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Nitrogen and rice straw incorporation impact Zn fractions and wheat yield in rice-wheat system

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ABSTRACT

A long-term experiment was conducted at research farm of department of Soil Science, PAU to investigate the impact of rice straw incorporation (0-10 t/ha/yr) and fertilizer N (0-150 kg N/ha) application on wheat yield and Zn fractions after 7 years (2010–17). The treatments were arranged in a split plot design with three replications, N (N_0, N_{90}, N_{120} and N_{150}) in main plots and rice straw (RS_0, RS_5, $RS_{7.5}$ and RS_{10}) in sub-plots. Zinc fractions were significantly increased with graded levels of RS incorporation. The greater part of total-Zn was present in residual form and only a minute part was present in readily available forms, i.e. WS+EX form. Regardless of the treatments, relative preponderance of these Zn fractions was: WS+EX Zn <SpAd-Zn <MnOx-Zn < OM-Zn<AFeOx-Zn <CFeOx-Zn < Res-Zn in soil. RS incorporation was found to increase all the Zn fractions and significantly higher concentration was found at RS_{10}. Correlation analysis has shown that soil organic carbon was significantly and positively correlated with Zn fractions. The grain yield of wheat in 120 kg N/ha and 10 t/ha RS incorporation plots were significantly higher than in the control. DTPA- extractable Zn was found to be and positively correlated with Zn fractions.

Keywords: N application, Rice straw incorporation, Wheat yield, Zinc fractions, Zn uptake

The rice-wheat cropping system (RWCS) is major cropping system and it occupies 13.5 million ha in the Indo-Gangetic plains of Asia. Soil health and sustainability of RWCS in the region are possibly adversely influenced due to in-situ burning of the rice residues in large quantity. In India, due to extended rice-wheat system, the deficiency of zinc (Zn) is becoming very common. Zinc availability to plant is influenced by amount of Zn present in different chemical pools which could be affected by incorporation of organic matter/crop residue in soil. Zinc is known to exist in soils in different chemical pools and its solubility and availability to plants is a function of physical and chemical properties of the soils. Soils under rice-wheat cropping system undergo cyclic oxidation-reduction process which has marked effect on the transformation of Zn from one chemical form to another and thus its availability to plants. Organic amendments such as FYM, compost, crop residues etc. are known to improve the soil productivity under rice-wheat cropping system. These amendments have marked effect on the solubility and availability of different forms of Zn because of their bio-degradation in soils besides supplying substantial amounts of their own zinc. For enhancing nutrient cycling through immobilization and various mineralization turnover added substances, organic material application is an important management practice, hence improve soil fertility and productivity. Crop residue enhances the soil properties, micronutrient supply and productivity. Positive influence of applied organic sources on crop performance has been reported earlier (Saini *et al*. 2019).

In rice-wheat cropping system, application of organic manures is desirable for sustained supply of Zn (Mishra *et al*. 2006), and for maintaining soil and crop productivity. The present study was conducted with a prime objective to investigate the impact of N and long-term rice straw incorporation on different fractions of Zn in soil and wheat grain yield.

MATERIALS AND METHODS

Site description and climate: A 7-year field experiment (2010–17) was conducted on rice-wheat cropping system (RWCS) at the Research Farm of Department of Soil Science, Punjab Agricultural University (PAU), Ludhiana, Punjab, India (30°56' N and 75°52' E) in the Indo-Gangetic plains in the north-western India. Predominated soil of the experimental site is an alluvial soil, and classified as *Typic Ustochrept*. The experiment was conducted on a fixed layout and each treatment was replicated thrice in which rice straw (RS) was chopped with rice straw chopper, incorporated

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with rotavator into soil followed by pre sowing irrigation and wheat crop sown with a zero drill.

Treatments details: There were four rates of rice straw incorporation (0, 5, 7.5 and 10 t/ha) and four levels of N (0, 90, 120 and 150 kg N/ha). The treatments comprised of: R_0N_0: Control; R_0N_{90}: No rice straw incorporation and N@90 kg/ha; R_0N_{120}: No rice straw incorporation and N@120 kg/ha; R_0N_{150}: No rice straw incorporation and N@150 kg/ha; R_5N_0: Rice straw incorporation @ 5 t/ha and no N; R_5N_{90}: Rice straw incorporation @ 5 t/ha and N@90 kg/ha; R_5N_{120}: Rice straw incorporation @ 5 t/ha and N@120 kg/ha; R_5N_{150}: Rice straw incorporation @ 5 t/ha and N@150 kg/ha; $R_{7.5}N_0$: Rice straw incorporation @ 7.5 t/ha and no N; $R_{7.5}N_{90}$: Rice straw incorporation @ 7.5 t/ha and N @90 kg/ha; $R_{7.5}N_{120}$: Rice straw incorporation @ 7.5 t/ha and N @120 kg/ ha; $R_{7.5}N_{150}$: Rice straw incorporation @ 7.5 t/ha and N @150 kg/ha; $R_{10}N_0$: Rice straw incorporation @ 10 t/ha and no N; $R_{10}N_{90}$: Rice straw incorporation @ 10 t/ha and N @90 kg/ha; $R_{10}N_{120}$: Rice straw incorporation @ 10 t/ha and N @120 kg/ha; $R_{10}N_{150}$: Rice straw incorporation @ 10 t/ha and N @150 kg/ha.

Soil organic carbon (SOC) was determined using Walkley-Black rapid titration method using diphenylamine indicator.DTPA extractable Zn was determined as described by Lindsey and Norwell (1978).The concentration of Zn in plant samples was estimated using Atomic Absorption Spectrophotometer. For the various fractions of Zn in soil, following method was used: Water soluble plus exchangeable Zn (WS+EX) was extracted by method given by Manchanda *et al.* (2006). Specifically adsorbed Zn (SpAd) was extracted and filtered by the method given by Iwaski *et al.* (1993). Mn-Oxide bound Zn (MnOx) by the method given by Chao, 1972. Amorphous Fe-Oxides bound Zn (AFeOx) was extracted by the method given by Chao and Zhau 1983. Crystalline Fe-Oxides bound Zn (CFeOx) by the method given by Manchanda *et al.* (2006). Residual Zn (Res) was computed by subtracting sum of all the fractions from total Zn fraction. For the determination of total-Zn, 0.5g soil sample was digested with a mixture of 5 ml of hydrofluoric acid (HF) + 1 ml of perchloric acid ($HClO_4$) and 5-6 drops of nitric acid (HNO_3) in platinum crucibles. The crucibles were placed on a hot plate at 140˚C to completely dry the content in the crucibles. The content in the crucibles were cooled and then completely dissolved in 6 N HCl, and transferred to a volumetric flask with double distilled. The solution was filtered and the filtrate was analyzed for Zn with AAS.

Statistical analysis: The data was subjected to split plot design and was analyzed by analysis of variance (ANOVA) (Cochran and Cox 1967). The treatment effects were compared by using LSD at $P<0.05$. Analysis was done in statistically package CPCS-1 (Cheema and Singh 1991). The Pearson correlation coefficients were computed to evaluate the correlation between the variables. Correlation and regression analysis was done by using the IBM SPSS 23 statistics.

RESULTS AND DISCUSSION

Effect of RS incorporation and N application on DTPA- Zn and soil Zn fractions

DTPA-extractable Zn: The incorporation of N and RS results an increase in DTPA- Zn content in soils over control (Table 1). The DTPA- Zn content under $RS_{7.5}$ and RS_{10} was registered a significantly increase of 40.2 and 56.8 % over the control. Higher Zn availability in organic manure treated plots might be due to mineralization of organically bound Zn and formation of organic chelates of greater stability, which decreased their susceptibility to adsorption, fixation and precipitation, thereby resulting in their enhanced availability in soil. The buildup of available Zn due to crop residues incorporation and this buildup were attributed to addition of Zn through crop residue and/or exploitation of native Zn by chelation through decomposition product of crop residues. Additional N supplies energy to the microbes and substitute the nitrogen demand, caused by immobilization

Table 1 Effect of RS incorporation and N application on soil zinc fractions and DTPA- Zn (mg/ kg) after 7 year of rice-wheat cropping

Treatment	DTPA- Zn	WS+EX Zn	SpAd-Zn	MnOx-Zn	AFeOx-Zn	CFeOx-Zn	OM-Zn	Res-Zn	Total-Zn
N levels (kg/ha)									
N_0	2.88	0.46	0.95	1.68	7.45	10.41	2.94	57.41	81.29
N_{90}	2.92	0.46	0.97	1.69	7.46	10.47	2.96	57.55	81.56
N_{120}	2.99	0.47	0.98	1.69	7.48	10.57	2.99	57.96	82.14
N_{150}	3.04	0.48	0.98	1.69	7.49	10.61	3.03	57.91	82.18
LSD ($P<0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rice straw incorporation (t/ha)									
RS_0	2.34	0.38	0.75	1.41	7.44	8.83	2.61	54.95	76.37
RS_5	2.55	0.42	0.97	1.52	7.44	9.33	2.86	56.33	78.87
$RS_{7.5}$	3.28	0.44	1.03	1.76	7.45	10.72	3.05	58.77	83.22
RS_{10}	3.67	0.62	1.12	2.05	7.57	13.16	3.41	60.78	88.71
LSD ($P<0.05$)	0.25	0.06	0.05	0.03	0.08	0.19	0.08	0.57	0.76
Interaction (RS × N)	NS	NS	NS	NS	NS	NS	NS	NS	NS

due to the formation of organic complex. The combined application of organic manures and nitrogen results in higher soil available zinc. Our results corroborate with Vijayaprabhakar *et al.* (2017) who found that incorporation of straw with application of 25 kg additional N/ has basal + bio-mineralizer + cow dung slurry registered the highest soil available N, P, K and micro nutrients at tillering, flowering and postharvest stages.

It is evident from data (Fig 1) that most of the total zinc was present in residual form and only a small fraction was present in easily available forms, i.e WS+EX form. The crop residue incorporation significantly increased the content of different fractions; however increase was very meager in amorphous fraction (Table 1). It was also clear from the data that most of the Zn recycled through crop residue either alone or along with applied Zn got accumulated in residual form followed by crystallize fraction. About 81% of the total native zinc existed in residual fraction. Regardless of the treatments, relative preponderance of these Zn fractions was: WS+EX Zn <SpAd-Zn <MnOx-Zn < OM-Zn <AFeOx-Zn <CFeOx-Zn < Res-Zn. These results were in conformity with Mittal *et al*. (2020). The increase was more pronounced when rice straw was incorporated at higher rate. Kumari *et al*. (2018) also reported that most of the Zn either native or applied was present in residual form and small fractions are present in easily soluble form like water soluble plus exchangeable, complexes and organic form. There was a significant increase of 15.8 and 63.2% in the WSEX- Zn content, under $RS_{7.5}$ and RS_{10}, respectively over the control (Table 1). The SpAd-Zn fraction, increased by 29.3%, 37.3% and 49.3% under RS_5, $RS_{7.5}$ and RS_{10}, respectively over the control. The MnOX-Zn content under RS_5, $RS_{7.5}$ and RS_{10} was found 7.8%, 24.8% and 45.4% higher, respectively over the control. A perusal of data further indicated a small increase in AFeOx-Zn with the increasing level of rice straw incorporation. The significant increase to the tune of 1.7% was observed only under RS_{10}, over the control.

The CFeOx-Zn content under RS_5, $RS_{7.5}$ and RS_{10} increased significantly by 5.7%, 21.4% and 49.0%, respectively over control. The OM-Zn content was significantly increased by 9.6%, 16.9% and 30.7% under RS_5, $RS_{7.5}$ and RS_{10}, respectively over control. This might be due to increase in SOC from 0.40-0.49% with rice straw incorporation. Similar increase in OM-Zn concentration was observed by Kumari *et al.* (2018) with residue incorporation in soil. Data illustrated that residual-Zn found under RS_5, $RS_{7.5}$ and RS_{10} was 2.5%, 7.0% and 10.6% higher, respectively over the control (Table 1). The total-Zn in soil was found to increase with increase in rice straw incorporation rate, and amounted to 3.3, 9.0 and 16.2%, increase in total-Zn under RS_0, $RS_{7.5}$ and RS_{10}, respectively, significantly over the control. Addition of crop residue enhanced the organic Zn and water soluble Zn fraction. Kumari *et al.* (2018) also observed a significant increase in different Zn fractions with crop residue incorporation which in turn resulted in increase in total-Zn in soil.

Effect of RS incorporation and N application on crop yield and Zn concentration and uptake by wheat grain and straw

Wheat yield, nutrient uptake and harvest index (HI): The wheat grain yield (Table 2) increased significantly with N application (N_{120}) and RS incorporation ($RS_{7.5}$) over control. In this study, increase in grain yield of wheat with RS incorporation and N application should be due to increased soil fertility and soil quality and chemical and physical properties of soil. Kumari *et al.* (2018) also reported that 21.7% and 15.2% higher grain and straw yield with 100% crop residue incorporation in both the crops in RWCS because of improved hydrothermal conditions, root growth, soil organic carbon and more uptakes of nutrients from soil. The overall increase in grain yield was 4.5%, 9.5% and 4.8% over the control under RS_5, $RS_{7.5}$ and RS_{10} t/ha straw incorporation rates respectively. With incorporation rate $RS_{7.5}$, the yield obtained (4.84 t/ ha) was significantly higher over RS_5 (4.62 t/ha). With application of N_{90}, the increase in yield (5.67 t/ha) was significantly higher over the control (1.64 t/ha), which was 3.46 fold higher over the control. The increased supply of nitrogen resulted in faster cell division and multiplication, thereby increased the yield. Similarly, positive impact of higher levels of nitrogen application on grain and straw yields were also reported by Malhi *et al.* (2006).

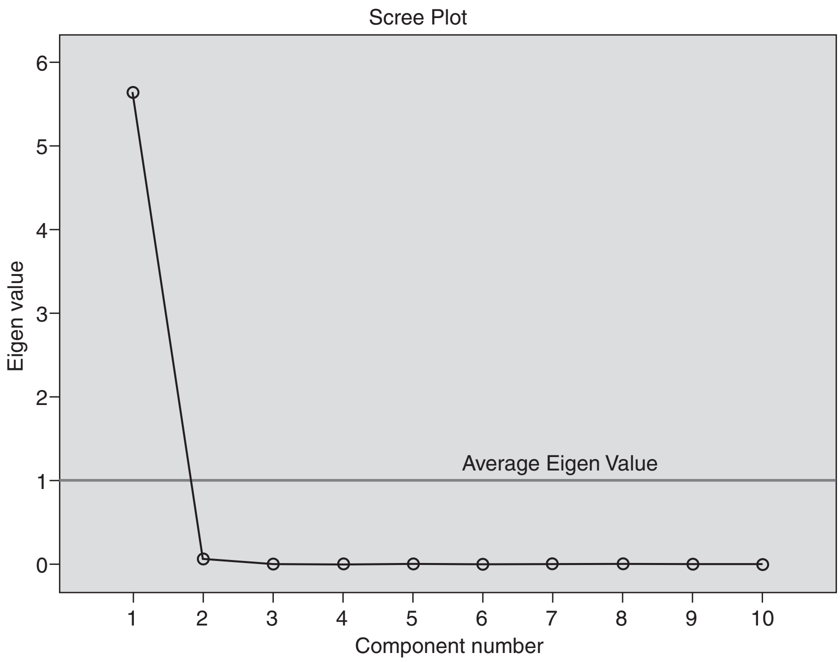

Fig 2 Scree plot of real Eigen values of PCs of DTPA-Zn, and different fractions of variable solubility of soils.

Table 2 Effect of RS incorporation and N application on grain and straw yield, harvest index (HI), Zn concentration and uptake in grain and straw and total Zn uptake

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)	Grain Zn concentration (mg/ kg)	Straw Zn concentration (mg/ kg)	Grain Zn uptake (g/ ha)	Straw Zn uptake (g/ ha)	Total Zn uptake (g/ ha)
N levels (kg/ha)								
N_0	1.64	3.68	0.31	21.20	10.11	40.06	37.31	77.37
N_{90}	5.67	6.03	0.48	26.46	10.34	139.62	62.42	202.04
N_{120}	6.57	7.99	0.45	26.72	10.54	163.20	84.22	247.42
N_{150}	6.46	8.00	0.45	27.95	10.81	163.64	86.61	250.26
LSD (P<0.05)	0.54	0.59	0.03	0.42	0.34	8.99	5.50	10.39
Rice straw incorporation levels (t/ha)								
RS_0	4.42	5.71	0.42	22.61	8.85	109.49	54.61	164.10
RS_5	4.62	5.89	0.42	24.23	9.89	124.24	64.89	189.13
$RS_{7.5}$	4.84	6.07	0.43	25.31	11.08	134.79	74.36	209.15
RS_{10}	4.63	5.91	0.43	26.83	11.99	138.00	76.72	214.71
LSD (P<0.05)	0.30	0.35	NS	0.69	0.29	10.86	5.11	12.03
Interaction (RS × N)	NS	NS	NS	NS	NS	NS	NS	NS

With N_{90} and N_{120} nitrogen levels, there was significant increase in straw yield over the control, which was 1.64 and 2.17 fold higher, respectively over the control. The straw yield obtained under N_{150} (8.00 t/ha) was significantly higher over N_0 and N_{90}. With straw incorporation, there was a significant increase in straw yield over the control. The overall increase in straw yield was 3.15%, 6.30% and 3.50% over the control with RS_5, $RS_{7.5}$ and RS_{10}, respectively (Table 2). Increase in grain and straw yield of wheat due to increase in levels of crop residues incorporation might be due to addition of nutrient through crop residues incorporation or increase in availability of nutrients by complexing properties of crop residues. Higher wheat yield recorded in case of N fertilization combined with stubble incorporation indicates optimum nutrient availability in these treatments compared with the treatments of no N fertilization (Malhi *et al.* 2006).

Harvest index (HI) indicates the effectiveness of crop plants to convert the manufactured food material at source level to the grains/sink. According to the data (Table 2), it increased with increase in straw incorporation rates and nitrogen levels. Nitrogen application significantly influenced HI of wheat. Maximum HI (0.48) was observed under N_{90} which was significantly higher as compared to the control (0.31), N_{120} (0.45) and $N1_{50}$ (0.45), respectively. However, an improvement was observed in harvest index with increased incorporation rates. RS and N application influenced Zn concentration and its uptake by wheat crop significantly.

Zn concentration in wheat grains was found to increase significantly with increase in RS incorporation levels, and the increase was 7.16%, 11.94% % and 18.66 % under RS_5, $RS_{7.5}$ and RS_{10}, respectively as compared to the control (Table 2). A significant increase in grain Zn concentration to the tune of 24.81%, 26.04% and 31.84% was found under N_{90}, $N_{120}$and N_{150}, respectively, as compared to the control. The straw Zn concentration significantly increased by 11.75%, 25.20% and 35.48% under RS_5, $RS_{7.5}$ and RS_{10}, respectively over control. In case of nitrogen application, straw Zn concentration was found to increase by 2.27%, 4.25% and 6.93% under N_{90}, N_{120} and N_{150}, respectively and significantly higher to control.

Rice straw incorporation increased Zn grain uptake significantly as an increase of 13.47%, 23.11% and 26.04% was found under RS_5, $RS_{7.5}$ and RS_{10}, respectively over control. Grain Zn uptake increased significantly with nitrogen application and 3.48, 4.07 and 4.08 fold increase was observed under N_{90} and N_{150}, respectively over control (Table 2). A significant increase of 18.82%, 36.17% and 40.49% was found in straw Zn uptake under RS_5, $RS_{7.5}$ and RS_{10}, respectively over the control. In case of nitrogen application, straw Zn uptake 1.67, 2.26 and 2.32 fold higher under N_{90}, N_{120} and N_{150}, respectively as compared to control.

The overall increase in total Zn uptake by wheat crop under RS_5, $RS_{7.5}$ and RS_{10} was higher by 15.25%, 27.45% and 30.84%, respectively over the control. In case of nitrogen application, the overall increase in total Zn was 2.61, 3.19 and 3.23 fold under N_{90}, N_{120} and N_{150}, respectively over control. Crop residues after decomposition produced several organic compounds including humic and fulvic acids and a variety of biochemical substances (organic acids, polyphenols, amino acids and polysaccharides) that form stable complexes with native zinc. These Zn complexes increased solubility and availability of Zn to wheat crops. The similar result was also reported by Prasad *et al.* (2010). Increase in Zn uptake may be due to the fact that application of N fertilizer results in increase in root biomass which in turn results in uptake of all the nutrients.

Principal component analysis (PCA) on the soil physical-chemical properties, DTPA-Zn and Zn fractions:

The minimum data set (MDS) was selected using the principal component analysis (PCA) to study the most important soils physical-chemical properties and different Zn fractions of variable solubility affecting the availability of DTPA-Zn. The PCA of the variables resulted in one principal component produced Eigen values>1 and accounted for 85.3% of the variance in the data (Fig 2). DTPA-Zn and its different fractions of variable solubility have already been identified as factors which affect the wheat grain yield.

All fractions of Zn were significantly correlated to SOC (r= 0.743-0.837**, P<0.01). Soil organic carbon was significantly and positively correlated with WS+EX-Zn (r=0.770**), SpAd-Zn (r=0.757**), MnOx-Zn (r=0.781**), AFeOx-Zn (r=0.743**), CFeOx-Zn (r= 0.774**), OM-Zn (r=0.828**), Res-Zn (r=0.837**) and total-Zn (r=0.817**). The addition of OM-Zn along with Res-Zn together contributed about 98.9% variation in DTPA-Zn. Further, when all the contributing Zn fractions were regressed together, they contributed 99.8% variation in DTPA-Zn in soil. The data further indicated that in case of wheat grain yield, when all the contributing fractions of Zn were regressed together, contributed about 74.4% variation in wheat grain yield. Similarly, in case of total Zn uptake, all the contributing Zn fractions, when regressed together, contributed about 78.6% variation in total Zn uptake in wheat crop.

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