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Comparative bio-efficacy of zinc fortified phosphatic fertilizers in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system in north-western India

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ABSTRACT

The field experiments were conducted during 2015–16 at five different locations in Punjab, north-western India to study the effect of soil and foliar application of zinc (Zn) either along with ordinary P fertilizers (DAP and SSP) or through their fortified sources (ZnDAP and ZnSSP). The field treatments consisted of control (NK), NK+ DAP, NK+ SSP, NK+ ZnDAP (ZnDAP), NK+ ZnSSP (ZnSSP), Zn (Zn spray), NK+ ZnDAP+ Zn spray (ZnDAP+ Zn spray) and NK+ ZnSSP+ Zn spray (ZnSSP+Zn spray) in a rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system. The application of ZnDAP increased wheat grain yield by 4.1–5.8%, compared with control at different experimental sites. The ZnDAP+ Zn spray and ZnSSP+Zn spray significantly increased the wheat straw yield by ~20.1 and 23.4%, respectively compared with the control. The increase in Zn concentration in wheat grains significantly (R^2=0.950-0.986**, P<0.01) increased the wheat grain yield. The application of ZnDAP and ZnSSP significantly increased the Zn concentration in wheat straw by ~19.0 and 27.6%, compared with control. The ZnDAP+ Zn spray and ZnSSP+Zn spray significantly increased the rice grain yield by ~14.4 and 16.5%, respectively, compared with control. The increased Zn concentration in rice grains significantly (R^2=0.756*, P<0.05 to 0.973**, P<0.01) increased the rice grain yield at different experimental sites.

Keywords: Crop yields, Grain Zn concentration, Rice-wheat cropping system, Zn fortified phosphatic fertilizers

Zinc is the most important essential micro-nutrient required for optimum plant growth. Most crops require ~15–20 mg Zn/kg biomass for various physiological and metabolic processes related to synthesis of protein, carbohydrates, auxins and chlorophyll for improved quality of produce due to increased enzymatic activity (Broadley *et al.* 2007). Nonetheless, Zn is a structural component of proteins, and the human body contains 1.5–2.5 g Zn, which is required at 10–14 mg Zn/day (WHO 2004). But most often, human diets contain less of the necessary essential nutrients leading to malnutrition (Sachdev *et al.* 1988). Sillanpaa and Vlek (1985) reported that >50% of cereal crops grown in a wide range of agro-climatic conditions are Zn deficient. About 54.5% of the intensively cultivated soils in Punjab (north-western India) are Zn deficient (Singh *et al.* 2009a), and therefore require adequate attention of Zn fertilization in crop production (Singh *et al.* 2020). Micro-nutrients enhance crops' nutritional quality, yield biomass production and resiliency towards biotic and abiotic stresses (Joy *et al.* 2015). The positive effects range from 10-70% dependent on the micro-nutrient and occur with or without NPK fertilization (Dimkpa and Bindraban 2016). In general, Zn is supplied as zinc sulphate heptahydrate ($ZnSO_4$.7 H_2O, 21% Zn) or zinc sulphate mono-hydrate ($ZnSO_4.H_2O$, 33% Zn) in field crops to meet crops' Zn requirement (Fagaria 2001, Singh and Saini 2011, Singh *et al.* 2013, Joy *et al.* 2015, Elemike *et al.* 2019). Till date, the research on field application of Zn fortified phosphate fertilizers has been scarce. Zinc applied in mixed form with other fertilizers as a compound or complex fertilizer for plant uptake in one application can be a good option for overcoming Zn deficiency. The effect of Zn fortified phosphatic fertilizers viz. ZnDAP and ZnSSP on bio-efficacy of Zn in a rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system have not been studied extensively. The present study was therefore, conducted at five different experimental sites in various agro-ecological sub-regions in Punjab (north-western India) to assess the effect of soil application of ZnDAP and ZnSSP, either alone or conjointly with foliar application of $ZnSO_4$ on crop yield and Zn concentration in a rice-wheat cropping system.

MATERIALS AND METHODS

Description of the study area: The field experiment was conducted at farmers' fields at Amritsar, Fatehgarh Sahib, Mansa, Ropar and Hoshiarpur districts in Punjab (north-

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western India) during 2015–16. All experimental soils were Zn deficient (DTPA-Zn <0.6 mg/kg soil). The climate of different experimental sites is sub-tropical, semi-arid and monsoonal with a mean annual rainfall varied between 250 and 950 mm. The initial soil chemical properties of the experimental site were generally favorable for crop production. The soil samples were passed through a 2.0 mm stainless steel sieve, and stored for analysis. Soil samples were analyzed for pH (1:2; soil: water suspension) using a glass electrode and electrical conductivity ($EC_{1:2}$) (1:2; soil: water supernatant) with a conductivity meter (Jackson 1973). The DTPA extractable Zn was determined after extracting the soils with DTPA solution (0.005 M DTPA + 0.01M $CaCl_2$ + 0.1M TEA buffer adjusted to *p*H=7.3) (Lindsay and Norvel 1978), followed by determinations on atomic absorption spectrophotometer. Soil organic C (SOC) concentration in soil samples was determined by wet-digestion method (Walkley and Black 1934). Soils at different locations were non-saline (EC=0.31-0.65 dS/m) with slightly alkaline (*p*H =7.60-8.26), low to medium SOC (2.80-5.60 g/kg), medium to high P (33.8-48.3 kg/ha) and low DTPA-Zn (0.24-0.30 mg/kg).

Field treatments and crop establishment: Field treatments consisted of control (NK), NK+P as DAP (DAP), NK+P as SSP (SSP), NK+ZnDAP (ZnDAP), NK+ZnSSP (ZnSSP), foliar application of Zn (Zn spray), NK+ZnDAP+Zn spray (ZnDAP+Zn spray) and NK+ZnSSP+ Zn spray (ZnSSP+ Zn spray) to rice, 125 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha was applied. Fertilizer N was applied in three equal splits; 1/3rd at transplanting, 1/3rd each at 21 and 42 days after transplanting. Fertilizer-P and K were applied as basal dose at last puddling. The preparatory tillage included operations of disk and tyne cultivator in standing water to puddle the soil followed by planking. Thirty-day-old rice seedlings were transplanted manually (2 seedlings per hill) in the second week of June each year. Rice fields were kept flooded for the initial 15 days after seedling transplanting, followed by irrigation at one-two days interval till physiological maturity. Rice was harvested manually in the last week of October to the first week of November. Wheat was sown with a seed-cum-fertilizer drill in rows 20 cm apart after about three weeks of pre-sowing irrigation at field capacity moisture content. Wheat received 125 kg N, 26 kg P and 25 kg K/ha. One-half of fertilizer-N (after adjusting N from DAP) and the whole of fertilizer-P and -K were drilled at wheat sowing. The remaining half of N was applied at first irrigation. Subsequent irrigations were applied by the farmers based on physical inspection of the field with underground and canal water. Crops (rice and wheat) were harvested from a small-sized plot (2.0-2.5 m wide × 4.0-5.0 m long). The grains from the biomass were removed manually and weighed. The straw yield was reported on an oven-dry weight basis.

Plant analysis: The grain and straw samples collected each season at maturity were oven-dried at 65°C for 48 h to a constant weight. Plant samples were ground to pass through a sieve with a mesh size of 0.5 mm. The 0.5g plant sample was digested in a triple-acid (HNO_3: H_2SO_4: $HClO_4$; 10:3:1), diluted adequately and analyzed for total Zn using atomic absorption spectrophotometer.

Statistical analysis: The data were analyzed using analysis of variance (ANOVA) for the completely randomized block design using SPSS for Windows 16 (IBM. SPSS Inc., Chicago, USA). All data sets were subjected to ANOVA and the differences between the means of treatment were separated by the Duncans' Multiple Range Test (DMRT) post hoc test at 95% confidence interval. The treatment means differing at P<0.05 were considered statistically significant. The experimental sites were considered as replicates (random effect).

RESULTS AND DISCUSSION

Grain and straw yield of wheat: Wheat grain yield varied widely at different experimental sites (Table 1). Mean wheat grain yield varied between 4.38 and 4.69 Mg/ha among different locations. The soil application of ZnDAP increased the wheat grain yield by 4.1-5.8%, compared with control (NK alone) at various experimental sites. Mean wheat grain yield increased significantly (P<0.05) by ~4.8% with ZnDAP application, compared with NK alone (Control). The ZnDAP+Zn spray and ZnSSP + Zn spray significantly increased the wheat grain yield, compared with control, although the two treatments did not differ significantly. Mean wheat straw yield varied between 6.31 and 7.78 Mg/ha, and was significantly increased with soil and foliar application of Zn with either source of P. The ZnDAP+Zn spray and ZnSSP+Zn spray significantly increased the wheat straw yield by ~20.1 and 23.3%, respectively compared with control. Higher grain yield due to Zn application could be due to activation of enzymes and production of auxin (Sachdev *et al.* 1988), improvement in the production of carbohydrates and their transfer to the site of grain production (Babu *et al.* 2007). Ahmad *et al.* (2018) also reported ZnSSP produced significantly higher grain yield and yield attributes, Zn concentrations in grains and leaves of maize. Soil application of Zn leads to increased Zn concentration in maize, rice and wheat grains by ~23, 7 and 19%, respectively while the foliar application of Zn increased the yields by ~30, 25 and 63%, respectively (Joy *et al.* 2015).

Zinc concentration in wheat grain and straw: Mean Zn concentration in wheat grains varied between 24.6 and 30.2 mg/kg, and was significantly higher in ZnDAP+Zn spray and ZnSSP+ Zn spray treatments, compared with control (Table 1). There was a significant increase in Zn concentration in wheat grain with ZnDAP and ZnSSP application, compared with the no-Zn application. The ZnDAP and ZnSSP significantly increased the Zn concentration in wheat grains by ~16.3 and 19.9%, compared with control. The wheat grain yield increased significantly (R^2=0.950-0.986**, *P*<0.01) with increasing Zn concentration in the wheat grain at all experimental sites (Fig 1). The ZnDAP and ZnSSP significantly increased the Zn concentration in wheat straw by ~19.0 and 25.2%, compared with control.

Table 1 Effect of different sources and application methods of Zn fertilizers on grain and straw yield of wheat and Zn concentration at different experimental sites in Punjab, north-western India

Treatment	Grain yield (Mg/ha)						Zn concentration in grain (mg/kg)					
	Amritsar	Fatehgarh Sahib	Mansa	Ropar	Hoshiarpur	Mean	Amritsar	Fatehgarh Sahib	Mansa	Ropar	Hoshiarpur	Mean
Control (NK)	4.41	4.31	4.50	4.24	4.42	4.38^{a}	23.1	24.4	25.9	25.7	24.1	24.6^{a}
DAP	4.49	4.38	4.66	4.32	4.53	4.48^{abc}	24.5	26.0	26.9	27.3	26.2	26.2^{abc}
SSP	4.54	4.46	4.70	4.37	4.58	4.53^{abcd}	25.1	27.2	28.6	28.2	27.1	27.2^{cd}
ZnDAP	4.63	4.52	4.76	4.41	4.63	4.59^{bcd}	26.4	29.2	28.9	29.2	29.1	28.6^{def}
ZnSSP	4.67	4.59	4.81	4.46	4.66	4.64^{cd}	27.1	30.3	29.4	30.8	29.9	29.5^{ef}
Zn spray	4.46	4.35	4.55	4.26	4.47	4.42^{ab}	23.8	25.2	26.7	26.4	24.7	25.4^{ab}
DAP+Zn spray	4.51	4.41	4.69	4.36	4.55	4.50^{abcd}	24.9	26.2	27.7	28.0	26.7	26.7^{bc}
SSP+ Zn spray	4.59	4.48	4.72	4.39	4.60	4.56^{abcd}	25.6	28.5	28.8	28.5	28.2	27.9^{cde}
ZnDAP+ Zn spray	4.64	4.56	4.80	4.44	4.64	4.62^{cd}	26.9	29.9	29.3	29.9	29.4	29.1^{ef}
ZnSSP+ Zn spray	4.73	4.63	4.95	4.47	4.68	4.69^{d}	27.8	31.3	30.0	31.3	30.5	30.2^{f}
	Straw yield (Mg/ha)						*Zn concentration in straw (mg/kg)*					
Control (NK)	6.34	6.21	6.57	5.92	6.50	6.31^{a}	16.1	17.4	12.5	12.5	15.2	14.7^{a}
DAP	7.14	6.46	7.73	6.19	7.02	6.91^{abc}	16.5	18.4	14.3	13.9	15.9	15.8^{abc}
SSP	7.42	6.81	8.07	6.26	7.42	7.20^{abc}	17.2	19.1	16.2	15.2	17.1	17.0^{bcde}
ZnDAP	7.70	7.19	8.23	6.45	7.59	7.43^{c}	17.8	19.6	16.8	15.8	17.7	17.5^{cde}
ZnSSP	7.80	7.74	8.63	6.57	7.67	7.68^{c}	18.1	19.7	17.6	17.1	19.6	18.4^{de}
Zn spray	6.66	6.46	6.73	6.14	6.64	6.53^{ab}	16.3	17.6	14.1	12.8	15.4	15.2^{ab}
DAP+Zn spray	7.28	6.56	7.90	6.21	7.27	7.04^{abc}	16.8	17.8	15.3	14.6	16.9	16.3^{abcd}
SSP+ Zn spray	7.47	7.04	8.17	6.38	7.51	7.31^{abc}	17.4	18.6	16.6	15.5	17.4	17.1^{abcd}
ZnDAP+ Zn spray	7.75	7.55	8.40	6.55	7.65	7.58^{c}	18.2	19.4	17.1	16.5	18.6	18.0^{cde}
ZnSSP+ Zn spray	8.03	7.77	8.73	6.61	7.74	7.78^{c}	18.6	19.8	18.1	18.0	20.8	19.1^{e}

Values with different letters are significantly different at $P<0.05$ by Duncan's multiple range test (DMRT).

Table 2 Effect of different sources and application methods of Zn fertilizers on grain and straw yield of rice and Zn concentration at different experimental sites in Punjab, north-western India

Treatment	Grain yield (Mg/ha)						Zn concentration in grain (mg/kg)					
	Amritsar	Fatehgarh Sahib	Mansa	Ropar	Hoshiarpur	Mean	Amritsar	Fatehgarh Sahib	Mansa	Ropar	Hoshiarpur	Mean
Control (NK)	5.70	5.64	5.93	5.28	5.95	5.70^{a}	10.5	13.1	12.5	9.5	11.5	11.4^{a}
DAP	5.83	5.93	6.16	5.64	6.33	5.98^{abc}	12.3	15.0	14.3	12.7	14.7	13.8^{bc}
SSP	6.01	6.20	6.63	5.76	6.57	6.23^{bcde}	14.2	15.4	16.2	13.9	15.9	15.1^{cde}
ZnDAP	6.10	6.37	7.06	5.89	6.66	6.42^{cde}	14.8	16.0	16.8	15.8	17.8	16.2^{ef}
ZnSSP	6.25	6.42	7.09	6.22	6.78	6.55^{de}	18.2	16.9	20.2	18.5	20.5	18.9^{g}
Zn spray	5.72	5.78	6.13	5.46	6.01	5.82^{ab}	12.1	13.9	14.1	9.7	11.7	12.3^{ab}
DAP + Zn spray	5.90	6.03	6.26	5.75	6.36	6.06^{abcd}	13.3	15.1	15.3	13.2	15.2	14.4^{cd}
SSP + Zn spray	6.06	6.22	6.74	5.87	6.61	6.30^{bcde}	14.6	16.0	16.6	14.6	16.6	15.7^{def}
ZnDAP + Zn spray	6.23	6.41	7.08	6.15	6.72	6.52^{de}	15.1	16.7	17.1	17.4	19.4	17.1^{f}
ZnSSP + Zn spray	6.27	6.44	7.17	6.39	6.91	6.64^{e}	18.4	19.6	20.4	19.3	21.3	19.8^{g}
	Straw yield (Mg/ha)						*Zn concentration in straw (mg/kg)*					
Control (NK)	8.62	8.39	8.26	7.39	8.32	8.20^{a}	15.2	17.4	19.4	15.5	17.6	17.0^{a}
DAP	9.05	8.66	8.34	7.95	8.46	8.49^{a}	15.9	18.4	20.4	16.2	20.8	18.3^{abc}
SSP	9.36	8.78	8.82	8.11	8.97	8.81^{abc}	17.1	20.1	22.1	17.4	22.1	19.8^{abcde}
ZnDAP	9.61	9.38	9.51	8.45	9.41	9.27^{cd}	17.7	20.4	22.4	18	23.8	20.5^{bcde}
ZnSSP	9.88	9.56	9.81	8.91	9.93	9.62^{d}	19.6	20.9	22.9	19.9	25.3	21.7^{de}
Zn spray	8.66	8.63	8.28	7.64	8.33	8.31^{a}	15.4	18.2	20.2	15.7	19.4	17.8^{ab}
DAP + Zn spray	9.17	8.78	8.66	8.05	8.63	8.66^{ab}	16.9	19.2	21.2	17.2	21.1	19.1^{abcd}
SSP + Zn spray	9.50	8.97	9.40	8.35	9.39	9.12^{bcd}	17.4	20.3	22.3	17.7	22.5	20.0^{abcde}
ZnDAP + Zn spray	9.65	9.55	9.79	8.71	9.41	9.42^{d}	18.6	20.8	22.8	18.9	24.5	21.1^{cde}
ZnSSP + Zn spray	9.90	9.78	9.92	9.02	9.98	9.72^{d}	20.8	21.5	23.5	21.1	25.6	22.5^{e}

Values with different letters are significantly different at $P<0.05$ by Duncan's multiple range test (DMRT).

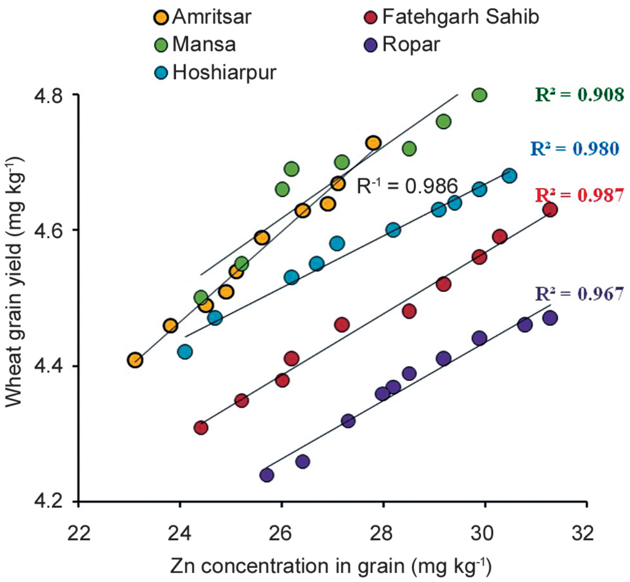

Fig 1 Relationship between grain yield and grain Zn concentration in wheat at different experimental locations in north-western India.

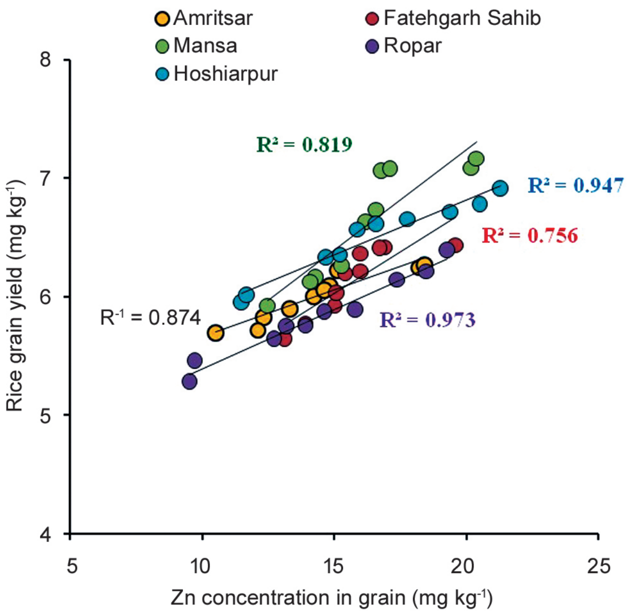

Fig 2 Relationship between grain yield and grain Zn concentration in rice at different experimental locations in north-western India.

Both the soil and foliar application of Zn in ZnDAP+Zn spray and ZnSSP+Zn spray significantly increased the Zn concentration in straw by ~22.4 and 29.9%, respectively than the control. This could be attributed to the increased solubility of Zn from the fortified phosphatic fertilizers (ZnSSP and ZnDAP), as it is in a readily soluble form. Dvorak *et al.* (2003) reported that Zn application improved its absorption by the plant roots and its translocation in the grains of maize, wheat and barley. These results were in agreement with Soleimani (2012), who recorded increased grain Zn content of wheat with an application of Zn as compared to control. Harris *et al.* (2007) also reported increased Zn concentration in cereal grain crops with $ZnSO_4$ application.

Grain and straw yield of rice: Soil and foliar application of Zn increased the rice grain yield at all experimental sites (Table 2). Mean rice grain yield increased significantly by ~12.6 and 14.9%, respectively with ZnDAP and ZnSSP treatments, compared with control. The combined soil and foliar application of ZnDAP+Zn spray and ZnSSP+Zn spray significantly increased the rice grain yield by ~14.4 and 16.5%, respectively, compared with control. The response of soil and foliar application of Zn towards straw yield of rice was variable but significant at all experimental sites. The ZnDAP and ZnSSP significantly increased the rice straw yield by ~13.0 and 17.3%, respectively than the control. However, with the combined application of soil and foliar application of Zn in ZnDAP+Zn spray and ZnSSP+Zn spray rice straw yield increased by ~14.9 and 18.5%, respectively than the control. The increased biological yield of rice was due to high availability of Zn to crops due to the application of ZnDAP and ZnSSP. These results corroborate earlier findings showing higher dry mass yield and accumulation of Zn in shoots with the use of Zn fortified NPK fertilizers compared with their physical mixing and soil application (Santos *et al.* 2016). Gilkes (1977) reported a higher solubility of Zn from blended Zn oxide with SSP. They said that the acidic solution developed inside fertilizer granules solublized most of Zn which is readily absorbed by plant roots.

Zinc concentration in rice grain and straw: The ZnDAP and ZnSSP significantly increased the grain Zn concentration in rice by ~42.1 and 65.8%, respectively compared with control (Table 2). The combined soil and foliar application of ZnDAP+Zn spray and ZnSSP+Zn spray significantly increased the Zn concentration in rice by ~50.0 and 73.7%, respectively than the control. The rice grain yield increased linearly and significantly (R^2=0.756*, $P<0.05$ to 0.973**, $P<0.01$) with increased Zn concentration in the rice grains at different experimental sites (Fig 2). The Zn concentration in rice grain was lower at Amritsar (15.2-20.8 mg kg^{-1}) and was the highest at Hoshiarpur (17.6-25.6 mg/kg) while other locations recorded yield in between these two locations (Table 2). Soil application of Zn as ZnDAP and ZnSSP significantly increased the Zn concentration in rice straw by ~20.6 and 27.6%, respectively than the control. The combined soil and foliar application of Zn as ZnDAP+Zn spray and ZnSSP+Zn spray significantly increased the Zn concentration in rice straw by ~24.1 and 32.4%, respectively, compared with control.

These results suggest that the bio-efficacy of Zn in terms of grain and straw yield and Zn concentration was higher under combined application of soil and foliar application of zinc. The two Zn fortified phosphatic fertilizers, viz. ZnDAP and ZnSSP were equally efficient for their effect on grain and straw yield and Zn concentration in grains and straw of rice and wheat in a rice-wheat cropping system. Rice and wheat grain yield respond positively to soil and foliar application of Zn through Zn fortified phosphatic fertilizers.

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