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Effect of Organic and Inorganic Fertilizers on Zinc Fractions and Their Contribution to Zinc Uptake under Rice-wheat System

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The long-term effect of organic and inorganic fertiliser on Zn fractions in soil and their relation with Zn uptake in the rice-wheat system was studied in calciorthents of the Dr. Rajendra Prasad Central Agricultural University, Pusa Samastipur, Bihar. Application of NPK and compost and crop residue increased the water-soluble + exchangeable, carbonate and amorphous oxide, organically bound, complexed, crystalline oxide, residual and total Zn in the soil. The decreasing order of dominance of different fractions in soil was: total Zn > residual Zn >Zn bound to crystalline oxide > complexed Zn > Zn bound carbonate and amorphous oxide > organically bound Zn > water soluble plus exchangeable Zn. All the soil Zn fractions were significantly correlated among themselves indicating the existence of dynamic equilibrium with each other. Zinc uptake by rice-wheat was improved with NPK along with crop residue plus compost. Among the different Zn fractions, Zn bound to crystalline oxide followed by Zn bound to carbonate and amorphous oxide play a key role in explaining the variation in yield and nutrient uptake by rice and wheat.

Keywords: Soil Zn fraction, Uptake, Rice, Wheat, Compost, Crop residue.

1. INTRODUCTION

Zinc, is an essential element for plant growth and metabolism, which exists in different forms such as primary and secondary minerals, insoluble inorganic and organic precipitates, soluble organic complexes and exchangeable and adsorbed forms and soil soluble form

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Kumari et al. [1]. These forms are in a state of dynamic equilibrium. The size of the labile Zn pool is determined by the amount and rate of transformation of these forms of zinc solution. Many reports are available on the study of different micro-nutrient fractions of soils [2,3,4,5,6].

But only a few studies were carried out with the application of organic and inorganic fertilisers on zinc fraction under rice-wheat cropping system in calcareous soils.

In Bihar, the calcareous soil occupies a sizeable area, which is deficient in zinc to the extent of 80-90%. Symptoms of zinc deficiency are frequently observed on many crops [7]. This widespread occurrence of soil zinc deficiency suggests that native and applied forms of Zn react with the organic, inorganic and phase in soil and thereby affects its availability. Diffusion of Zn is one of the most limiting steps in calcareous soil, and is affected by the application of organic materials. Availability of Zn by plants is influenced by the amount of Zn present in different chemical pools which could be affected by organic matter incorporation [1]. Zinc is known to exist in soil in different chemical pools and its solubility and availability to plant is a function of physical and chemical properties of the soil. Organic amendments such as FYM, compost, crop residue etc. have marked effect on the solubility and availability of different forms of Zn because of their bio-degradation in soil [8,9].

Hence, for long-term sustained agricultural productivity, proper appraisal of different zinc forms and their relationships with soil characteristics and Zn uptake by crops is required. The present work was done to study the effect of organic and inorganic fertiliser on zinc fractions on a calciorthents and their influence on zinc uptake.

2. MATERIALS AND METHODS

A long-term experiment is in progress since *Rabi* 1988 at Pusa farm in RAU, Bihar, Pusa, Samastipur. The general properties of surface soil were, pH 8.4, EC 0.36 dS/ m, organic carbon 5.0 g/kg, free $CaCO_3$ 34.2%, available zinc 0.79 mg/kg. Four fertility levels consisting of control, low fertility (50% of recommended NPK), medium fertility (100% of recommended NPK) and high fertility (150% of recommended NPK) were used as treatments in main plots. Each main plot was divided into 4 sub-plots in which sub-treatments (1) no crop residue or compost, (2) compost @ 10 t/ha, (3) crop residue (100%) and (4) 10 t/ha compost + 100% crop residue were superimposed over NPK levels. The recommended dose of 100% NPK referred to 100 kg N/ha, 26.7 kg P/ha and 32.2 kg K/ha to each rice and wheat crops under rice-wheat cropping system. Nitrogen, phosphorus and potash were supplied in the form of urea, single super-phosphate and muriate of potash as inorganic source, respectively. The plot size was 10 m^2. The crops in this manuscript were 48th crop rice (cv. Rajshree) in *Kharif* and 49th crop wheat (cv -HD 2733) in *Rabi* season with continuous application of compost @ 10 t/ha to each rice and wheat crops and/or 100% crop residues of respective plot alone or in combination with different levels of NPK viz. 0, 50, 100 and 150 per cent of recommended dose of fertilizers. The residue of wheat before rice transplanting and the residue of rice before wheat sowing were incorporated to the soil. Half dose of nitrogen and entire dose of P and K were applied at the time of transplanting of rice and sowing of wheat and remaining N fertilisers were applied in the equal split at tillering and flowering initiation stages. Rice-wheat cropping sequence was followed.

The composite surface (0-15 cm) soil samples from each plot of the field experiment were collected after harvest of wheat in rice-wheat rotation. Samples were air-dried, ground to pass through a 2 mm nylon sieve and various pools of Zn were determined using different extractants according to the scheme described by Raja and Iyenger [6].

3. RESULTS AND DISCUSSION

3.1 Distribution of Zinc into Different Fractions

The water-soluble + exchangeable Zn was lowest as compared to other fractions and decreased from 0.62 to 0.50 mg/kg with increasing levels of fertiliser from 0 to 150 per cent NPK due to higher removal of Zn by rice and wheat crops owing to increased biomass productions (Table 1). Water-soluble + exchangeable Zn varied from 0.66 to 0.75 mg/kg under different treatment of organic sources. This fraction in soil treated with organic manure and crop residue was higher than that of untreated soil [10]. Complexed Zn varied from 1.96 to 2.12 and 1.62 to 1.91 mg/kg, respectively under different treatment of NPK and organic sources.

Table 1. Effect of organic and inorganic fertilizers on Zn fraction (mg/kg) in calcareous soil under rice-wheat cropping system

Treatment	Water soluble + Exchangeable	Complexes Zn	Organically bound Zn	Zn bound to Carbonate and amorphous oxide	Zn bound to Crystalline oxide	Residual Zn	Total Zn
Inorganic Sources							
0 % NPK	0.62	1.96	2.45	1.31	2.40	113.90	122.36
50 % NPK	0.56	2.03	2.57	1.36	2.86	116.40	126.00
100 % NPK	0.52	2.09	2.64	1.43	3.38	118.24	128.46
150 % NPK	0.50	2.12	2.69	1.49	3.78	119.6	130.48
CD (P= 0.05)	0.02	0.04	0.08	0.04	0.03	0.69	0.98
Organic Sources							
No organics	0.66	1.62	1.92	1.13	2.81	115.58	123.54
Compost	0.72	1.85	2.81	1.42	3.12	117.27	127.20
Crop residue	0.70	1.73	2.75	1.31	2.96	116.66	126.24
Compost + crop residue	0.75	1.91	2.88	1.64	3.53	118.63	129.32
CD (P= 0.05)	0.05	0.03	0.07	0.03	0.02	0.62	0.91

Table 2. Correlation coefficient among soil Zn fractions

Treatment	Complexes Zn	Organically bound Zn	Zn bound to Carbonate and amorphous	Zn bound to Crystalline oxide	Residual Zn	Total Zn
Water salable + exchangeable -Zn	0.592*	0.747*	0.737*	0.795**	0.855**	0.868**
Complex Zn		0.371	0.577*	0.792**	0.842**	0.860**
Organically bounded – Zn			0.821**	0.518	0.547*	0.638**
Zn bound to Carbonate and amorphous oxide				0.783**	0.756**	0.817**
Zn bound to Crystalline oxide					0.969**	0.961**
Residual - Zn						0.989**

**Significant at 5%level of significance; ** Significant at 1%level of significance*

Table 3. Simple correlation coefficient (r) between fraction of Zn and plant parameters

Soil Zn fractions	Rice					Wheat				
	Grain yield	**N uptake**	**P uptake**	**K uptake**	**Zn uptake**	**Grain yield**	**N uptake**	**P uptake**	**K uptake**	**Zn uptake**
Water salable + exchangeable -Zn	0.741**	0.802**	0.776**	0.780**	0.825**	0.787**	0.835**	0.833**	0.799**	0.837**
Complex Zn	0.914**	0.883**	0.900**	0.891**	0.836**	0.853**	0.817**	0.820**	0.838**	0.814**
Organically bounded – Zn	0.540*	0.564*	0.521*	0.526*	0.580*	0.511*	0.530*	0.533*	0.514*	0.533*
Zn bound to Carbonate and amorphous oxide	0.734*	0.769**	0.733**	0.722**	0.811**	0.706**	0.715**	0.718**	0.725**	0.767**
Zn bound to Crystalline oxide	0.942**	0.973**	0.966**	0.964**	0.976**	0.970**	0.971**	0.978**	0.982**	0.982**
Residual - Zn	0.949**	0.978**	0.972**	0.967**	0.977**	0.971**	0.979**	0.979**	0.968**	0.980**
Total - Zn	0.963**	0.984**	0.976**	0.971**	0.980**	0.964**	0.968**	0.969**	0.963**	0.974**

**Significant at 5%level of significance; ** Significant at 1% level of significance*

Table 4. Path coefficient analysis showing the contribution of Zn fractions towards Zn uptake by rice

Forms of Zn	Water soluble + Exchangeable Zn	Complexes Zn	Organically bound Zn	Zn bound to Carbonate and amorphous	Zn bound to Crystalline oxide	Residual Zn	Total Zn
Water salable + exchangeable -Zn	**-0.5004**	-1.1386	0.2479	0.0934	1.2365	0.2224	-0.2496
Complex Zn	-0.2893	**-1.9696**	0.0977	0.1545	2.0126	0.0282	-0.4795
Organically bounded – Zn	-0.3125	-0.4831	**0.0983**	0.0323	0.5463	0.2413	0.2024
Zn bound to Carbonate and amorphous oxide	-0.2963	-1.9298	0.0817	**0.1577**	1.9884	0.0551	-0.4651
Zn bound to Crystalline oxide	-0.3037	-1.9457	0.1068	0.1539	**2.0372**	0.0650	-0.4073
Residual - Zn	-0.1720	-0.0859	0.1485	0.0134	0.2046	**0.0470**	-0.6311

Residual effect=0.3776

Table 5. Path coefficient analysis showing the contribution of Zn fractions towards Zn uptake by wheat

Forms of Zn	Water soluble + Exchangeable Zn	Complexes Zn	Organically bound Zn	Zn bound to Carbonate and amorphous	Zn bound to Crystalline oxide	Residual Zn	Total Zn
Water salable + exchangeable -Zn	-0.4966	-0.8968	0.1880	0.3328	1.1617	0.2341	-0.3006
Complex Zn	-0.2871	-1.5512	0.0741	0.5443	1.8908	0.0297	-0.5316
Organically bounded – Zn	-0.3091	-0.3805	0.3020	0.1118	0.5132	0.2540	0.1503
Zn bound to Carbonate and amorphous oxide	-0.2940	-1.5199	0.0619	0.5453	1.8681	0.0580	-0.5262
Zn bound to Crystalline oxide	-0.3014	-1.5324	0.0810	0.5322	1.9139	0.0684	-0.4625
Residual - Zn	-0.1707	-0.0676	0.1126	0.0464	0.1922	0.0681	0.5278

Residual effect= 0.3140

The higher value of complexed Zn possibly resulted from the complexation of native Zn in calcareous soil of high pH [11]. Organically bound Zn contributed a relatively higher proportion of total Zn. It is possible that the pyrophosphate reagent extracted only organically bound Zn, which ranged from 1.92 to 2.88 mg/kg. Zn bound to carbonate, and amorphous oxide fraction ranged from 1.13 to 1.64 mg/kg under different treatments. This form of Zn in soil treated with organic manure and crop residues was greater than that of the untreated soils. Zn bound to crystalline and amorphous varied from 2.40 to 3.78 mg/kg under different treatments. Residual Zn fraction ranged from 113.90 to 119.60 mg/kg. Most of the total Zn was present in residual form and the only small fraction was present in easily available form. It was observed the crop residue, and compost incorporation increased that residual zinc fraction [10,12].

3.2 Relationship among the Different Fractions of Zinc

The water-soluble plus exchangeable form of Zn was positively and significantly correlated with complexed Zn, Zn bound to crystalline oxide, Zn bound to carbonate and amorphous oxide, residual Zn and total Zn (Table 2). However, complexed Zn had a significant positive correlation with all fractions of Zn except organically bound Zn, indicating there was a dynamic equilibrium among them. This indicates that most of the weakly organically bound Zn normally exists in the solution. Zn bound to carbonate, and amorphous oxide was positively and significantly correlated with Zn bound to crystalline oxide, residual Zn and total Zn. Zn bound to crystalline oxide was positive and significantly correlated with residual and total Zn. The Zn bound to carbonate and amorphous oxide and Zn bound to crystalline oxide had a significant relationship with residual Zn. Both carbonate and amorphous oxide-Zn and crystalline oxide Zn forms are relatively stable and do not equilibrate readily with soil solution [13,14].

3.3 Relationship between Soil Zn Fractions and Plant Parameters

In case of grain yield of rice, all the fractions of soil Zn viz. water-soluble plus exchangeable, complexed, organically, carbonate and amorphous oxide, crystalline oxide, residual and total Zn showed a positive and significant correlation (Table 3). However simple correlation coefficient (r) analysis revealed that most important Zn fraction for N, P, K and Zn uptake were complexed, crystalline oxide, residual and total Zn showing their highest importance in maintaining Zn nutrition to rice. In the case of the wheat crop, all the Zn fractions showed a significant positive correlation with grain yield, N, P, K and Zn uptake (Table 3).The results regarding the relationship between soil Zn fractions and plant parameters conform to the findings of Chawdhary et al. [13] and Sharad and Verma [15].

3.4 Path Analysis

The quantity and direction of the contribution of Zn fractions towards Zn uptake by rice and wheat were studied through path coefficient analysis (Tables 4 and 5). A perusal of data indicated that among Zn fractions, the total effect was found to be highest for organically bound Zn followed by Zn bound to carbonate and amorphous oxide [1]. The overall direct effect on plant parameter was found to be highest for Zn bound to crystalline oxide. This was followed by Zn bound to carbonate and amorphous oxide. The negative value of path coefficient for water-soluble plus exchangeable and complexed Zn indicated its availability to plant indirectly through Zn bound crystalline to oxide, Zn bound to carbonate and amorphous oxide and organically bound-Zn. The path coefficient study confirmed the importance of Zn bound to crystalline oxide, Zn bound to carbonate and amorphous oxide and organically bound-Zn. The very low residual effect of path analysis indicated that the contribution of other unaccounted factors in the study was very little and these Zn fractions suitably describe the variations in Zn uptake by rice and wheat.

4. CONCLUSIONS

The different fractions of soil Zn are in dynamic equilibrium with each other, and their availability to growing crop depends on their intensities and soil condition. This implies that depleted levels of readily available Zn in soil could be replenished by the other pools of soil Zn. Among the different Zn fractions, Zn bound to crystalline oxide followed by Zn bound to carbonate and amorphous oxide played a key role in explaining the variation in yield and Zn uptake by rice and wheat in calciorthents.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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