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Effect of different Zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw

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Abstract: Zinc (Zn) is essential micronutrient for plants, animals and humans. Zn deficiency is widely spread in paddy soils of Pakistan, and has negative impact of national rice production. A field experiment was conducted at the research area of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad to compare rice (*Oryza sativa* L.) yield and nutrients components i.e., nitrogen (N), phosphorus (P), potassium (K) and Zn, of paddy and straw in response to Zinc sulfate ($ZnSO_4.H_2O$), Zinc sulfate heptahydrate ($ZnSO_4.7H_2O$), Zn-ethylene diamine tetraacetate (Zn-EDTA) and zinc oxide (ZnO) as Zn sources which were either incorporated into the soil or applied as foliar spray 14 days after rice transplantation (DAT). Zn application significantly increased the Chlorophyll contents, tillers m^{-2}, total biomass and paddy yield, as well as the Zn concentration in the grain and the straw, except P content in the paddy and straw. Zn-EDTA incorporated in soil (10.0 kg ha^{-1}) resulted in greater values for these parameters as compared to other sources of Zn application. Among the method of Zn application, soil application resulted in higher yield, biomass, N and K contents in the grain and straw. Foliar application caused greater P concentration in both grain and straw, however, chlorophyll, K contents in paddy remained unaffected by method of Zn application. Zn-EDTA proved to be the most efficient source of Zn for rice production.

Key words: Foliar application, rice, micronutrients, zinc

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1. Introduction

Rice (*Oryza sativa* L.) is the staple food for 50% of the world population. Global rice production in 2008 was 661.811 million tones, and about 95 % of the rice is produced and consumed in developing countries especially in Asia (FAO, 2008; Rehmani et al., 2014). In Pakistan rice is the second largest food crop after wheat (*Triticum aestivum* L.), its contribution in value added and gross domestic product is 1.1% and 5.5. Rice is grown on 2.515 million hectares and its production is 5.56 million tons (GOP, 2008).

High-yielding varieties and greater fertilizer inputs were the strategies to raise the crop yield potential and feed increasing population. Increased application of fertilizers were not sufficient to compensate over-use of cultivated land. High-yielding varieties rapidly depleted soil micronutrients, therefore recent literature witnessed Zn deficiency, along with Iron (Fe), vitamin A, and Iodine (I) deficiency. Micronutrient deficiency is considered as a major threat to the global and regional food security (Ezzati *et al*., 2002).

The concentration of Zn in average soils ranged from 10 to 300 mg kg^{-1} (Mengel and Kirkby, 1987). In spite of the fact that the total soil Zn content is relatively high but a small fraction of it is available to plants (Mandal *et al*., 1992). In addition to high-yielding cultivars and heavy fertilizer inputs, Zn deficiency in rice may also induced by several other factors, including high soil pH, excess bicarbonate and low redox potential. Zinc concentration is decreased at high pH. If pH of soil increased then Zn concentration decreased 100 fold by one unit increased in pH (Chand *et al.*, 1981; Nadeem et al., 2013). Adsorption of Zn to clay and CaCO3 under high pH is the primary reason of reduced availability of Zn in calcareous soils (Broadley *et al.*, 2007).

It is therefore likely that several tolerance mechanisms need to be combined if a genotype is to fully overcome the effects of Zn deficiency (Widodo *et al*., 2010).

In biological systems Zn is enjoying unique status of being the only metal which is the component of enzymes of all six enzyme classes, i.e., oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases (Broadley *et al*., 2007) Zinc plays a very important regulatory role in various metabolic processes of plants including carbohydrate metabolism, cell wall development, gene expression, protein synthesis and respiration (Klug and Rhodes, 1987; Broadley *et al.*, 2007).

Rice is sensitive low Zn condition which is common in submerged paddy soils therefore; Zn deficiency frequently occurs (Hazra *et al*., 1987). Zinc deficient rice plants show poor ability root respiration during especially under flooded paddy soils (Slaton *et al*., 2001). Application of zinc salts e.g., zinc sulphate is a common practice to correct Zn deficiency. Moreover,Zn chelates, such as Zinc ethylene diamine tetra acetic acid (Zn-EDTA), which supply significant amount of Zn to the plant without interacting with soil components. In Zn-EDTA Zn ion (Zn^{2+}) is surrounded by chelated ligands (Mortvedt, 1979). Efficient uptake and transport of micronutrients to the grains can be increased by foliar application of micronutrient containing fertilizers. Therefore, like other micronutrients, foliar application of Zn is considered as potential method to ameliorate Zn deficiency in cereal grains (Cakmak, 2008: Fang *et al*., 2008)

This study was aimed to investigate the effects of different sources of zinc applied through soil or foliar method on rice yield dynamics and nutrients status in paddy grains and straw. Results of this study will help to mitigate zinc deficiency in rice and improve zinc use efficiency in the rice paddies.

2. Material and Methods

Experiment was conducted at the research area of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Soil samples were taken, in bulk from 0-30 cm depth, before rice transplantation to analyze physico-chemical characteristics using methods of Page *et al.* (1982) with slight modifications (Table 1).

Table 1: Physico-chemical characteristics of the soil at experimental site

Parameter	Value
Texture	Loamy
pH	70.93
EC_e (dSm^{-1})	2.57
Organic matter (%)	0.75
Total Nitrogen (mg kg^{-1})	0.08
Avalable Phosphorus (mg kg^{-1})	7.49
Extractable Potassium (mg kg^{-1})	132.2
DTPA extractable Zn (mg kg^{-1})	0.39

The experiment was laid out in a randomized complete block design (RCBD) having 4 replications. Nursery of *indica* rice (variety: super) was sown on 10 June 2009 and transplanted on 29 June 2009 in plots, each of an area of 20 m^2. All plots (except absolute control) received 110 kg ha^{-1} N as urea, 90 kg ha^{-1} of P as P_2O_5 and 60 kg ha^{-1} of K as K_2O. Full dose of P and K was applied one day before transplantation, urea was applied in two split application: the first split was applied at 55 kg N ha^{-1} one day before transplantation and the second split was applied at 55 kg N ha^{-1} 14 days after transplantation (DAT). The experiment included 10 treatments (Table 1).

Table1.Treatments, method and rates of nutrient application.

	NPK (kg ha^{-1})	Zn source	Zn Application	Zn (kg ha^{-1})
T_1	0	-	-	-
T_2	110:90:60	-	-	-
T_3	110:90:60	$ZnSO_4.H_2O$	Soil	12.5
T_4	110:90:60	$ZnSO_4.7H_2O$	Soil	20
T_5	110:90:60	Zn-EDTA	Soil	10
T_6	110:90:60	ZnO	Soil	5
T_7	110:90:60	$ZnSO_4.H_2O$	Foliar	1.6
T_8	110:90:60	$ZnSO_4.7H_2O$	Foliar	2.5
T_9	110:90:60	Zn-EDTA	Foliar	1.0
T_{10}	110:90:60	ZnO	Foliar	0.65

[a] T_1, absolute control; T_2, Zn-control; T_3-T_6 Zn incorporated in the soil; T_7-T_{10}, Zn applied as foliar spray

Zinc sources were applied in soil after 14 DAT. For foliar spray 0.2 % Zn solution of above mentioned zinc sources was dissolved in 0.1 % HCl and applied 14 DAT. All other agronomic practices were kept same and uniform for all the treatments. Data on following parameters were collected for analysis.

Rice chlorophyll contents were determined by using chlorophyll content meter (CCM-200, Apogeee, USA). Average number of tillers m^{-2} from each experimental unit was calculated per square meter. At physiological maturity rice plants were manually harvested from 1m^2, in the center of each plot, and these plants were used to determine total biomass, grain and straw yield (Rehmani *et al.,* 2014). After measuring total biomass (t ha^{-1}), paddy grains were manually threshed and carefully separated from straw. Separated paddy grains were weighed to calculate paddy yield (t ha^{-1}). Straw yield was obtained by subtracting paddy yield from total biomass.

3. Results and Discussion

3.1 Number of tillers

In cereals, tillering capacity is one of the main components of grain yield. Higher yield potential can be achieved by greater tillers per plant. The data regarding the number of tillers as influenced by Zn application is presented in Fig. 1.A. Zn application significantly increased number of tillers per plant ($P < 0.05$).

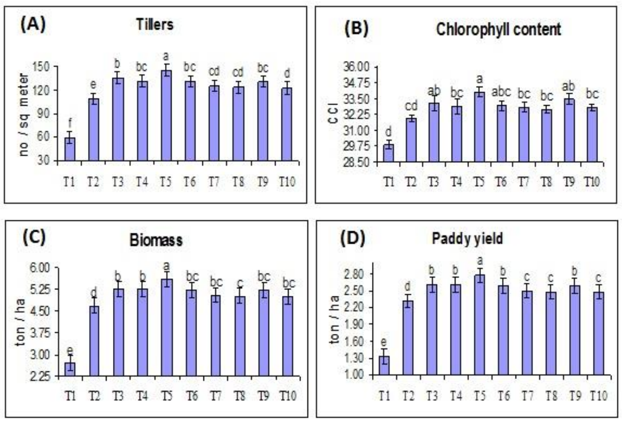

Figure 1. Number of tillers, chlorophyll content, total biomass and paddy yield as affected by soil and foliar applications of different sources of zinc. Values are means of three replicate plots. Means with different letters are statistically different from each other at 5% level.

Among the Zn sources, soil applied Zn-EDTA (10.0 kg ha^{-1}) produced maximum number of tillers per plant (145 tillers), which was significantly different from all other treatments. Minimum of 60 tillers per plant were observed under treatment T_1 (without fertilizer) followed by T_2 (recommended $N:P_2O_5:K_2O$ @ 110:90:60 kg ha^{-1}). In case of foliar Zn application, T_9 produced significantly higher (131) number of tillers m^{-2}, when Zn-EDTA was applied @ 1.00 kg ha^{-1}, which was statistically similar to other Zn sources applied as foliar fertilizer, except T_{10} (ZnO @ 0.65 kg ha^{-1}). Increased tiller production can be attributed to Zn induced enzymatic activity and auxin metabolism in plants. These results are similar to the findings of Ghani *et al.* (1990).

3.2 Chlorophyll content

Content of plant pigments like chlorophyll determines color and appearance, and is an indicator of plant health (Abbot, 1999). Zn is proposed to be involved in chlorophyll formation through regulation of nutrients homeostasis in cytoplasm (Aravind and Prasad, 2004). The analysis of the data showed that various treatments had significant effect ($P < 0.05$) on chlorophyll content (Fig. 1B). The highest value (34.05 CCI) was obtained in T_5 (Zn-EDTA was applied @ 10.00 kg ha^{-1} in soil) followed value (32.83 CCI) of T_{10} (ZnO was applied @ 0.650 kg ha^{-1} as foliar). The minimum value (29.90 CCI) was obtained in T_1 (No fertilizer, no zinc).

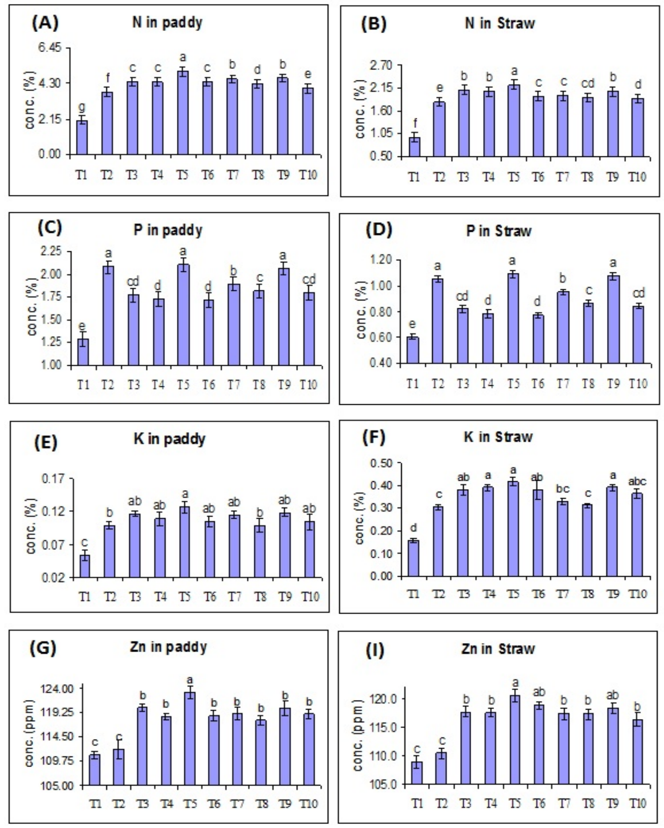

Figure 2. Nitrogen, phosphorus, potassium and zinc contents in rice paddy and straw as affected by soil and foliar applications of different sources of zinc. Values are means of three replicate plots. Means with different letters are statistically different from each other at 5% level.

3.3 Biomass

The data on biomass of rice is presented in Fig. 1C. The statistical analysis of the data showed that effect of the treatments on biomass was significant ($P < 0.05$). The maximum biomass ton ha^{-1} was recorded in T_5 (5.61) when Zn-EDTA was applied @ 10.00 kg ha^{-1} in soil followed by T_3 (5.28) when $ZnSO_4.H_2O$ was applied @ 12.50 kg ha^{-1} and T_6 (5.22) when ZnO was applied @ 5.00 kg ha^{-1} in soil as compared to T_1 (2.72). Srivastava *et al.* (1999) also presented similar findings.

3.4 Paddy yield

The impact of various sources and method of Zn application on paddy yield were evaluated (Fig 1D). The statistical analysis for paddy yield showed that

Zn treatments resulted in significant increase ($P < 0.05$) in the paddy yield. The maximum paddy yield ton ha^{-1} was recorded in T_5 (2.78) when Zn-EDTA was applied @ 10.00 kg ha^{-1} in soil followed by T_3 (2.62) when $ZnSO_4.H_2O$ was applied @ 12.50 kg ha^{-1} and T_6 (2.59) when ZnO was applied @ 5.00 kg ha^{-1} as compared to control T_1 (1.34). This result is in arrangement with the finding of Karak *et al.* (2005) who reported that Zn chelates proved to be most efficient Zn source for rice in calcareous paddy soils.

3.5 Nitrogen content in paddy and straw

The data on N content in paddy and straw are presented in Fig.2A & 2B. The N content in paddy and straw were significantly ($P < 0.05$) increased with Zn application over both absolute and Zn-control. Maximum N content in paddy (5.02 %) and straw (2.22 %) were recorded in T_5 (Zn-EDTA applied @ 10.00 kg ha^{-1} in soil). The minimum N content in paddy (2.10 %) and straw (0.97 %) were observed under absolute control (T_1). Concentration of N in paddy grains was higher as compared to straw, under all applied treatments. These results are in agreement with findings of Singh *et al*. (1990) and Takkar (1996).

3.6 Phosphorus content in paddy and straw

Data regarding P concentration in paddy is presented in Fig. 2C and D. Statistical analysis showed that variation due to different treatments was significant ($P < 0.05$). Lowest P concentrations for paddy and straw were recoded under absolute control (T_1). When compared with Z-control (T_2) different sources of Zn application resulted in decreased P content in paddy and straw (except Zn-EDTA application, both soil and foliar). Maximum value of P content in paddy (2.11 %) and straw (1.09 %) were obtained in T_5 (Zn-EDTA applied @ 10.00 kg ha^{-1} in soil) followed by T_2. Among the Zn treatments, T_6 (ZnO applied @ 5.00 kg ha^{-1} in soil) recorded lower P contents in paddy (1.72 %) and straw (0.77 %). Similar results also reported Chaudhry *et al.* (1992) and Yaseen *et al.* (1999)

3.7 Potassium content in paddy and straw

The data on the potassium concentration in paddy is presented in Fig.2E and F. Statistical analysis showed that variation due to different treatments was significant ($P<0.05$). Significantly maximum K contents in paddy (0.13 %) and straw (0.42 %) were observed in T_5 (Zn-EDTA applied @ 10.00 kg ha^{-1} in soil) while minimum K content in paddy (0.05 %) and straw (0.16 %) were observed in T_1 (Absolute control). Overall, paddy grains have significantly lower concentration of K as compare to that in straw. These results are confirmation findings of Iqbal *et al.* (2000), they reported that K concentration of both paddy and straw showed increasing trend with Zn fertilizer application.

3.8 Zinc content in paddy and straw

The data on the zinc concentration in paddy is presented in Fig. 2 G and H. Zinc concentration in both paddy and straw significantly enhanced by Zn application as compared to absolute control (T_1) and Zn-control (T_2) ($P < 0.05$). Different sources of Zn were statistically similar except Zn-EDTA application. Maximum Zn contents in paddy (123.18 ppm) and straw (120.5 ppm) were observed in T_5 (Zn-EDTA applied @ 10.00 kg ha^{-1} in soil), while minimum Zn content in paddy (111.07 ppm) and straw (108.9 ppm) were observed in T_1 (Absolute control). Stunted growth of rice plants under Zn deficient conditions may reduce Zn uptake and ultimately compromised Zn concentration in paddy and straw. These results are in agreement with the finding of Devarajan and Ramanathan (1995).

4. Conclusion

Our results shows that rice under climatic conditions of Faisalabad, Pakistan, Zn-EDTA applied incorporated in the soil 14 days after transplantation, along with recommended N:P:K proved to be appropriate to ameliorate zinc deficiency. Soil application of Zn-EDTA significantly increased yield components, as well as nutrient contents in paddy grains and straw. Application of Zn-EDTA will be helpful to reduce zinc deficiency in rice.

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Competing Interests

Authors declare that they have no competing interests.

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