn in rice crop grown on a calcareous saline sodic soil.

MATERIALS AND METHODS

General conditions: The study was carried in a wire-house of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad during June 2010. Average precipitation during the study period was 1.00 mm, and mean daily temperature 33.9ºC (at 12:00 pm) with a 40% relative humidity.

Soil analysis and Zn treatments: A pot experiment was conducted with sandy clay loam soil (fine, mixed, hyperthermic Typic Calciargids) collected from a farmer's field (73°04'38 N, 31°26'58 E) located in Sultan town of Faisalabad. The soil was air-dried and ground to pass through a 2-mm sieve.

A subsample of the sieved soil was analysed for various physico-chemical properties. Soil texture was sandy clay loam (sand 65%; silt 13.8%; clay 20.7%) as determined by a hydrometer method (Gee & Bauder, 1986). Soil organic matter, determined by Walkley-Black method (Nelson & Sommers, 1982), was 5 g kg^{-1} soil. Free lime (calcium carbonate; $CaCO_3$), estimated by acid dissolution (Allison & Moodie, 1965), was 33 g kg^{-1} soil. Plant-available Zn in the soil was 0.9 mg kg^{-1} soil, as extracted by AB- DTPA (Lindsay & Norvell, 1978) and measured on an atomic absorption spectrophotometer (PerkinElmer, AAnalyst 100, Waltham, USA). Cation exchange capacity of soil was 6.50 $cmol_c$ kg^{-1} soil (Rhoades, 1982).

Ten different Zn treatments were applied to respective pots before transplanting of rice seedlings (cv. Shaheen Basmati) to evaluate its accumulation in various parts of rice plants along with its effects on straw and grain yield. Treatments were comprised of $ZnSO_4$ (21% Zn) alone @ 1.5, 3 or 6 mg Zn kg^{-1} soil; Zn-EDTA (7% Total Zn) @ 1.5, 3 or 6 mg Zn kg^{-1} soil; $ZnSO_4$ enriched in farm yard manure ($ZnSO_4$+FYM) @ 1.5, 3 or 6 mg Zn kg^{-1} soil. Farm yard manure (pH 7.8; Organic Carbon 348.9 g kg^{-1} and Zn 0.07 mg g^{-1}) was applied at a uniform rate of 5 % (w/w) of soil. Treatments also included a control in which Zn was not applied in any form. Pots lined with polyethylene bags were filled with 12 kg soil in each. The treatments in triplicates were laid out according to completely randomized design.

Nursery raising and transplantation: Viable seeds of rice (cv. Shaheen Basmati) were sown in acid-washed sand taken in polyethylene lines iron trays. Seedlings were supplied with distilled water to maintain moisture contents at field capacity. Seven seedlings of uniform growth were transplanted in each pot after 15 d of growth. These were finally thinned to maintain 4 seedlings per pot after 7 days of transplantation. At the time of transplantation of nursery, 42 mg N, 54 mg K and 53 mg P kg^{-1} soil were added to each pot by applying urea, potassium sulphate and di-ammonium phosphate. Two more splits of N (42 mg N kg^{-1} soil each) were applied as urea after 25 and 45 days of transplantation. The crop was irrigated with water having pH 7.94, EC 0.61 dS m^{-1}, SAR 1.21 ($mmol_c$ L^{-1})$^{1/2}$, and undetectable concentrations of Zn.

Harvesting and growth parameters: Crop was harvested at maturity. Harvested plant samples were washed respectively with acidified and distilled water to remove the aerial deposits. The plant samples were oven dried at 70°C in forced air driven oven till a constant weight. The panicles were threshed manually to separate rice grains and straw to measure dry matter yields.

Collected samples of straw, roots and grains were ground to powder with Wiley mill fitted with stainless steel chamber and blades. Ground samples were digested with a di-acid mixture of HNO_3 and $HClO_4$ (ratio of 2:1) (Jones & Case, 1990). Zinc was determined in digested samples on an atomic absorption spectrophotometer (Thermoelectorn, Solar S-series, UK) after calibrating it with standard solutions.

Statistical analysis: The variance and significant differences between treatments were analyzed by ANOVA and DMR test using MSTAT-C (Russel & Eisensmith, 1983).

RESULTS

Plant growth and grain yield: There were significant ($P \leq 0.05$) effects of Zn application on straw and grain yields (Table I). Both grain and straw yields were increased with gradual increase in Zn application by either source. However, $ZnSO_4$ proved better than Zn-EDTA in increasing plant growth and grain yield. Zinc sulphate-enriched farm yard manure also significantly improved the grain and straw yield compared with control as well as with $ZnSO_4$ alone. However, the differences among various rates of Zn applied as $ZnSO_4$+FYM were not significant except the lowest rate (1.5 mg Zn kg^{-1} soil). Compared to control, maximum increase in straw (48%) and grain (41%) yields was achieved respectively at 1.5 and 6 mg Zn kg^{-1} soil when applied as $ZnSO_4$+FYM. Root dry matter production also followed a similar pattern with maximum root dry weight was obtained in treatment receiving maximum rate of Zn as $ZnSO_4$+FYM (Table I).

Zinc concentration in various plant tissues: Zinc concentration in straw was significantly ($P \leq 0.05$) influenced with addition of Zn by either source (Table II). Zinc concentration in rice straw gradually increased with incremental Zn additions by various sources. Zinc concentration in straw was greatest when Zn was applied as $ZnSO_4$ (6 mg Zn kg^{-1} soil) followed by application of $ZnSO_4$+FYM (6 mg Zn kg^{-1} soil). However, application of $ZnSO_4$ alone or $ZnSO_4$+FYM did not significantly affected Zn concentration in straw except when at the highest rate (6 mg Zn kg^{-1} soil).

Zinc concentration in grains was significantly influenced ($P \leq 0.05$) by Zn application (Table II). At various rates of Zn application, applied as $ZnSO_4$, Zn-EDTA and $ZnSO_4$+FYM, grain Zn concentration ranged from 9.0 to 13.9 mg kg^{-1}. Compared to control Zn application, grain Zn concentration was significantly increased by Zn application by either source and at any rate. There were no differences among $ZnSO_4$ and Zn-EDTA at either rate for Zn concentration in grains. Enrichment of FYM with $ZnSO_4$ improved Zn concentration in grains when Zn was applied at highest rate at it was 54% greater than control. However, this increase was statistically similar to that at 3 mg Zn kg^{-1} soil applied as $ZnSO_4$+FYM.

There were significant ($P \leq 0.05$) differences among various Zn applications treatments for root Zn concentration (Table II). Gradual increase in Zn concentration in roots was observed with both Zn sources ($ZnSO_4$ & Zn-EDTA) and Zn enriched FYM ($ZnSO_4$+FYM), however differences were not significant among lower Zn rates (1.5 & 3 mg Zn kg^{-1} soil). Maximum root Zn concentration was observed when Zn was applied @ 6 mg Zn kg^{-1} soil as $ZnSO_4$, whereas enrichment of FYM at this rate of $ZnSO_4$ decreased root Zn concentration.

Zinc content in various plant parts: Compared to control, grain Zn content was significantly ($P \leq 0.05$) greater in treatments with Zn addition at all rates and with either source. The highest Zn content was accumulated in treatments where FYM was added along with $ZnSO_4$ (Table III). Grain Zn contents were slightly higher in plants receiving $ZnSO_4$ compared to those receiving Zn-EDTA.

Zinc content was significantly ($P \leq 0.05$) improved in straw with application of Zn in soil. Maximum increase in straw Zn content was observed at highest rate of Zn application. Straw Zn content was higher in plants grown with Zn-EDTA compared to those grown with $ZnSO_4$. Zinc content in roots linearly increased with application of Zn using either of the sources. Maximum increase was observed as expected in treatments receiving 6.0 mg Zn kg^{-1} soil. Application of FYM with 3.0 mg Zn kg^{-1} soil significantly increased root Zn content compared to plants receiving only $ZnSO_4$ or Zn-EDTA.

DISCUSSION

Plant growth and grain yield was significantly increased with the application of Zn to soil by either source (Table I). This increase was not expected as the soil was only marginally deficient in Zn (0.9 mg Zn kg^{-1} soil). However, the high lime contents and saline/sodic nature of soil combined with reduced soils conditions might have hampered plant Zn uptake in control treatment. Therefore, growth and yield of Zn fertilized plants was significantly increased over control. Plants respond to Zn fertilization on calcareous soils because Zn availability is generally reduced under these conditions (Khan *et al.*, 2002; Aziz *et al.*, 2010; Gurmani *et al.*, 2012; Hussain *et al.*, 2012a,b) particularly when soils are saline-sodic. Maximum straw and grain yields were achieved with treatments having $ZnSO_4$ in combination with FYM. Including other biological, physical and chemical changes, the increase in shoot dry weight with the application of $ZnSO_4$+FYM might be due to intermediates/metabolites of decomposition of FYM that

Table I: Grain yield, straw yield and root dry matter of rice (cv Shaheen Basmati) as affected by various Zn sources and rates; and Zn enriched farm yard manure grown on a moderately saline sodic soil. The values are mean of 3 replicates. The digits following same letter are not significantly different from each other at p<0.05

Treatments	Zn rate (mg Zn kg^{-1} soil)	Dry matter (g pot^{-1})		
		Grain yield	Straw yield	Root dry matter
Control	0	26.1 f	54 d	20.2 g
Zn SO_4	1.5	27.3 e	67 a-c	21.9 f
	3.0	30.5 c	71 ab	25.6 d
	6.0	33.7 b	61 b-d	28.1 c
Zn-EDTA	1.5	27.3 e	58 cd	21.8 f
	3.0	29.0 d	67 a-c	22.0 f
	6.0	29.6 cd	71 ab	23.8 e
$ZnSO_4$ + farm yard manure 5% of soil (w/w)	1.5	32.6 b	75 a	26.0 d
	3.0	35.9 a	75 a	29.2 b
	6	36.9 a	67 a-c	31.3 a
LSD at p< 0.05		0.6	5.07	0.48

Table II: Zinc concentration in grains, straw and roots of rice (cv Shaheen Basmati) as affected by various Zn sources and rates; and Zn enriched farm yard manure grown on a moderately saline sodic soil. The values are mean of 3 replicates. The digits following same letter are not significantly different from each other at p<0.05

Treatment	Zn rate (mg Zn kg^{-1} soil)	Zn concentration (mg kg^{-1})		
		Grain	Straw	Root
Control	0	9.04 e	7.09 e	20.26 h
Zn SO_4	1.5	10.83 cd	10.51 d	30.85 de
	3.0	11.97 bc	11.15 d	32.67 d
	6.0	12.16 bc	18.84 a	46.78 b
Zn-EDTA	1.5	9.81 de	13.74 c	28.13 f
	3.0	10.96 b-d	14.60 bc	29.27 ef
	6.0	11.84 bc	16.17 b	52.53 a
$ZnSO_4$ + farm yard manure 5% of soil (w/w)	1.5	11.71 bc	13.72 c	25.41 g
	3.0	12.63 ab	14.97 bc	42.85 c
	6.0	13.90 a	19.09 a	45.38 bc
LSD at p< 0.05		0.83	1.16	1.83

hold Zn in forms available to plants or release of Zn-mobilizing compounds such as phytosiderophores from roots, and induction of polypeptides involved in Zn uptake and translocation to shoots (Marschner, 1995; Cakmak & Braun, 2004). The high organic carbon content coupled with acidic reaction under reduced condition could have favoured the formation of organic complexes and increased the availability of Zn (Marschner, 1995). It could also be due to integrated use of both these amendments that have avowable effects on soil chemical properties by forming soluble complexes with Zn which ultimately increased the nutrient availability to plants resulting higher dry biomass. Similarly, the increase in root dry weight may be due to increased availability of Zn from rhizosphere by mechanisms such as pH decrease, release of organic acids due to decomposition of FYM, chelating and other compounds resulting an increase in root growth that

Table III: Zinc contents in grains, straw and roots of rice (cv Shaheen Basmati) as affected by various Zn sources and rates; and Zn enriched farm yard manure grown on a moderately saline sodic soil. The values are mean of 3 replicates. The digits following same letter are not significantly different from each other at p<0.05

Treatment	Zn rate (mg Zn kg^{-1} soil)	Zinc contents (mg pot^{-1})			
		Grain	Straw	Root	Total Zn contents
Control	0	0.24 f	0.14 e	1.00 e	1.38 d
Zn SO_4	1.5	0.33 c-e	0.23 de	2.00 cd	2.56 bc
	3.0	0.36 cd	0.29 c-e	2.26 c	2.91 b
	6.0	0.41 bc	0.53 ab	3.10 b	4.04 a
Zn-EDTA	1.5	0.27 ef	0.29 c-e	1.61 d	2.17 c
	3.0	0.32 d-f	0.32 c-e	1.90 cd	2.54 bc
	6.0	0.35 c-e	0.39 b-d	3.61 a	4.34 a
$ZnSO_4$ + farm yard manure 5% of soil (w/w)	1.5	0.38 b-d	0.36 b-d	1.85 cd	2.59 bc
	3.0	0.45 ab	0.44 a-c	3.17 ab	4.06 a
	6.0	0.51 ab	0.60 a	3.01 b	4.12 a
LSD at p< 0.05		0.07	0.05	0.47	0.49

promoted the increased in nutrient uptake per unit root volume (Kochian, 1991; Aziz *et al*., 2010).

Efficiency of Zn sources mainly depends on their solubility. Though $ZnSO_4$ is soluble source of Zn, however, some others have reported high retention of Zn in calcareous soils when applied as $ZnSO_4$ (Hussain *et al*., 2011; Rehman *et al*., 2012). Therefore, chelated Zn sources, such as Zn-DTPA and Zn-EDTA, are also recommended (Chand *et al*., 1981). In present study, $ZnSO_4$ was marginally better than Zn-EDTA in increasing plant growth and Zn concentration in various plant tissues (Westfall *et al*., 1971; Savithri *et al*., 1999). In contrary, Naik and Das (2007) reported that Zn-EDTA was better than $ZnSO_4$ with regard to grain yield because of higher availability of Zn in soil Zn-EDTA. The differences in soil chemical properties such as pH, lime contents and salinity might be responsible for these contrasting results. Application of $ZnSO_4$+FYM proved beneficial over $ZnSO_4$ and Zn-EDTA. This could be due the fact that the soil used was alkaline with pH of 8.51 and application of FYM decreased the soil pH and increased availability of Zn (Raman *et al*., 1999). Maskina and Randhawa (1983) reported positive effect of $ZnSO_4$ and organic matter in increasing Zn availability from soil and Srivastava *et al*. (2008) reported positive effects of Zn enrichment with biosludge on grain yield in rice. Due to these reasons, Zn concentration in various plant tissues differentially increased with Zn application by various sources.

Increase in Zn concentration in rice roots with Zn application was expected as Zn applied Zn may be held in the root cell walls, resulting in less Zn transportation to the upper portion of the plant (Youngdahl *et al*., 1977). High concentration of Zn in roots also attributed to apoplastic extracellular precipitation of Zn (Hassan *et al*., 2005). Zinc application significantly increased Zn concentration in straw and grains of rice plants. Higher grain Zn concentration in various plant parts is required by better growth and improved grain yield as well as for better human nutrition (Cakmak, 2008; Hussain *et al.*, 2012b; Rehman *et al.*, 2012). Application of $ZnSO_4$ enriched FYM could be a best strategy to increase grain Zn concentration of rice grown on saline-sodic soils.

In conclusion, Zn application to saline-sodic soil significantly increased grain yield and Zn concentration in rice grains. Application of $ZnSO_4$ enriched FYM proved better over application of alone $ZnSO_4$ or Zn-EDTA indicating the positive role of organic matter in increasing grain yield and grain Zn concentration on soils affected with salts and depleted in organic matter.

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