

Original Research Article

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Residual Effect of Zn Fertilization on Wheat (*Triticum aestivum* L.) Grown in Soils with Divergent Characteristics

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ABSTRACT

Though one sixth of the global population resides in India, paradoxically, one third of about two billion people are suffering from vitamin and micronutrient deficiency in India due to heavy dependence on cereals grown in Zn- deficit soils. With the hypothesis that the residual Zn present in soil can also enhance the grain Zn content, a study was conducted with wheat variety 'HD 2329' to assess the grain concentrations of Zinc (Zn), Iron (Fe) and Phosphorus (P) grown on residual zinc in soils with divergent characteristics. Wheat crop was grown in the same pots on residual Zn fertility in which rice cultivars were grown with six Zn treatments in a completely randomised design (Factorial). The results of the study clearly indicated that wheat crop yield was not significantly influenced by the Zn applied to previous rice crop i.e. residual Zn fertility. However, the Zn concentration in wheat crop grown on residual fertility across the treatments ranged 29.6 to 33 mg kg⁻¹. Residual Zn could maintain 11.5% more grain Zn concentration as compared to control. Among the Zn treatments, 5 mg Zn kg⁻¹ (basal) plus FYM (5 mg Zn kg⁻¹) could maintain highest Zn (33 mg kg⁻¹) as compared to other treatments in wheat grain and straw. Among the soils, CRIDA soil could maintain higher grain Zn as compared to IARI and Karnal soil. There was an increase in DTPA-extractable Zn content in soils due to application of Zn in all the soils except in which Zn was supplied through foliar spray. Zinc application @ 5 mg Zn kg⁻¹ (basal) plus FYM (5 mg Zn kg⁻¹) significantly increased the DTPA- extractable Zn content over control in all the soils with mean value of 2.2 mg kg⁻¹. More or less similar trend was observed in DTPA- extractable Zn in soil samples collected and analysed after the harvest of the wheat crop.

Keywords

Grain Yield, Iron;
 Phosphorus,
 Residual zinc,
 Wheat, Zinc

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Introduction

Zinc deficiency is one of the causes for rheumatoid arthritis, diabetes, and cancers,

which are associated with chronic inflammation and oxidative stress (Kumar *et al.*, 2016). Zinc is involved in numerous aspects of cellular metabolism. Zinc

deficiency in humans is mainly due to heavy dependence on cereal food grains grown in Zn-deficit soils. And, among the cereals, next to rice, wheat is most important cereal crop. In India, rice-wheat cropping system contributes about 40% of the country's total food grain basket in an area of about 10.5 M ha (Saharawat *et al.*, 2010). In India, rice-wheat rotation is dominant in Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh with a share of 75% of national food grain production (Mahajan and Gupta, 2009). Wheat grains contain about 25–30 mg Zn kg⁻¹ dry weight, while desired wheat grain Zn concentration should be >50 mg kg⁻¹ dry weight for a measurable impact of Zn biofortification on human health (Cakmak, 2008). In wheat seed, Zn is predominantly localized in the embryo and aleurone layer up to 150 mg per kg seed whereas endosperm contains around 15 mg Zn per kg seed which is much less (Ozturk *et al.*, 2006). Iron showed large variation among 66 wheat genotypes in a study carried in common wheat in central Asia, ranging from 25 mg kg⁻¹ to 56 mg kg⁻¹ (mean 38 mg kg⁻¹) and Zn concentration ranging between 20 mg kg⁻¹ and 39 mg kg⁻¹ (mean 28 mg kg⁻¹) (Morgounov *et al.*, 2007). A strong correlation between grain Zn and Fe concentrations was recorded in germplasm containing wild wheat (Cakmak *et al.*, 2004). When 150 bread wheat lines were analysed, grain Zn ranged from 13.5 to 34.5 mg kg⁻¹; grain Fe content ranged from 28.9 to 50.8 mg kg⁻¹ and found that durum, einkorn, emmer and spelt showed similar ranges as that of bread wheat (Zhao *et al.*, 2009).

Wheat removes 47-91 g of Zn for every 3 tonnes of grains produced per hectare (Norton, 2012). Yet, farmers apply nitrogen, phosphorus and potassium fertilizers ignoring Zn application. Advantage of Zn application is Zn being highly immobile in soil, it has a residual effect for years on succeeding crops (Brennan, 2001; Rashid, 2005). Generally Zn

application is recommended for every 3 years although the residual effect is dependent on soil types. It was reported that the residual effect of Zn last for 2 to 8 years (Lindsay, 1972). According to Brennan and Bolland (2007), this effect was estimated to be about 23 and 40 years for single application of 0.5 and 1 kg Zn ha⁻¹. Research findings report that residual effect of Zn can increase yield of subsequent crops. Residual effect of 10 kg Zn ha⁻¹ increased the grain yield in wheat (Khan *et al.*, 2009) and increase was up to 30% over control (Khan *et al.*, 2007). Increase in paddy yield up to 6.1% with residual application of 5 kg Zn ha⁻¹ was reported by Hussain (2004). There are also reports that residual effects of Zn increased the grain Zn content (Soleimani, 2012) and straw Zn content (Jat *et al.*, 2012). Information on the residual effect of Zn fertilization after application is also desirable to determine the optimum application of Zn in crop rotation and to minimise the fertilizer usage. Most of the studies have focussed on studying the effect of residual Zn on yield on subsequent crops and there is very little information regarding its role in enriching the grain Zn content. Hence, our objective was to study residual effect of Zn application doses and methods followed in rice on the grain yield, grain Zn and Fe as well as P content in wheat.

Materials and Methods

Pot experiment was conducted to evaluate the residual effect of Zn (applied to the first crop-rice) on yield and nutrient content of wheat grown in a rice-wheat rotation at IARI, New Delhi. After the harvest of rice, the wheat (HD 2329) crop was grown only with basal dose of nitrogen, phosphorus and potassium but no Zn in the same layout. The first crop was grown in three different soils collected from Research Farm of IARI, New Delhi; farmer's field in Shamgarh, Karnal, Haryana and Hayathnagar Research Farm of Central Research Institute

for Dry land Agriculture (CRIDA), Hyderabad with six treatments of Zn comprising control (T_1), 5 mg Zn kg^{-1} (basal) (T_2), foliar spray of 0.5% ZnSO₄ (bi-weekly) (T_3), 5 mg Zn kg^{-1} (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly) (T_4), 5 mg Zn kg^{-1} (basal) + FYM (5 mg Zn kg^{-1}) (T_5), 2.5 mg Zn kg^{-1} (basal) + FYM (2.5 mg Zn kg^{-1}) (T_6) replicated two times in a completely randomised design (Factorial). As per soil taxonomy, the IARI soil belongs to typic Haplustept, CRIDA soil to typic Haplustalf and Karnal soil Typic Ustochrepts subgroup. The IARI and CRIDA soils were having sandy clay loam texture while Karnal soil was having sandy clay texture. The experimental soils were divergent in their characteristics with varying pH, EC, mineral N, available P, K status and micronutrient content (Table 1).

At maturity, wheat crop was harvested manually. The grain and straw samples were washed under 0.01N HCl and under running water to remove the adhering impurities.

The samples were air dried and placed in the oven at 65 ± 5 °C. When the samples became brittle, they were hand pounded with pestle and motor to separate grain and husk and these samples were digested in diacid (HNO₃:HClO₄) mixture. Iron and Zinc content in the digested samples were determined using Atomic Absorption spectrophotometer (Model : ZEE nit 700) and P content was estimated by vanado-molybdate- yellow colour method (Jackson 1973). Soil samples from each pot were collected at the harvest of wheat crop. The collected soil samples were air-dried and pulverized to pass through 2mm sieve. Available Zn content was determined by Lindsay and Norvell (1978).

All the data obtained were statistically analyzed using the F-test as per the procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at $P = 0.05$

were used to determine the significance of differences.

Results and Discussion

Crop Performance

After the harvest of the main crop of rice, the wheat crop was sown on residual Zn fertility in same pots. When the wheat crop was grown on residual Zn fertility, wheat grain yield ranged from 8.9 to 9.3 g pot^{-1} in IARI soil, 7.8 to 7.9 g pot^{-1} in CRIDA soil and 8.2 to 8.5 g pot^{-1} in Karnal soil (Table 2). In our study, no definite yield trend was observed. The Zn treatments did not have significant effect on wheat grain yield. Only soils had a significant effect on wheat grain yield. Similarly, the residual Zn had non-significant effect on straw yield of wheat. Straw yield ranged from 8.9 to 9 g pot^{-1} in IARI soil, 7.9 to 8.9 g pot^{-1} in CRIDA soil and 8.8 to 9.5 g pot^{-1} in Karnal soil (Table 3). The two way interactive effect of soil and Zn treatment were found to be non-significant. In our study, the residual Zn did not have any significant effect on grain and straw yield in wheat. It was reported by Kulhare *et al.*, (2014) that the residual effect of 2.5 t FYM ha^{-1} was insufficient to increase the grain yield of wheat and the residual effect of 5 kg Zn ha^{-1} was not significant for grain yield of wheat.

Residual effect of Zn on grain and straw Zn, Fe and P content in wheat

The Zn content in wheat grain ranged 29.4 to 31.2 mg kg^{-1} grown on different soils with previous Zn application in rice crop and 35.8 to 36.5 mg kg^{-1} in wheat straw (Table 4). The soils had a significant effect in grain but not in straw. Among the Zn treatments, 5 mg Zn kg^{-1} (basal) plus FYM (5 mg Zn kg^{-1}) could maintain highest Zn (33 mg kg^{-1}) concentration as compared to other treatments in wheat grain and straw. Among the soils,

CRIDA soil could maintain higher grain Zn as compared to IARI and Karnal soil. However, the two way interactive effects on grain and straw Zn content were found to be non-significant. Only soils had a significant effect on grain Fe content in wheat but not in straw. The grain Fe content in wheat ranged 29.9 to 30.3 mg kg⁻¹ in IARI soil, 27 to 27.5 mg kg⁻¹ in CRIDA soil and 28.6 to 29.6 mg kg⁻¹ in Karnal soil and straw Fe ranged 193 to 196 mg kg⁻¹ in IARI soil, 194 to 197 mg kg⁻¹ in CRIDA soil and 192 to 194 mg kg⁻¹ in Karnal soil (Table 5). The two way interactive effects were found to be non-significant in both grain and straw. However, all main and interactive effects on P content in wheat grain and straw were non-significant (Table 6). The use efficiency of micronutrient is abysmally low hovering around two percent; it may go up to 5-6% if residual effect has been taken (Rattan *et al.*, 2008). This is reflected well in marginal enhancement of Zn content in wheat grown on residual fertility of Zn applied in previous crop (rice). Lyons *et al.*, (2005) reported that the Zn content in wheat grain ranged 42 to 68 mg kg⁻¹ and Zn content of wheat grain in our study was considerably lower than those obtained by Lyons *et al.*, (2005) and consistent with the findings of Cakmak *et al.*, (2004) who reported that Zn content of wheat grain ranged from 8 to 34 mg kg⁻¹ in the Middle Anatolia region. The wheat grain maintained Fe content similar to that of Zn content and the residual Zn did not interfere significantly on Fe accumulation in grain. It is reported by Cakmak *et al.*, (1999) that soil application of Zn is most advisable to harness its residual effect by subsequent crops. Our study indicated that residual Zn also had a positive impact on grain Zn concentration. The residual Zn did not have any significant effect on grain P content although it has being reported that there exists antagonism between P and Zn (Hopkins and Elisworth, 2003; Hague *et al.*, 2008). Earlier it was reported by Srinivasarao *et al.*, (2008) that only at higher P

levels, there exists an antagonistic interaction between P and Zn. However, Soltangheisi *et al.*, (2014) reported that Zn application did not have any effect on P concentration in corn.

Residual effect of applied Zn on Zn, Fe and P uptake by wheat

Zinc uptake by wheat ranged from 567 to 589 µg pot⁻¹, Fe uptake varied from 1928 to 1991 µg pot⁻¹ (Table 7) and P uptake varied from 36.3 to 37.1 mg pot⁻¹ (Table 8) in wheat grown on different soils. The previously grown rice cultivars did not have a significant effect on Zn, Fe and P uptake by wheat.

Among the different Zn treatments, Zn uptake was found highest in 5 mg Zn kg⁻¹ (basal) plus FYM (5 mg Zn kg⁻¹). The Zn treatments (residual) could have a significant effect on Zn and non-significant effect on Fe and P uptake by wheat. The two way interactive effect of soil and treatment was found to be non-significant for Zn and P uptake and significant for Fe uptake. Individual effect of soils was found to be significant on P uptake. When simultaneous effect of treatments was studied, their two way interaction was found non-significant for Zn, Fe and P uptake. Residual effect of Zn application through ZnSO₄ and FYM could maintain higher Zn uptake by wheat as compared to other treatments. This finding is in line of earlier reports of Kulhare *et al.*, (2014) where application of Zn along with FYM (residual) had positive impact on Zn uptake by wheat over control. Dhaliwal *et al.*, (2014) reported that the Zn content in wheat grain ranged from 21.0 to 26.7 mg kg⁻¹ and found significantly higher Zn uptake (102.7 to 117.3 g ha⁻¹) in the treatment that received organic manure @ 6 t ha⁻¹. This may be related to positive impact in terms of enhancing solubility of applied Zn in soil. Iron uptake by wheat was found higher in combined application of Zn and FYM.

Table.1 Chemical characteristics of the experimental soils

Parameter	IARI soil	CRIDA soil	Karnal soil
pH	8.2	6.0	8.4
Ec (dS m ⁻¹)	0.33	0.08	0.43
Organic carbon (g kg ⁻¹)	3.42	1.49	3.48
Cation exchange capacity (c mol(p ⁺) kg ⁻¹)	14.3	11.5	19.5
Mineral N (Kg ha ⁻¹)	15.7	14.3	21.9
Available P (Kg ha ⁻¹)	21.1	14.6	18.6
Available K (Kg ha ⁻¹)	279	149	273
Available S (Kg ha ⁻¹)	22.3	18.4	28.7
DTPA Extractable micronutrients (mg kg⁻¹)			
Zn	2.16	0.78	1.32
Fe	14.9	7.21	23.2
Cu	1.15	0.69	0.79
Mn	7.13	18.0	7.13

Table.2 Residual effect of Zn on grain yield (g pot⁻¹) of wheat grown on three different soil types

Zinc treatment (T)	Soil (S)			
	IARI	CRIDA	KARNAL	Mean
Control	9.0	7.5	8.5	8.3
5 mg Zn kg ⁻¹ (basal)	9.2	7.8	8.5	8.5
Foliar spray of 0.5% ZnSO ₄ (bi-weekly)	8.9	8.1	8.4	8.4
5 mg Zn kg ⁻¹ (basal) + foliar spray of 0.5% ZnSO ₄ (bi-weekly)	9.3	7.8	8.7	8.6
5 mg Zn kg ⁻¹ (basal) + FYM (5 mg Zn kg ⁻¹)	9.4	7.4	8.2	8.3
2.5 mg Zn kg ⁻¹ (basal) + FYM (2.5 mg Zn kg ⁻¹)	9.1	8.5	7.8	8.5
CD (P=0.05)	S= 0.3		T= NS	S x T= NS

Table.3 Effect of Zn treatment (T) on straw yield (g pot⁻¹) of wheat grown on three different soil types

Zinc treatment (T)	Soil (S)			
	IARI	CRIDA	KARNAL	Mean
Control	8.8	7.2	9.6	8.5
5 mg Zn kg ⁻¹ (basal)	8.9	8.2	9.3	8.8
Foliar spray of 0.5% ZnSO ₄ (bi-weekly)	8.6	7.7	9.1	8.4
5 mg Zn kg ⁻¹ (basal) + foliar spray of 0.5% ZnSO ₄ (bi-weekly)	9.1	7.9	9.7	8.9
5 mg Zn kg ⁻¹ (basal) + FYM (5 mg Zn kg ⁻¹)	9.1	8.6	8.9	8.8
2.5 mg Zn kg ⁻¹ (basal) + FYM (2.5 mg Zn kg ⁻¹)	9.3	10.2	7.5	9.0
CD (P=0.05)	S= 0.52		T= NS	S x T= 1.3

Table.4 Effect of residual Zn on Zn content (mg kg⁻¹) in wheat grown on three different soil types

Zinc treatment (T)	Soil (S)							
	IARI		CRIDA		KARNAL		Mean	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control	30.2	27.9	30.2	29.7	28.5	23.4	29.6	26.9
5 mg Zn kg ⁻¹ (basal)	30.6	34.9	32.0	33.9	29.1	35.6	30.6	34.8
Foliar spray of 0.5% ZnSO ₄ (bi-weekly)	30.3	31.3	30.5	30.0	28.7	31.0	29.9	30.4
5 mg Zn kg ⁻¹ (basal) + foliar spray of 0.5% ZnSO ₄ (bi-weekly)	31.2	38.9	31.7	40.8	29.2	38.4	30.7	39.4
5 mg Zn kg ⁻¹ (basal) + FYM (5 mg Zn kg ⁻¹)	32.9	44.6	35.6	44.4	30.5	43.4	33.0	44.1
2.5 mg Zn kg ⁻¹ (basal) + FYM (2.5 mg Zn kg ⁻¹)	32.3	42.5	33.9	41.1	29.8	38.8	32.0	40.8
CD (P=0.05)	Grain		S= 1.3		T= 1.9		S x T = NS	
	Straw		S= NS		T= 3.1		S x T = NS	

Table.5 Effect of residual Zn on Fe content (mg kg^{-1}) in wheat grown on three different soil types

Zinc treatment (T)	Soil (S)							
	IARI		CRIDA		KARNAL		Mean	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control	32.1	194	25.9	197	30.8	193	29.6	195
5 mg Zn kg⁻¹ (basal)	28.5	198	26.8	199	29.0	194	28.1	197
Foliar spray of 0.5% ZnSO₄ (bi-weekly)	30.7	193	27.3	198	30.2	193	29.4	195
5 mg Zn kg⁻¹ (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly)	28.6	196	26.9	195	28.2	194	27.9	195
5 mg Zn kg⁻¹ (basal) + FYM (5 mg Zn kg⁻¹)	30.8	192	28.8	191	28.7	190	29.4	191
2.5 mg Zn kg⁻¹ (basal) + FYM (2.5 mg Zn kg⁻¹)	30.3	192	27.8	194	27.9	192	28.7	193
CD (P=0.05)	Grain		S= 1.7		T= NS		S x T = NS	
	Straw		S= NS		T= NS		S x T = NS	

Table.6 Effect of Zn application on P content (mg g^{-1}) in wheat grown as influenced by different soil types

Zinc treatment (T)	Soil (S)							
	IARI		CRIDA		KARNAL		Mean	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control	3.37	0.97	3.37	0.97	3.55	1.03	3.43	0.99
5 mg Zn kg⁻¹ (basal)	3.30	0.90	3.23	0.87	3.45	1.05	3.34	0.94
Foliar spray of 0.5% ZnSO₄ (bi-weekly)	3.28	0.88	3.30	0.90	3.38	0.95	3.32	0.91
5 mg Zn kg⁻¹ (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly)	3.38	0.98	3.38	0.98	3.30	0.90	3.36	0.96
5 mg Zn kg⁻¹ (basal) + FYM (5 mg Zn kg⁻¹)	3.32	0.90	3.30	0.90	3.50	1.05	3.37	0.95
2.5 mg Zn kg⁻¹ (basal) + FYM (2.5 mg Zn kg⁻¹)	3.30	0.90	3.33	0.93	3.30	0.90	3.31	0.91
CD (P=0.05)	Grain		S= NS		T= NS		S x T = NS	
	Straw		S= NS		T= NS		S x T = NS	

Table.7 Effect of Zn application on Zn and Fe uptake ($\mu\text{g pot}^{-1}$) by wheat as influenced by previous grown rice cultivars

Zinc treatment (T)	Soil (S)							
	IARI		CRIDA		KARNAL		Mean	
	Zn	Fe	Zn	Fe	Zn	Fe	Zn	Fe
Control	517	2006	440	1612	472	2131	477	1917
5 mg Zn kg⁻¹ (basal)	595	2038	526	1855	579	2061	567	1984
Foliar spray of 0.5% ZnSO₄ (bi-weekly)	541	1941	467	1756	522	2009	510	1902
5 mg Zn kg⁻¹ (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly)	641	2046	569	1776	632	2140	614	1988
5 mg Zn kg⁻¹ (basal) + FYM (5 mg Zn kg⁻¹)	717	2046	645	1887	636	1922	666	1952
2.5 mg Zn kg⁻¹ (basal) + FYM (2.5 mg Zn kg⁻¹)	689	2077	704	2221	527	1673	640	1991
CD (P=0.05)	Zn		S= 38.3		T= 54.3		S x T = NS	
	Fe		S= 139		T= NS		S x T = 342	

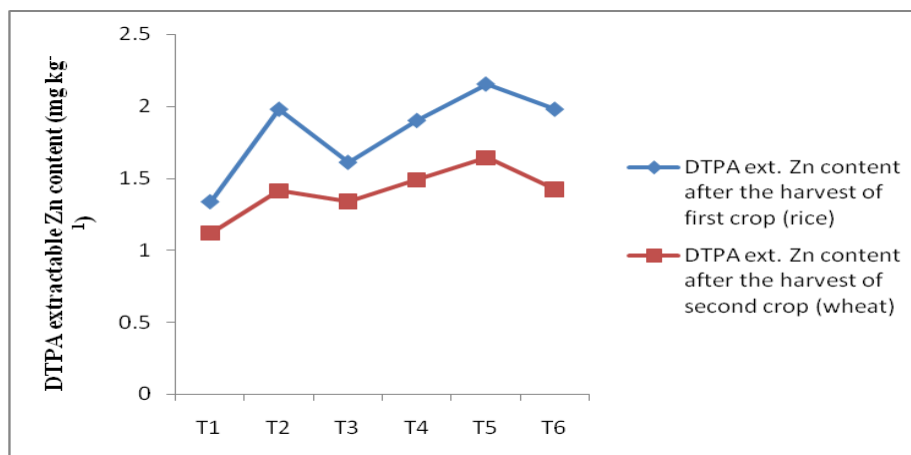
Table.8 Effect of Zn application on P uptake (mg pot^{-1}) by wheat as influenced by previous grown rice cultivars

Zinc treatment (T)	Soil (S)			
	IARI	CRIDA	KARNAL	Mean
Control	38.8	32.2	40.0	37.0
5 mg Zn kg⁻¹ (basal)	38.3	32.6	39.2	36.7
Foliar spray of 0.5% ZnSO₄ (bi-weekly)	36.9	33.6	37.0	35.9
5 mg Zn kg⁻¹ (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly)	40.2	34.3	37.7	37.4
5 mg Zn kg⁻¹ (basal) + FYM (5 mg Zn kg⁻¹)	39.3	32.3	37.9	36.5
2.5 mg Zn kg⁻¹ (basal) + FYM (2.5 mg Zn kg⁻¹)	38.5	37.7	32.9	36.4
CD (P=0.05)	S= 2.1		T= NS	S x T = NS

Table.9 DTPA extractable Zn (mg kg^{-1}) in three different soil types as influenced by residual Zn application at the harvest of wheat

Zinc treatment (T)	Soil (S)			
	IARI	CRIDA	KARNAL	Mean
Control	1.53	0.74	1.07	1.11
5 mg Zn kg^{-1} (basal)	1.86	1.13	1.23	1.41
Foliar spray of 0.5% ZnSO ₄ (bi-weekly)	1.74	1.15	1.11	1.33
5 mg Zn kg^{-1} (basal) + foliar spray of 0.5% ZnSO ₄ (bi-weekly)	2.06	1.25	1.14	1.48
5 mg Zn kg^{-1} (basal) + FYM (5 mg Zn kg^{-1})	2.12	1.46	1.33	1.64
2.5 mg Zn kg^{-1} (basal) + FYM (2.5 mg Zn kg^{-1})	1.99	1.07	1.19	1.42
CD (P=0.05)		S= 0.1	T= 0.2	S x T= NS

Fig.1 Mean DTPA extractable zinc content in soils after the harvest of first crop (rice) and second crop (wheat)



T₁=Control; T₂=5 mg Zn kg^{-1} (basal); T₃= Foliar spray of 0.5% ZnSO₄ (bi-weekly); T₄=5 mg Zn kg^{-1} (basal) + foliar spray of 0.5% ZnSO₄ (bi-weekly); T₅=5 mg Zn kg^{-1} (basal) + FYM (5 mg Zn kg^{-1}); T₆=2.5 mg Zn kg^{-1} (basal) + FYM (2.5 mg Zn kg^{-1})

Phosphorus uptake by wheat remained unaffected by Zn application. Phosphorus uptake by wheat was not significantly affected by Zn application. Zhu *et al.*, (2001) also reported that the Zn application had little effect on tissue P concentration and P uptake.

DTPA-extractable Zn in post harvest soil of wheat

The DTPA-extractable Zn after the harvest of wheat crop was found high in IARI soil (1.88 mg kg⁻¹) followed by Karnal soil (1.19 mg kg⁻¹) and was low in CRIDA soil (1.14 mg kg⁻¹). The soils imparted a significant effect on DTPA-extractable Zn. The Zn treatments applied to previous rice had a significant effect on DTPA-extractable Zn. Among the different treatments, the DTPA-extractable Zn was found highest in 5 mg Zn kg⁻¹ (basal) plus FYM (5 mg Zn kg⁻¹) treatment (Table 9).

All the two way interactions were found to be non-significant. By and large, level of DTPA-extractable Zn was higher in all the soils after the harvest of rice than that after harvest of wheat (Fig 1). Similar trend was also reported by Mishra *et al.*, (2009). In general, positive effect of applied Zn on subsequent crops in the rotation may last over variable periods (Brennan 2001).

In the absence of repeated Zn applications, soil Zn levels decreased gradually with successive cropping (Abid *et al.*, 2013). Increase in the residual Zn content could be due to conversion of applied Zn of labile into non-labile forms.

In our study, the DTPA-extractable Zn was found higher in 5 mg Zn kg⁻¹ (basal) plus FYM (5 mg Zn kg⁻¹) as compared to other treatments which implied that FYM is capable of keeping applied Zn into more labile pool that becomes available to next crop. Therefore, Zn fertilizer requirement for second

crop in cropping system be decided based on Zn fertilization history of previous crop.

Effectiveness of residual Zn in alleviating its deficiency in human by consuming wheat grown on residual Zn

In the present investigation, daily dietary intake of Zn through consumption of 200 g of wheat was only 5.92 mg day⁻¹ without previous Zn application and 6.61 mg day⁻¹ with previous application through fertilizer and FYM.

There is an increase in Zn intake through wheat consumption by human due to residual Zn. This increment would be higher if wheat is grown on a highly deficient soil as compared with Zn-treated soil.

The current study showed that the Zn supplied through ZnSO₄ has maintained a residual effect on to the next crop in addition to enhancing soil fertility and this residual Zn was effective in enhancing grain Zn concentrations in wheat in rice-wheat cropping system.

Based on the grain Zn concentrations, residual effect of Zn was more in CRIDA soils in which previously Zn was applied through zinc sulphate and FYM (Basal).

This residual effect can meet daily dietary intake of Zn by 6.61 mg day⁻¹ in humans, by consumption of 200g of wheat grain. Although these are far below than daily recommended Zn intake, such increases will undoubtedly help in alleviating the widespread Zn deficiency in Indian population.

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