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Effect of Organic Manure and Zinc Fertilization on Zinc Transformation and Biofortification of Crops in Vertisols of Central India

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Abstract

The studies are described to indicate biofortification of micronutrients into seed and their various fractions availability into soil. The primary application of biofortification is to alleviate micronutrient deficiencies in developing country populations. Soil samples were analyzed for the DTPA (pH 7.3), extractable micronutrients were extracted by 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M triethanol amine and determined on atomic absorption spectrophotometer (AAS). The total zinc was determined with hydrofluoric and perchloric acid by AAS. The objectives of experiment were to examine the effect of Zn biofortification and transformation under various organic and zinc fertilization for realizing maximum use efficiency in Vertisols. Among organic manures, sugarcane press mud recorded more yield, higher Zn concentration, fractions, uptake and their use efficiency than other. Application of Zinc @ 10 kg ha^{-1} recorded the highest water soluble Zn, exchangeable Zn, complexed Zn, organic bond zinc, occluded Zn and residual zinc in rice and chickpea, respectively. Various fractions of zinc positively correlated with each other. However, Organic and zinc fertilization in rice offers a practical and useful approach to improve bioavailable Zn in rice and chickpea.

Keywords: biofortification, chickpea, rice transformation, vertisols, zinc

1. Introduction

Micronutrients play a vital role in plant nutrition; their importance has attracted the attention of agriculture scientists all over the world. Application of Zn fertilizers or Zn-enriched NPK fertilizers (e.g., agronomic biofortification) offers a rapid solution to the problem, and represents useful complementary approach to on-going breeding programs. There is increasing evidence showing that foliar or combined soil + foliar application of Zn fertilizers under field conditions are highly effective and very practical way to maximize uptake and accumulation of Zn in whole grain. Zinc-enriched grains are also of great importance for crop productivity resulting in better seedling vigor, denser stands and higher stress tolerance on potentially Zn-deficient soils. Agronomic biofortification strategy appears to be essential in keeping sufficient amount of available Zn in soil solution and maintaining adequate Zn transport to the seeds during reproductive growth stage. Finally, agronomic biofortification is required for optimizing and ensuring the success of genetic biofortification of cereal grains with Zn. In case of greater bioavailability of the grain Zn derived from foliar applications than from soil, agronomic biofortification would be a very attractive and useful strategy in solving Zn deficiency-related health problems globally and effectively.

Zinc (Zn) is one of the eight trace elements among Fe, Cu, Mn, Cl, B, Mo and Ni which are essential for the normal healthy growth and reproduction of crop plants. It plays a key role in various plant metabolism processes such as the development of cell wall, respiration, carbohydrate metabolism and gene regulation (Cakmak, 2008).

Zinc deficiencies also results in the inability of rice plant to support root respiration during flooded conditions (Slaton et al., 2005). Zinc is a component of the enzyme system that leads to the formation of indole acetic acid from tryptophane which is found in plants and also in the activity of dehydropeptidase and glycoglycine dipeptidase, which play a specific role in the protein metabolism. It is required for the formation of certain microbial enzymes. Under deficient condition, the crops are likely to respond to the application of zinc, as the same is the constituent of various enzymes and involved in photosynthesis and nitrogen metabolism of plants: It also regulates the auxin content in plants; hence, the plant growth and maturity are adversely affected due to its deficiency. Rice and most staple cereals contain low zinc (Zn) levels, most of which is lost during grain processing. Populations with monotonous diets consisting mainly of cereals are especially prone to Zn deficiency, which affects about two billion people (Sperotto et al., 2012). Supplementation or food fortification programs have not always been successful. Breeding and genetical programme is also not so successful on farmer's field. Crop Zn fertilization is an alternative solution that efficiently mobilize, enhance their uptake by different edible portions of plant also not very effective due to Fe soil insolubility. Organic manures play a vital role in improving availability of zinc by direct contribution as well as indirectly by influencing chemical transformation reaction and microbial activity (Rathod et al., 2012). Zinc exists in soil in different forms viz., primary and secondary minerals; insoluble inorganic and organic precipitates; soluble organic complexes; exchangeable and adsorbed forms; and soil solution zinc. These forms are in a state of dynamic equilibrium. The amount and rate of transformation of these forms determine the size of the labile zinc pool (Mishra et al., 2009). The deficiency of micronutrients has become a major constraint of productivity, stability and sustainability in many Indian soils. Deficiency of micronutrients may either be primary, due to their low total contents or secondary, caused by soil factors reducing their availability to plants. The emergence of micronutrient deficiency has generally been considered as secondary (Sharma & Choudhary, 2007). If zinc deficiency is not diagnosed and rectified timely, the problem will become alarming in the years to come because land has been cultivated more intensively to have additional production to meet the requirement of increasing population. Till date very meager information is available on different forms of zinc and their availability in rice-chickpea cropping sequence in Vertisols of black soils. In this paper, we have attempted to examine the effect of organic manures and Zn on sustaining productivity, Zn biofortification and their transformation in rice-chickpea cropping sequence for realizing sustainable production.

2. Material and Methods

A field experiment was conducted at Jabalpur during *kharif* 2008-2009 and *rabi* 2009-2010 sixteen treatments comprised under split plot design with replicated thrice. In which four source of organic manures (No manures, 5t ha^{-1} farm yard manure, 5t ha^{-1} poultry manure and 5t ha^{-1} sugarcane press mud) as main plot treatments and four doses of zinc (0, 2.5, 5.0 and 10.0 kg Zn ha^{-1}) applied with term of $ZnSO_4 \cdot 7H_2O$ as sub plot treatments. The soil of the experimental site falls under Vertisols and belongs to Kheri -series of fine montmorillonite -Hyperthermic family of *Typic Haplusterts* popularly known as "Black soil". The soil of experimental site was clayey in texture, neutral in reaction, non calcareous, medium in organic carbon content and low in DTPA extractable Zn. The Micro nutrients in organic manures and physico-chemical properties of soil are presented vide Table 1 and Table 2. The rice (JR-201) and chickpea (JG-11) were sown in July 2009 and December 2009, respectively. A basal dose of 60:80:40 and 20:60:20 N, P_2O_5, and K_2O were applied before sowing of rice and chickpea, respectively through urea, super phosphate and muriate of potash fertilizers. The 60 kg N was applied rice crop in two splits doses during crop growth.

Table 1. Micro nutrients in organic manures

Organic manures	Micro nutrients (mg kg^{-1})			
	Zn	Cu	Fe	Mn
Farm yard manure	93.75	37	2599.6	224
Poultry manure	212.7	40	2419.8	368
Sugarcane press mud	239.7	81	2046.9	454

Table 2. Physico-chemical properties of soil

Properties	Content
Sand	25.3%
Silt	17.9%
Clay	56.8%
Soil texture	Clayey
Soil pH (1:2)	7.6
Electrical conductivity	0.22 dSm^{-1} 25 ^{o}C
Calcium carbonate	20.5 g kg^{-1}
Organic carbon	4.5 g kg^{-1}
Available Nitrogen	223.0 kg ha^{-1}
Available Phosphorus (Olsen)	25.9 kg ha^{-1}
Available Potassium	314.3 kg ha^{-1}
Available Sulphur	18.7 mg kg^{-1}
DTPA extractable Zn	0.70 mg kg^{-1}
DTPA extractable Cu	1.40 mg kg^{-1}
DTPA extractable Fe	9.30 mg kg^{-1}
DTPA extractable Mn	5.48 mg kg^{-1}

Composite representative soil samples were collected from each plot thereafter soil samples were air dried, processed by wooden pestle- mortar then passed through 2 mm sieve and finally prepared samples were used for analysis. Processed soil samples (< 2 mm) were analyzed for different physicochemical properties following standard procedures i.e. Soil pH was determined by glass electrode method in 1:2 soil: water suspension (Jackson, 1965). Electrical conductivity was measured in the supernatant liquid of 1:2 soil: water suspensions by solu-bridge method (Jackson, 1965). Organic carbon was determined by rapid titration method of Walkley and Black as described by Jackson (1965). Calcium carbonate in soil samples was determined by the rapid titration method as described by Jackson (1965). Available nitrogen in soil samples was determined by adopting the alkaline permanganate method (Subbiah & Asija, 1956). The phosphorus content of soil was estimated by colourimetric procedure described by Olsen et al. (1954). The available potassium was extracted by neutral normal ammonium acetate and estimated by using Flame Photometer (Muhr et al., 1963). Available sulphur was determined by 0.15% solution of calcium chloride turbidimetric method (Chesin & Yien, 1951). Soil samples were also analyzed for the DTPA (Diethylene Triamine Penta Acetic acid pH 7.3), extractable micronutrients were extracted by 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M triethanol amine (TEA) and determined on atomic absorption spectrophotometer (Lindsay & Norvell, 1978). The total zinc was determined, after digesting soil with hydrofluoric (HF) and perchloric acid ($HClO_4$) as described by Jackson (1965) on atomic absorption spectrophotometer. Various fractions of zinc were determined by procedure of Smith and Shoukry (1968) with some modification as suggested by Iyenger and Deb (1977). The extraction procedure is given in the flow sheet Figure 1. The extraction period of one hour was employed and suspension was centrifuged to get clear solution and determined for zinc on atomic absorption spectrophotometer. The residual zinc was determined by subtracting all fractions of zinc from total zinc content in soil. Multiple correlations of different Zn fractions were worked out by standard statistical methods. Zinc use efficiency was calculated as per formula used by Dobermann (2005). The zinc use efficiency was calculated by using the following formula: Zinc utilization (%) = {Zinc uptake in treated plot - Zinc uptake in control plot/Zinc dose} × 100.

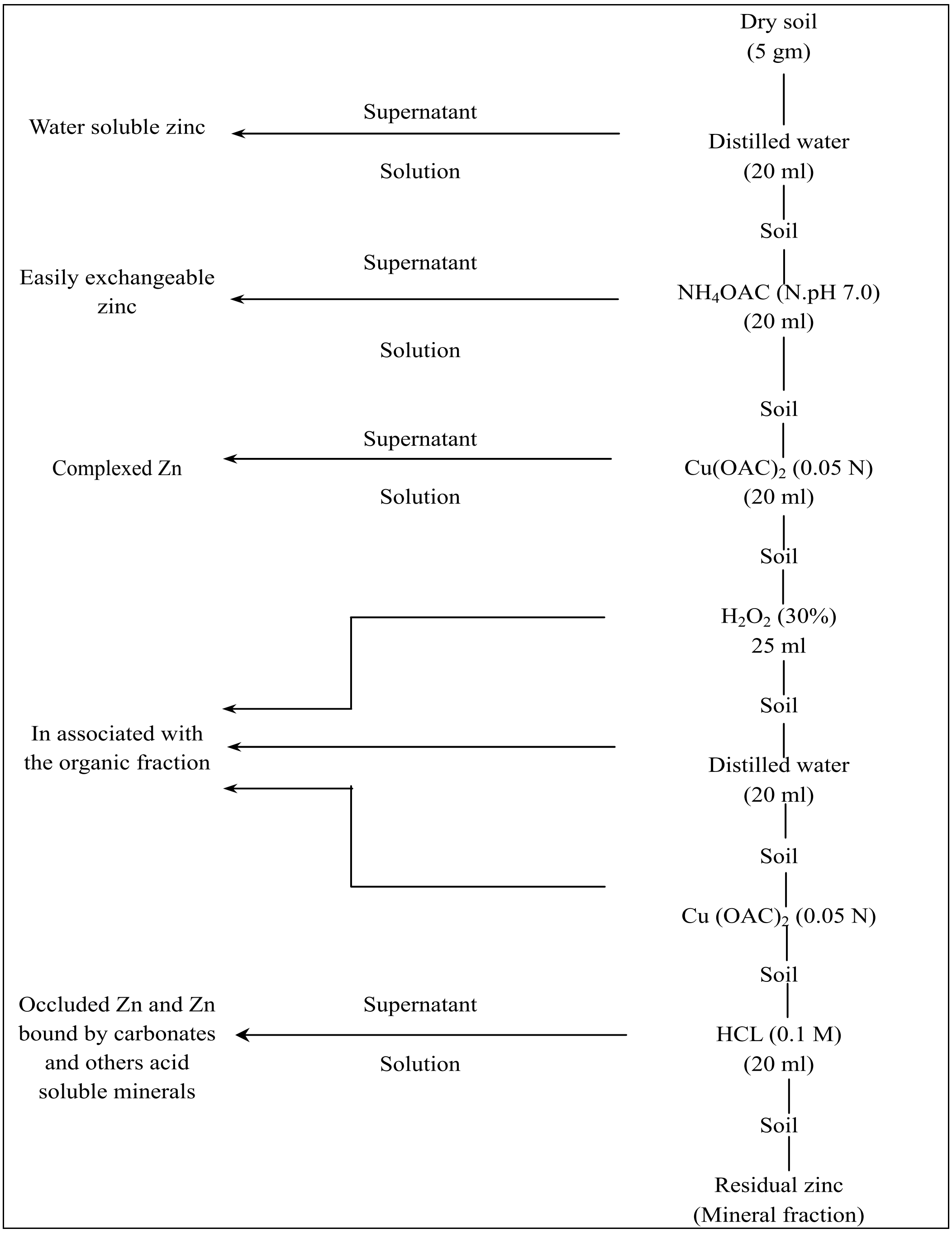


Figure 1. Flow sheet showing extraction mode to determine various soil fractions of zinc in soil

3. Results and Discussion

3.1 Zinc Concentration

Application of organic manures in the form of FYM, poultry manure and sugarcane press mud significantly increased the zinc concentration in rice and chickpea. The percent response was in the order of sugarcane press mud (16.57%) > poultry manure (13.04%) > farm yard manure (10.38%) in grain, sugarcane press mud (12.50%) > poultry manure (12.22%) > farm yard manure (7.81%) in straw, sugarcane press mud (30.43%) > poultry manure (23.83%) > farm yard manure (14.71%) in dehusk and sugarcane press mud (17.53%) > poultry manure (15.44%) > farm yard manure (11.02%) in husk of rice. The residual effect of organic manures significantly increased the Zn concentration in grain and stover of chickpea over control. The percent response was (8.81%) > (6.02%) > (3.46%) in grain and (27.9%) > (16.4%) > (7.3%) in stover, of the order of performance was sugarcane press mud > farm yard manure > poultry manure. In contrast to foliar Zn fertilization significantly ($P < 0.05$) increased the Zn concentration in rice grain and husk and grain and stover of chickpea (Table 3), consisted with the previous studies (Wu et al. 2010; Fang et al. 2010). The zinc concentration increased by 15.9%, 33.3%, 53.7% in grain, 18.1%, 26.4%, 34.5% in straw, 18.6%, 31.7%, 44.7% in dehusk and by 14.5%, 22.8% and 25.0% in husk with application of 2.5 kg Zn ha^{-1}, 5 kg Zn ha^{-1}, and 10 kg Zn ha^{-1} respectively. Similarly, zinc concentration of chickpea increased by 10.5%, 15.3%, 19.8% in grain and 15.2%, 23.4%, 32.9% in straw, as a residual effect of 2.5 kg Zn ha^{-1}, 5 kg Zn ha^{-1}, 10 kg Zn ha^{-1}, respectively. Thus, application of Zn as an effective method could boost Zn level in rice grain and subsequent crops. Here, in this study, particular attention should be given in the Zn concentration of grain and dehusk rice, as this is the predominant fraction consumed by human. Increase in the concentration of micro nutrients due to application of farm yard manure and other organic manures have been reported by Kumar et al. (2004). These results are also in agreement with the findings of Akinrinde et al. (2006).

Table 3. Effect of organic manures and Zn fertilization on Zinc concentration, DTPA extractable Zn by rice- chickpea cropping sequence

Treatments	Zinc Concentration (mg kg^{-1})						DTPA extractable- Zn (mg kg^{-1})	
	Rice				Chickpea		Rice	Chickpea
	Grain	straw	Dehusk- rice	Husk	Grain	Straw		
Organic Manures								
Control	14.9	18.2	10.0	35.6	37.4	13.8	1.07	1.14
FYM	16.4	19.6	11.4	39.5	39.6	16.0	1.19	1.29
PM	16.8	20.4	12.3	41.1	38.7	14.8	1.24	1.33
SPM	17.3	20.4	13.0	41.8	40.7	17.6	1.29	1.38
CD (P=0.05)	1.07	1.05	1.03	1.96	1.83	1.19	0.10	0.10
Zinc Fertilization								
Zn_0	13.0	16.4	9.4	34.3	35.1	13.2	0.87	0.96
Zn_1	15.1	19.4	11.2	39.2	38.8	15.2	1.11	1.27
Zn_2	17.3	20.7	12.4	41.5	40.5	16.3	1.31	1.40
Zn_3	20.0	22.0	13.7	42.9	42.0	17.5	1.50	1.52
CD (P=0.05)	1.04	1.02	0.83	2.71	1.98	0.84	0.08	0.09

3.2 DTPA Extractable - Zn

The result on the DTPA extractable zinc was presented in Table 3. As regards the effect of application of various organic manures, increase in zinc content of soil over control. The DTPA extractable Zn (Table 3) in the soil of the current field study was higher than the critical level for rice (0.8 mg kg^{-1}); Dobermann and Fairhurst (2000), thus the plant was in the sufficient Zn nutritional status. Our results are also agreement with Appauv et al. (2001) they have observed that the incorporation of organic manures (poultry manure, goat manure and farm yard manure) increased the available zinc content. The zinc content in soil of rice and chickpea increased with the increasing level of zinc from 28.6 to 73.3% and 32.8% to 58.4%. We observed that Zn content increased in plant parts by the combined application of poultry manure and $ZnSO_4$. These results are in conformity with the work of Patnaik et al. (2008) who observed the significant increase in DTPA extractable zinc content 0.58, 1.26, 2.73, 4.16 and 5.78 mg kg^{-1} at 0, 25, 50, 75 and 100 Kg $ZnSO_4$ ha^{-1} applications. Similar findings have been reported by Meena et al. (2006).

3.3 Fractionation of Zinc

Effect of organic manures and zinc found to be also significant after harvest of rice (Table 4). Various fractions increased in the order of 13.4% >12.7% > 8.1%, 24.0% > 15.9% > 8.2%, 19.2% > 10.8% > 10.7% and 15.3% > 12.4% > 11.6% with the application sugarcane press mud > poultry manure > farm yard manure in case of water soluble, exchangeable, complexed and organically bound fractions, respectively. Similarly, the Zn content in water soluble, exchangeable, complexed and organically bound fractions increased with the increasing levels of zinc, the maximum value obtained 66.7%, 24.5%, 75.4% and 19.8%, respectively, at the level of 10 kg Zn ha^{-1}, over control. However, the occluded and residual fractions of zinc were found to be not significant due to the application of either organic manures or zinc.

Table 4. Effect of organic manures and Zn on various fractions (mg kg^{-1}) of zinc in soil after harvest of rice and chickpea (mean of two years)

Treatments	Water soluble zinc		Exchangeable Zn		Complexed Zn		Organic bound Zn		Occluded Zn		Residual Zn	
	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea
Organic Manures												
Control	0.062	0.061	0.17	0.16	0.69	0.67	0.69	0.66	1.08	1.06	70.72	68.7
FYM	0.067	0.065	0.19	0.18	0.76	0.74	0.77	0.76	1.10	1.08	71.56	69.2
PM	0.070	0.067	0.20	0.18	0.76	0.75	0.78	0.76	1.11	1.08	72.07	70.1
SPM	0.073	0.072	0.22	0.19	0.82	0.81	0.80	0.77	1.18	1.17	72.67	71.6
CD (P=0.05)	0.003	0.003	0.008	0.009	0.051	0.037	0.033	0.050	NS	0.069	NS	NS
Zinc Fertilization												
Zn_0	0.051	0.051	0.17	0.16	0.56	0.54	0.69	0.69	1.07	1.05	70.24	68.2
Zn_1	0.060	0.059	0.19	0.18	0.68	0.67	0.74	0.72	1.09	1.08	71.37	69.2
Zn_2	0.075	0.072	0.20	0.19	0.80	0.79	0.79	0.75	1.14	1.11	72.26	70.5
Zn_3	0.085	0.083	0.21	0.19	0.99	0.96	0.82	0.77	1.17	1.15	73.16	71.7
CD (P=0.05)	0.004	0.004	0.008	0.010	0.036	0.037	0.044	0.043	NS	NS	NS	NS

Residual effect of organic manures and zinc had also significant on various forms of zinc after harvest of chickpea (Table 4). Various fractions increased in the order of 19.5% >11.0% > 6.9%, 17.6% > 12.8% > 9.2%, 21.0% > 12.8% > 10.3% and 16.5% > 14.5% > 14.4% with the residual effect of sugarcane press mud > poultry manure > farm yard manure in case of water soluble, exchangeable, complexed and organically bound fractions, respectively. Similarly, the Zn content in water soluble, exchangeable, complexed and organically bound fractions increased with the increasing levels of zinc, maximum value was reported as 64.6%, 23.0%, 78.1% and 11.9%, respectively, at the level of 10 kg Zn ha^{-1}, over control. However, the occluded and residual fractions of zinc were not affected significantly due to the application of either organic manures or zinc. Our finding have been supported by Jalali et al. (1999) who studied the distribution of zinc in various chemical pools in 104 soil samples. Water soluble and exchangeable Zn levels were low. Complexed/Chelated zinc content varied from 0.32 to 3.22 ppm. Shetty et al. (2001) also studied the distribution of Zn among different fractions. They also reported that water soluble + exchangeable forms vary in the range of 0.14- 0.32 mg kg^{-1} with the lowest contribution (0.32-0.74 percent) to total Zn. However, residual fraction contributed highest to total zinc (86.68- 91.64 per cent). Rupa et al. (2003) found that the application of 7.5 mg Zn kg^{-1} soil showed the maximum fractions of soil Zn and significantly increased the Zn utilization by wheat (0.87-1.17%) as compared to other Zn levels (0.58-0.88%).

3.4 Zinc Uptake

The uptake of nutrient is a function of yield and its concentration in crop. The application of Zn increases in the yield as well as zinc concentration, ultimately the Zn uptake also increased. Application of organic manures, zinc uptake increased from 61.1 to 87.4 g ha^{-1} rice grain, 83.7 to 119.8 g ha^{-1} rice straw, 65.5 to 89.8 g ha^{-1} g ha^{-1} chickpea grain and 38.3 to 59.6 g ha^{-1} chickpea stover over control to sugarcane press mud. Similarly, Zinc uptake increased 51.2 to 102.1 g ha^{-1} in rice grain, 70.0 to 134.2 g ha^{-1} in rice straw, 56.7 to 94.6 g ha^{-1} in chickpea grain and 33.7 to 63.1 g ha^{-1} in chickpea stover at control to 10 kg Zn ha^{-1}.

The result indicated (Table 5) that total zinc uptake increased 43.1% and 41.6%, 36.2% and 29.7% and 18.5% and 24.9% with the application of sugarcane press mud, poultry manure and farm yard manure, respectively in case of rice and chickpea. On the other hand total zinc uptake in rice and chickpea increased with the application of Zn. The magnitude of increase was 94.9% and 74.5% with application of 10 kg Zn ha^{-1}. The uptake of nutrient is a function of yield and its concentration in crop as the residual effect of Zn there was increase in the yield as well as zinc concentration, ultimately the Zn uptake also increased. Zn uptake by rice crop increased from 214.9 g ha^{-1} at 100% NPK to 315.2 g ha^{-1} at 100% NPK + farm yard manure, 382.6 g ha^{-1} at 100% NPK + Zn. Application of 30 kg ZnSO4 ha^{-1} recorded the highest values of yield uptake of Zn, N and K by rice plant (Ghatak et al., 2005).

Table 5. Effect of organic manures and Zn on Zinc and uptake (g ha^{-1}) by rice-chickpea cropping sequence

Treatments	Zinc Uptake					
	Rice			Chickpea		
	Grain	straw	Total	Grain	straw	Total
Organic Manures						
Control	61.1	83.7	144.8	65.5	38.3	103.8
FYM	76.8	104.1	180.9	81.2	51.1	134.6
PM	84.0	113.2	197.3	76.4	46.6	123.0
SPM	87.4	119.8	207.3	89.8	59.6	147.0
CD (P=0.05)	9.29	11.43	14.73	9.62	8.83	14.40
Zinc Fertilization						
Zn_0	51.2	70.0	121.3	56.7	33.7	90.3
Zn_1	69.8	100.1	169.9	75.6	45.1	120.7
Zn_2	86.3	116.5	202.7	86.1	53.5	139.6
Zn_3	102.1	134.2	236.3	94.6	63.1	157.7
CD (P=0.05)	6.96	11.52	15.37	7.63	4.77	9.38

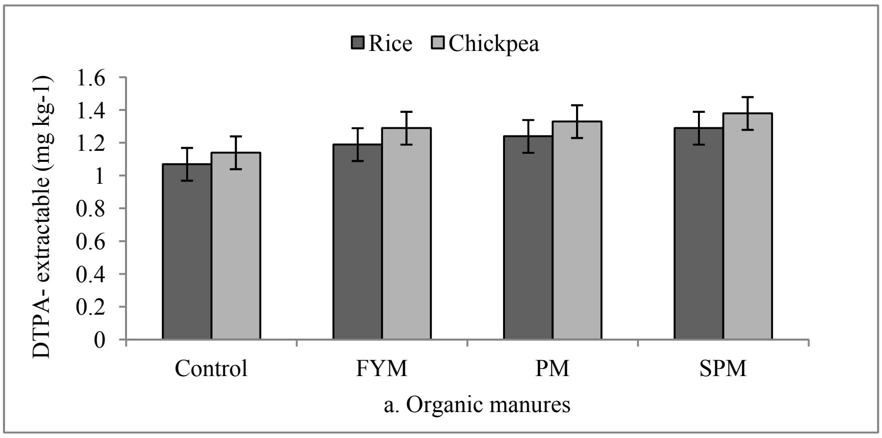
Table 6. Correlation between Zn fractions with DTPA-Zn, and various Zn fractionations in rice- chickpea crops

Zn Fractions	DTPA- Zn		Water Soluble		Exchangeable		Complexed		Organic Bound		Occluded		Residual	
	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea	Rice	Chickpea
Water Soluble	0.90**	0.79**	1.00	1.00	0.77**	0.74**	0.91**	0.92**	0.70**	0.49**	0.43**	0.45**	0.28	0.41**
Exchangeable	0.76**	0.77**			1.00	1.00	0.78**	0.75**	0.67**	0.55**	0.41**	0.38**	0.32*	0.40**
Complexed	0.87**	0.86**					1.00	1.00	0.73**	0.51**	0.43**	0.54**	0.28	0.42**
Organic Bound	0.70**	0.53**							1.00	1.00	0.46**	0.42**	0.21	0.23
Occluded	0.40**	0.54**									1.00	1.00	0.20	0.36*
Residual	0.34*	0.43**											1.00	1.00

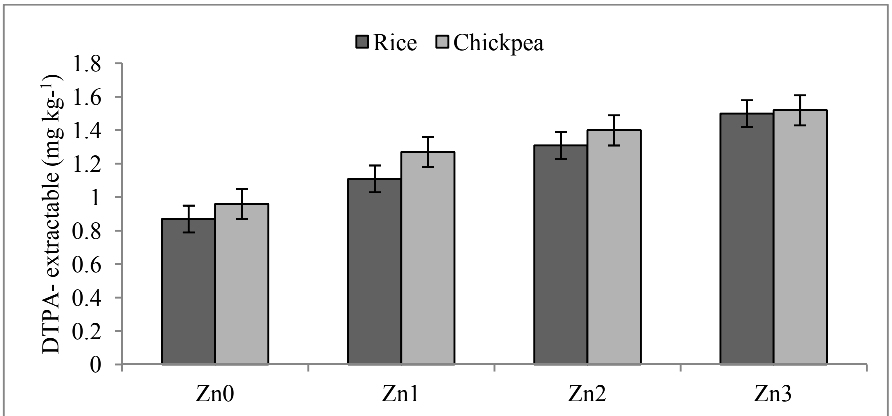
Note: * Significant at P= 0.05 ** Significant at P= 0.01.

3.5 Zinc Use Efficiency (ZUE)

Zinc use efficiency (Figure 3) increased from 1. 34% (control) to 1.69% with poultry manure and 1.77% with farm yard manure and sugarcane press mud application in case of rice. Whereas, as a residual effect, zinc use efficiency increased significantly from 0.77% at no organic manure (control) to farm yard manure (1.23%) and sugarcane press mud (1.18%) whereas, the application of poultry manure could not exerted any significant residual effect (0.78%). On the other hand, Zinc use efficiency by rice and chickpea decreased significantly with the increasing levels of zinc from 1.97% and 1.21% at 2.5 kg ha^{-1} Zn level to 1.25% and 0.74% at 10 kg ha^{-1} Zn level. Over all the zinc use efficiency was 1.64% in case of rice which decreased to 0.99% as a residual effect on chickpea. It was due to more uptake of Zn under FYM and SPM and lesser uptake in control, which resulted into more yield per unit of Zn uptake. On the other hand, Zinc use efficiency by rice and chickpea decreased significantly with the increasing levels of zinc. Our results are agreement with Rathod et al. (2012) they also reported that Zinc use efficiency due to Zn-enrichment of organics at 2.5 kg ha^{-1} improved over its, application as zinc sulphate in both wheat and maize crops.



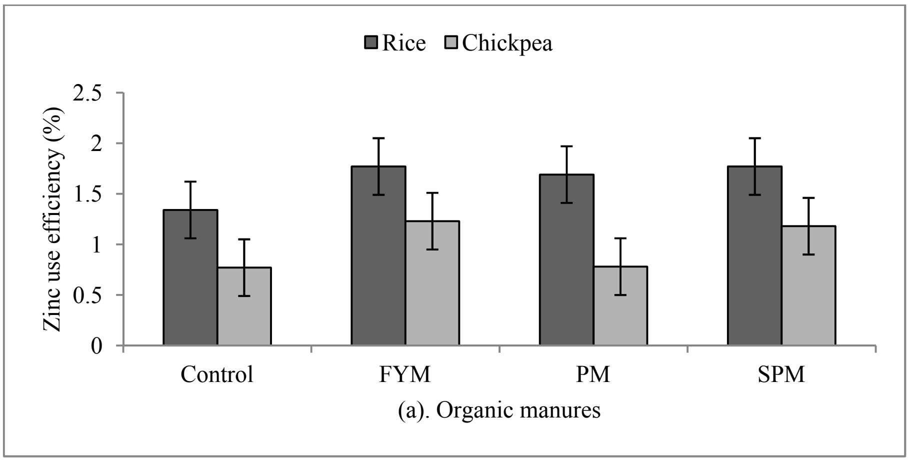
a. Organic manures



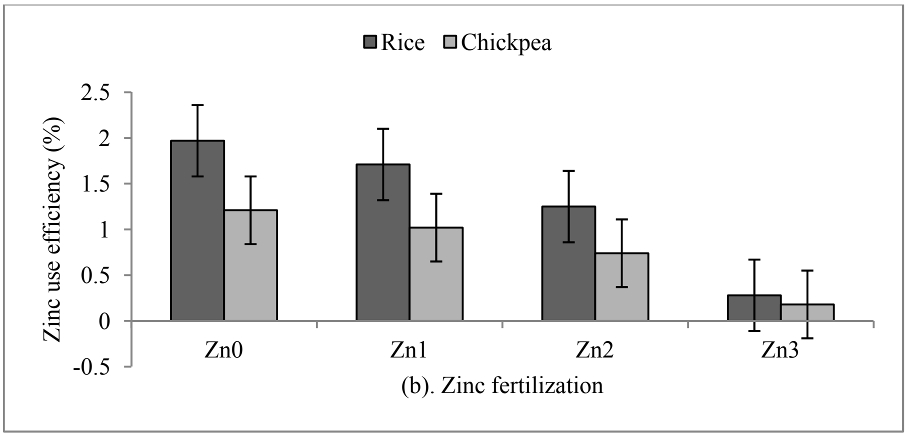
b. Zinc fertilizations

Figure 2. Effect of organic manures and zinc fertilization on extractable zinc in soil

Note: Vertical bar represent the significant level (P=0.05).



(a). Organic manures



(b). Zinc fertilization

Figure 3. Effect of organic manures and zinc fertilization on zinc use efficiency of rice and chickpea

3.6 Correlation Coefficient

Correlation coefficient (r) indicated that water soluble form of zinc correlated positively and significantly in order of complexed > Exchangeable > organically bound and > occluded > residual. Exchangeable fraction significantly correlated with complexed > organically bound > and > occluded. Complexed zinc was found positive relationship with organically bound, occluded and residual fraction while organically bound positively correlated with occluded zinc. The occluded and residual fractions also correlated significant with other fraction concluding that the Zn in soil remains in equilibrium in various pools and the direction of equilibrium, changes due to use or application of Zn from other sources. The more soluble fractions like water soluble, exchangeable and organic matter occluded ones are major contributors to available zinc. Our findings are conformity with Kumar et al. (2004). Similarly, Valdivia et al. (2002) also observed that the micronutrient content in maize positively correlated with the water-soluble plus exchangeable Zn as well as with the available Zn determined by the diethylene triamine penta acetic acid.

4. Conclusions

Zn fertilization in rice offers a practical and useful approach to improve bioavailable Zn in rice. According to current study 10 kg Zn ha^{-1} with sugarcane press mud @ 5 t ha^{-1} are recommended as excellent Zn forms to ongoing agronomic biofortification. The available Zn status of soil increased significantly with the levels of Zn and amongst the organic manures in the order of sugarcane press mud > poultry manure > farm yard manure. Increasing levels of Zn contributed to the Zinc content in various fractions in soil. Organic manure also increased Zn content in various pools.

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