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PS Kulhare
Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur-482006 Madhya Pradesh, India

GS Tagore
Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur-482006 Madhya Pradesh, India

GD Sharma
Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur-482006 Madhya Pradesh, India

Correspondence
PS Kulhare
Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur-482006 Madhya Pradesh, India

Effect of foliar spray and sources of zinc on yield, zinc content and uptake by rice grown in a vertisol of central India

PS Kulhare, GS Tagore and GD Sharma

Abstract
A field experiment was conducted in *kharif* during 2010 and 2011 to study the effect of foliar spray of 0.5, 1.0% Zn salts and 1.0% Zn salts +0.5% lime concentration of different sources of Zn ($ZnSO_4.7H_2O$, $ZnCl_2$, $Zn_3(PO_4)_2$, ZnO and Na_2Zn-EDTA) on yield, Zn content, uptake and Zn use efficiency in rice (*Pusa Basmati*) grown on Typic Haplusterts. The rice grain yield significantly increased with the foliar application of Zn-EDTA over all the sources of Zn but the other Zn sources were found on par amongst themselves. While the Zn content in grain and straw with $Zn_3(PO_4)_2$ and Zn EDTA was found significantly superior to $ZnCl_2$ except Zn content in straw with $Zn_3(PO_4)_2$. The Zn uptake by grain with $ZnSO_4.7H_2O$, $Zn_3(PO_4)_2$, ZnO and Zn EDTA were also found significantly superior to $ZnCl_2$ but the sources of zinc were found non-significant for Zn uptake by straw and total Zn uptake. The Zn use efficiency by Zn EDTA and $ZnSO_4.7H_2O$ was found significantly superior to $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO. However, the Zn use efficiency with Zn EDTA was also found significantly higher than $ZnSO_4.7H_2O$. Foliar application of 1.0% zinc salts was found significantly superior to 0.5% Zn salt for yield, Zn content and uptake. However, the Zn uptake with 1.0% zinc salts was found significantly higher than 1.0% zinc salts+0.5% lime application. The zinc use efficiency with 0.5% Zn salt was found significantly higher than 1.0% Zn salts+0.5% lime but 0.5% Zn salt was found on par with 1.0% Zn salts for available Zn.

Keywords: Foliar application, sources of Zn, Rice, Zn uptake, Yield, Zn use efficiency

1. Introduction
Rice (*Oryza sativa* L.) is staple food for more than 60% of world population (Parthipan and Ravi 2016) and it contribute 45% to the total food grain production in India (Ram *et al*., 2013). Rice is one of highly sensitive crops to Zn deficiency and Zn limits growth and yield of rice. Zinc deficiency in rice has been widely reported in many rice-growing regions of the world. In India 47% and in MP 60.3% of the soils found deficient in Zn (Shukla and Tiwari, 2014). Zn deficiency in crop plants results not only in yield reduction but also Zn malnutrition in humans, i.e. diarrhea in infants, dwarfism in adolescents, where a high proportion of rice is consumed as a staple food (Chasapis *et al*., 2012) [3]. Increasing Zn concentration of rice grains, and bioavailability of food crop, through bio-fortification appears to be the most feasible, sustainable and economical approach among the different interventions to address human Zn deficiency (Salunke *et al*., 2011) [22].

Foliar application of Zn is a simple way for making quick correction of plant nutrient status as reported for wheat (Erenoglu *et al*., 2002) [5] and maize (Grzebisz *et al*., 2008) [7]. The external spray of Zn boost process responsible for potential yield of crops as Zn exerts a great influence on basic plant life process such as (i) nitrogen metabolism, uptake of N and protein, (ii) photosynthesis-chlorophyll synthesis carbonic anhydrase activity (iii) resistant to abiotic and biotic stresses-protection against oxidative damage (Cakmak 2008) [2]. Potarzycki and Grzebisz (2009) [18] reported significant response of foliar application of Zn @ 1 kg ha-1 to total uptake and grain yield by improvement of yield structure elements i.e. number of kernel plant-1 and length of cob. Foliar Zn application resulted greater bioavailability of grain Zn than soil application.

Zn fertilization to cereal crops improves productivity and grain Zn concentration (Phattarakul *et al*., 2012) [17], and thus contributes to grain nutritional value for human beings. However, the vast majority of Zn fertilizer trials and resulting fertilizer recommendations in rice have been in the context of managing the Zn deficiency, with very few studies related to Zn bio-fortification (Impa and Johnson-Beebout, 2012) [8].

In order to achieve higher crop production, through selection of appropriate Zn sources for foliar application to fortify seed and straw with Zn, the present investigation was under taken.

2. Materials and Methods

A field experiment was conducted at the Research Farm of College of Agriculture, Jabalpur under under All India Co-ordinated Research Project on Micro Secondary Nutrients and Pollutant Elements in Soils and Plants in Department of Soil Science & Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh to assess the effect of foliar application of zinc sources on yield, Zn content and uptake by rice grown in a Vertisol in *kharif* during 2010 and 2011. The experiments were conducted on a separate site to avoid residual effects. Two concentration of zinc salts i.e. 0.5%, 1.0% and 1.0% salt + 0.5% lime spray were applied at tillering and flag leaf stage through $ZnSO_4.7H_2O$, $ZnCl_2$; $Zn_3(PO_4)_2$, ZnO and Zn EDTA. There were fifteen treatments randomly allocated in 3 replications in a factorial randomized block design. The recommended dose of 120 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O were applied for rice crop. A basal dose of 60 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O were applied at the time of sowing. Remaining 60 kg N was applied in two equal split dose of 30 kg N ha^{-1} at the time of tillering and flags leaf stage.

The soil of the field had mean pH 8.1 (1:2.5 soil: water ratio) organic carbon 0.47% (Walkley and Black 1934) 175 kg ha^{-1}, alkaline permanganate oxidizable N (Subbiah and Asija, 1956) [25], 14.7 kg ha^{-1} available P (Olsen *et al*., 1954), 213 kg ha^{-1} 1 N ammonium acetate extractable K (Jackson 1973) and 0.69 mg kg^{-1} diethylene triamine penta acetic acid (DTPA) extractable Zn (Lindsay and Norvell, 1978) [11]. Zn content in grain and straw samples was analyzed by digesting the plant samples with $HClO_4:HNO_3$ mixture in 3:10 ratio then analyzed with Atomic Absorption Spectrophotometer.

Recovery efficiency (RE) was computed using the following expressions as suggested by Dobermann (2005) [4] and Shivay *et al*. (2010) [23]: $RE = [(U_{Zn}-U_{Pu}) / Zn_a]\times100$

Where in U_{Zn} refer to the total Zn uptake in treated plot (kg ha^{-1}) and U_{Pu} refer to the total Zn uptake in control plot (kg ha^{-1}), respectively, Zn_a refers to the Zn applied (kg ha^{-1}). Data were statistically analyzed using LSD values at p=0.05 to determine the significance of differences between treatment means as suggested by Panse and Sukatme (1985) [15].

3. Results and Discussions

3.1 Grain and Straw Yield

The pooled data presented in table 1 showed that the application of Zn-EDTA significantly increased the grain yield of rice (4.10 t ha^{-1}) over all other sources of zinc but the sources i.e. $ZnSO_4$, $ZnCl_2$, ZnO and $Zn_3(PO_4)_2$ were found on par amongst themselves. Similarly, all the Zn sources were found on par for straw yield of rice. A better Zn supply from Na_2Zn-EDTA application to the plants might have led to the increased grain and straw yield of rice. Similar results were reported by Naik and Das (2007) [13], Verma *et al*., (2015) [27] and Talib *et al*., (2016) [26].

The foliar spray of 1.0% Zn salt significantly increased the rice grain and straw yield over 0.5% spray of Zn salts alone and 1% Zn salts along with 0.5% lime application. The lower grain and straw yield of rice with 1.0% Zn salts along with 0.5% lime application might be due to decrease in the Zn uptake as Ca application reduce the Zn uptake. There was no scorching effect of zinc salts application without addition of lime. The increase of grain yield with foliar application of Zn was reported by Potarzycki and Grzebisz (2009) [18], Phattarakul *et al*., (2012) [17] Rehman *et al*., (2012) [21] and Beutler *et al*., (2014) [1].

3.2 Zinc concentration

The pooled data presented in table 1 indicated that the application of $Zn_3(PO_4)_2$ and Na_2 Zn-EDTA significantly increased the Zn content of grain and straw of rice over $ZnCl_2$ except zinc content in straw with $Zn_3(PO_4)_2$ but the other sources were found on par amongst themselves for Zn content in grain and straw. The maximum Zn content in grain 11.10 mg kg^{-1} and in straw 19.07 mg kg^{-1} was observed with Zn EDTA. Verma *et al*., (2015) [27] reported the highest Zn concentration in grain and straw with effect of EDTA-chelated Zn in on rice as compare to $ZnSO_4.7H_2O$ and $ZnSO_4.H_2O$. It is also in line the finding of Rana and Kashif (2014) [20] Talib *et al*., (2016) [26] and Islam *et al*., (2016) [9].

The foliar application of 1% Zn salt concentration and 1% Zn salt+0.5% lime significantly increased the Zn content in grain and straw over 0.5% spray of Zn salts except Zn content in straw with 1% salt concentration+0.5% lime application. The interaction between Zn sources and their concentration was found non-significant for Zn content in grain and straw. The lower Zn concentration in grain and straw with 1% Zn salts +0.5% lime might be due to presence of Ca might reduce the Zn absorption than Zn salts alone. Foliar application of Zn was quite effective in rice likely because of the Zn was directly absorbed by rice plant leaves and finally accumulated into grain. It is evident from the above results that N interacted positively with Zn and the synergistic effect of Zn and N are mainly attributed to an increased availability of Zn in soil due to the acid forming effect of N. The increase of Zn concentration with foliar application of Zn was confirmed by Erenolugh *et al* (2002) [5] Grezelfiz *et al*., (2008) [7], Phattarakul *et al*., (2012) [17] and Rehman *et al*., (2012) [21].

3.3 Zinc uptake

The pooled data presented in table 2 indicated that the application of $ZnSO_4.7H_2O$, $Zn_3(PO_4)_2$, ZnO and Zn-EDTA significantly increased the Zn uptake by rice grain over $ZnCl_2$. However, the Zn uptake by rice grain with Zn-EDTA was found significantly superior to all other sources of zinc but the Zn uptake by grain with $ZnSO_4.7H_2O$, $Zn_3(PO_4)_2$ and ZnO were found on par amongst themselves. Similarly, the maximum Zn uptake by straw and total Zn uptake by rice was observed with Zn EDTA followed by ZnO, $ZnSO_4.7H_2O$, $Zn_3(PO_4)_2$ and $ZnCl_2$ but these sources were found non-significant. These findings are well corroborated with Verma *et al*., (2015) [27] and Islam *et al*., (2016) [9]

The foliar application of 1% zinc salt and 1.0% zinc salt +0.5% lime significantly increased the zinc uptake by grain over 0.5% zinc salt. However, the Zn uptake by grain, straw and total zinc uptake by rice with foliar application of 1% zinc salt was found significantly superior to 0.5% zinc salt and 1% zinc salt +0.5% lime. Foliar application of Zn is considered as potential method to ameliorate Zn deficiency in cereal grains (Cakmak, 2008 and Fang *et al*., 2008) [2, 6]. The increase of Zn uptake with foliar application of Zn was supported by Potarzycki and Grzebisz (2009) [18].

3.4 Zinc recovery efficiency

Application of Zn-EDTA and $ZnSO_4.7H_2O$ significantly increased the Zn use efficiency by rice over $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO. However, the Zn use efficiency with Zn-EDTA was also found significantly superior to $ZnSO_4.7H_2O$ but the zinc sources i.e. $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO were found on par. The zinc use efficiency with 0.5% foliar application of zinc salts was found (0.82%) significantly superior to 1.0% zinc salt +0.5% lime application (0.52%) but the difference between the Zn use efficiency with 0.5% and 1.0% zinc salts was found non-significant. The results are in agreement with Muthukumararaja and Sriramachandrasekharan (2012) [12].

3.5 Available Zn

The application of foliar application $ZnSO_4.7H_2O$, $Zn_3(PO_4)_2$ and Zn-EDTA significantly increased the available Zn content in soil over ZnO during 2010. However, the available Zn content with Zn-EDTA was found significantly superior to all the sources of Zn but the $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO were found on par amongst themselves. The application of foliar spray of 1.0% zinc salt and 1.0% zinc salt+0.5%lime were found significantly superior to 0.5% zinc salt application but the difference between the two treatments was found non-significant during 2010.

Table 1: Effect of zinc sources and their concentration of spray on yield and zinc content of rice during 2010 and 2011

Treatments	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Grain Zn (mgkg^{-1})			Straw Zn (mgkg^{-1})		
	2010	2011	pooled	2010	2011	pooled	2010	2011	pooled	2010	2011	pooled
$ZnSO_4.7H_2O$	3.93	3.40	3.67	7.12	6.22	6.67	10.34	10.83	10.59	18.34	17.92	18.13
$ZnCl_2$	3.83	3.50	3.67	7.13	6.63	6.88	9.74	10.01	9.87	16.05	16.40	16.23
$Zn_3(PO_4)_2$	3.82	3.29	3.55	6.56	6.58	6.57	11.28	10.71	10.99	15.05	19.07	17.06
ZnO	3.94	3.58	3.76	6.80	7.57	7.18	9.99	10.83	10.41	16.32	19.89	18.11
Na_2Zn-EDTA	4.04	4.17	4.10	6.84	6.91	6.87	10.65	11.54	11.10	17.30	20.84	19.07
SEm±	0.080	0.116	0.103	0.264	0.308	0.272	0.455	0.281	0.255	0.733	0.67	0.675
CD (p=0.05)	NS	0.337	0.291	NS	NS	NS	NS	0.814	0.722	2.122	1.946	1.909
Foliar Spray conc. (%)												
0.5	3.68	3.54	3.61	6.75	6.67	6.71	9.61	10.25	9.93	15.71	16.79	16.25
1.0	4.31	3.83	4.07	7.12	7.41	7.27	11.21	11.29	11.25	17.61	20.76	19.19
1.0+0.5Lime	3.74	3.40	3.57	6.80	6.26	6.53	10.38	10.82	10.60	16.52	18.92	17.72
SEm±	0.062	0.090	0.080	0.205	0.239	0.211	0.353	0.218	0.198	0.567	0.521	0.523
CD (p=0.05)	0.179	0.261	0.225	NS	0.692	0.597	1.021	0.630	0.559	NS	1.507	1.479
Source X conc.												
SEm±	0.138	0.202	0.178	0.457	0.53	0.472	0.788	0.487	0.442	1.269	1.164	1.169
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Effect of Zn sources and their concentration of foliar spray on Zn uptake, Zn use efficiency and post harvest soil Zn during 2010 and 2011

Treatments	Zn uptake (g ha^{-1})									Zn use efficiency (%)			Soil Zn (mg kg^{-1})	
	Grain			Straw			Total							
	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled	2010	2011
$ZnSO_4.7H_2O$	40.69	36.85	38.77	130.45	111.98	121.35	171.14	148.83	160.12	0.81	0.76	0.79	1.30	1.44
$ZnCl_2$	37.42	34.99	36.20	114.57	109.10	111.58	151.99	144.09	147.78	0.38	0.55	0.47	1.19	1.05
$Zn_3(PO_4)_2$	43.20	35.40	39.30	98.55	126.13	112.30	141.75	161.53	151.60	0.22	0.38	0.30	1.22	0.93
ZnO	39.56	38.82	39.19	111.68	150.11	130.79	151.25	188.93	169.98	0.19	0.34	0.26	1.06	1.40
Na_2Zn-EDTA	43.15	48.14	45.65	118.33	143.90	131.19	161.48	192.04	176.84	1.15	1.99	1.57	2.26	0.98
SEm±	1.936	1.628	0.730	6.640	7.397	7.837	6.918	7.331	8.012	0.085	0.115	0.103	0.070	0.034
CD (p=0.05)	NS	4.716	2.064	19.231	21.424	NS	NS	21.233	NS	0.246	0.333	0.291	0.204	0.100
Foliar Spray conc. (%)														
0.5	35.35	36.33	35.84	106.01	111.85	108.97	141.36	148.18	144.80	0.67	0.96	0.82	1.26	0.97
1.0	48.23	43.40	45.82	125.59	153.94	139.80	173.82	197.34	185.62	0.54	0.86	0.70	1.54	1.33
1.0+0.5Lime	38.84	36.80	37.82	112.54	118.95	115.55	151.37	155.74	153.37	0.45	0.59	0.52	1.42	1.18
SEm±	1.500	1.261	0.565	5.143	5.730	6.070	5.359	5.679	6.206	0.066	0.089	0.080	0.055	0.027
CD (p=0.05)	4.343	3.653	1.599	14.896	16.595	17.170	15.520	16.447	17.553	NS	0.258	0.225	0.158	0.078
SourceXconc.														
SEm±	3.353	2.820	1.264	11.501	12.812	13.574	11.982	12.698	13.877	0.147	0.199	0.178	0.122	0.0603
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4. Conclusion

Application of Zn-EDTA and $ZnSO_4.7H_2O$ significantly increases the zinc recovery efficiency of rice over $ZnCl_2$, $Zn_3(PO_4)_2$ and oxide. However, the zinc recovery efficiency with zinc EDTA was found significantly superior to $ZnSO_4.7H_2O$. Since the Zn-EDTA is recommended due to its higher recovery efficiency but its cost is very high therefore the $ZnSO_4.7H_2O$ is recommended for the rice cultivation because of it low cost and high solubility.

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