



Effect of long-term fertilization on zinc distribution and its uptake by wheat (*Triticum aestivum*)

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ABSTRACT

Zinc (Zn) is one of the seventeen essential nutrients required for proper growth and development of plants. Majority of soils of India (about 43% of its cultivated soil) are deficient in Zn. Long-term fertilizer experiments (LTFE) are the perfect platform to investigate the impact of integrated nutrient management (INM) over a long period of time on Zn availability and uptake by crops. With this aim, soil samples were collected from an on-going 47 year-old long-term fertilizer experiment at ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi after harvesting of wheat during April, 2018. The selected fertilizer and manurial treatments includes control, N alone, NP, NPK, 150% NPK, NPK+Zn and NPK+FYM were studied. Results of the study reveal that yield of wheat, Zn content and uptake varied from 1.95–5.58 t/ha, 29.8–42.3 mg/kg, and 96.5–368 g/ha, respectively, across the nutrient management practices. It was also found that residual Zn was the major fraction in soil which accounted for 86–90% of the total Zn followed by oxide bound Zn (5.4–9.2%), organically bound Zn (1.9–3.8%), carbonate bound Zn (0.34–0.82%) and water soluble plus exchangeable Zn (0.26–0.58%). Grain yield of wheat was at par in NPK+Zn and NPK+FYM indicating that similar response of the applied Zn as compared to integrated nutrient management. Thus, NPK+Zn are the best option for producing Zn-fortified grains and sustainable crop production.

Keyword: Wheat yield, Zinc fractions, Zinc uptake

The introduction of high yielding varieties along with use of high analysis chemical fertilizers and expansion of irrigated area during late 1970s drive the country to self sufficiency in food production. Such increase in food production has been responsible for depletion of micronutrients from soil reserve over the years that led to deficiency of micronutrients (Shukla *et al.* 2018, Shukla *et al.* 2020). Among the micronutrients, Zn deficiency is the most common in India, particularly in alkaline and calcareous soils of Indo-Gangetic plains (Meena *et al.* 2006a, Rathod *et al.* 2012). Cakmak (2008) observed that despite of very high total Zn in soil, plants showed Zn deficiency because majority of Zn were associated with organic matter, oxides and primary minerals which reduced its bioavailability (Yadav and Meena 2009). Thus, understanding the distribution of Zn in various soil fractions as affected by continued application of fertilizers and manures will help to characterize chemistry of Zn in soils and its availability for plant uptake (Golui *et al.* 2020). The contribution of all these pools towards Zn availability to the

plants depends on the dynamic equilibrium among different fractions. Beside this, availability of the micronutrients, particularly Zn also affected by pH, organic matter, redox status *etc.*; all of the soil properties are greatly modified by application of fertilizers and manures over a long period of time. Therefore, suitable information regarding different Zn forms and their relationship with uptake is very much important for sustainable crop production on a long-term basis but most of the studies conducted by previous authors focused on to examine the impact of different nutrient management practices on basic soil properties and DTPA-extractable micronutrients but basic information regarding the distribution of Zn in different fractions as well as Zn uptake especially under different nutrient management options of long-term fertilizer experiment are very limited. Hence, present experiment was carried out to study the effect of long-term fertilization and manuring on wheat yield, Zn fractions and Zn uptake by wheat in an Inceptisol of New Delhi.

MATERIALS AND METHODS

The on-going field experiment (since 1971) with maize-wheat cropping system under the All India Coordinated Project on Long Term Fertilizer Experiment (AICRP-LTFE), Delhi Centre at ICAR-IARI was selected for the study. The experimental site is located at latitude of 28°37'–28°39'N, longitude of 77°9'–77°11' and altitude of 217 m above mean

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sea level (amsl). The experimental site is characterized as sub-tropical with semi-arid climate experiencing annual rainfall of about 650 mm and a mean annual maximum and minimum air temperature of 40.5 °C and 16 °C, respectively. Soil of the long-term experimental site was sandy loam in texture, alkaline in reaction (pH 8.0), non-saline (EC 0.45 dS/m), with low soil organic carbon (SOC) (0.44%) status. Experiment was carried out in the Randomized Block Design (RBD) with four replications, and each plot having size of 21 m × 8 m with ten treatments, but seven fertilizer and manurial treatments with 3 replications were selected for the present study, viz. No fertilization (control), recommended nitrogen alone (N), recommended nitrogen and phosphorus (NP), recommended nitrogen, phosphorus, and potassium (NPK), 1.5 fold of recommended NPK (150% NPK), recommended NPK and zinc (NPK+Zn), recommended NPK along with FYM @ 5 t/ha (NPK+FYM). The recommended dose of the fertilizers was as 120 kg N/ha, 60 kg P₂O₅/ha and 40 kg K₂O/ha. Wheat was shown in the month of November and harvested in the week of April. At the maturity, yield data of wheat were recorded as per standard protocols and harvested. Grain and straw sampled were collected and processed. The samples were digested with the help of diacid mixture (HNO₃:HClO₄ = 4:1), and digested samples were used for Zn analysis with help of atomic absorption spectrophotometer (AAS). Zinc uptake by grain and straw was worked out.

After wheat harvest, soil samples (0-15 cm) were collected and processed. Soil samples analyzed for different physico-chemical properties following standard protocols (Jackson 1973). The available Zn was determined using procedure line-out by Lindsay and Norvell (1978). Fractions of Zn such as water soluble plus exchangeable Zn, carbonate bound Zn, oxide bound Zn, organically bound Zn and residual Zn were determined by modified sequential extraction method as described by Phillips and Chappie (1995). Available Zn was also determined in archived samples collected after wheat harvest of each year during the period of 1996-2018. Zinc content in extracted solution was determined using AAS. The Zn content in different fractions express as percentage of total Zn. Analysis of variance method was followed through adopting randomized blocked design and statistical analysis

system (SAS 9.4).

RESULTS AND DISCUSSION

Changes in soil properties: Soil properties (such as pH, electrical conductivity and organic carbon *etc.*) varied significantly with the different long-term nutrient management practices (Table 1). Soil pH values varied from 8.15–8.37, with the highest value being observed under control and lowest value being observed under NPK+FYM. This reduction in soil pH in FYM treated plot may be attributed to the production of different organic and inorganic acids during the decomposition of organic matter (Meena *et al.* 2006a,b, Meena *et al.* 2012). There was no change in electrical conductivity (EC) in the different fertilizers and manurial treatments. Long-term application of manure and fertilizers resulted into significantly higher Walkley-Black C (WBC) compared to control. The highest value of WBC was observed in NPK+FYM, which was 53% higher than control (Table 1). Beside this, significant increased in WBC in 150% NPK may be related to higher root biomass production (due to super optimal dose of N,P and K nutrients) that contributed higher organic matter and *vice-versa* was true for control (Dwivedi *et al.* 2009).

KMnO₄-extractable N, Olsen P and NH₄OAc-extractable K ranged from 179 to 270, 16.3 to 41.1 and 172 to 330 kg/ha, respectively across the treatments (Table 1). Continuous application of 150% NPK and NPK+FYM registered statically similar KMnO₄-N and Olsen P which were significantly higher as compared to all other treatments irrespective of fertilization practices. The highest NH₄OAc-extractable K was observed under 150% NPK, which is almost double than that under control (172 kg/ha). This highest value of available N, P and K in 150% NPK treatments related to application of super optimal dose over a long period of times that caused build-up those particular nutrients. Beside this, Meena *et al.* (2012) also reported that application of optimum dose of NPK along with organic manures significantly increased the soil KMnO₄ extractable N and Olsen P.

Changes in plant available Zn: DTPA-extractable Zn content in soil ranged between 1.06 and 2.55 mg/kg after 47 years of continuous cultivation and fertilization (Table 1). A significant improvement in the status of DTPA-extractable

Table 1 Effect of long-term nutrient management options on basic soil parameters

Treatment	pH	Electrical conductivity (dS/m)	Organic carbon (%)	DTPA -Zn (mg/kg)	KMnO ₄ -N	Olsen P	NH ₄ OAc-K
						(kg/ha)	
Control	8.37 ^a	0.33 ^a	0.36 ^d	1.06 ^d	179 ^c	20.2 ^c	172 ^c
N	8.28 ^b	0.31 ^a	0.44 ^c	1.14 ^d	226 ^b	16.3 ^c	241 ^d
NP	8.28 ^b	0.33 ^a	0.43 ^c	1.21 ^{cd}	230 ^b	34.1 ^b	252 ^d
NPK	8.27 ^b	0.29 ^a	0.44 ^c	1.42 ^{bc}	216 ^b	36.1 ^b	288 ^{bc}
150% NPK	8.26 ^b	0.31 ^a	0.52 ^{ab}	1.36 ^c	270 ^a	41.1 ^a	330 ^a
NPK+Zn	8.31 ^{ab}	0.31 ^a	0.48 ^{bc}	2.55 ^a	228 ^b	33.9 ^b	277 ^c
NPK+FYM	8.15 ^c	0.3 ^a	0.55 ^a	1.62 ^b	263 ^a	40.6 ^a	303 ^b

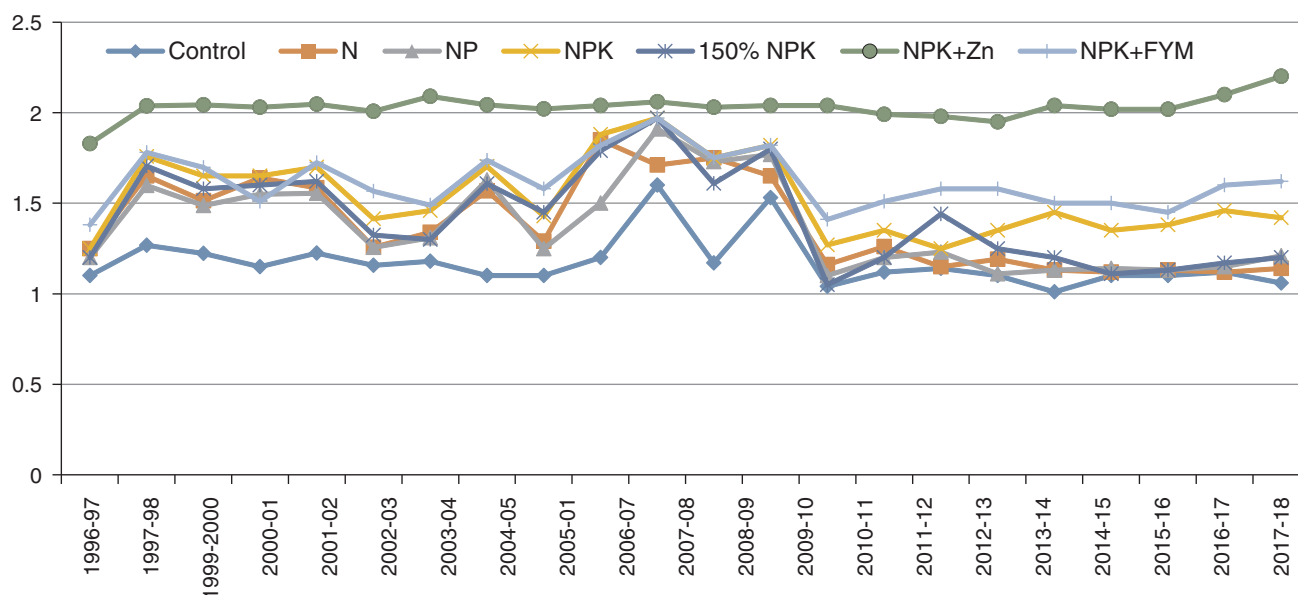


Fig 1 Effect of long-term nutrient management options on DTPA-extractable zinc during the period of 1996-2018.

Zn under NPK+Zn treated plots was observed, which may be due to the continuous supply of Zn through the fertilizer over a long period that caused build up of Zn. Beside this, result of DTPA-Zn was consistently higher under NPK+Zn and consistently lower under control treatment during 22 years (Fig 1). A significant improvement of DTPA-extractable Zn under NPK+FYM was also observed because organic manure contains sufficient amount of Zn, which may fulfill the requirement of crop as well as improves the available Zn in soils and organic matter promotes chemical and biological reactions that increased Zn solubility (Meena *et al.* 2006a,b,c, Rathod *et al.* 2012). Further, different organic chelating agents as produced during the decomposition of organic manure form soluble organic complex with Zn leading to increase its availability (Behera *et al.* 2008).

Wheat yields: Treatments which received fertilizers and manure produced significantly higher yields as compared to control (Table 2). Grain yield of the wheat was ranged from 1.95 t/ha under control to 5.58 t/ha under 150% NPK, whereas straw yield ranged from 3.23 to 7.96 t/ha. Highest grain yield was recorded in 150% NPK, which was at par with NPK+Zn, and NPK+FYM indicating that similar response of the applied Zn as compared to NPK. Application

of NPK+Zn as well as NPK+FYM, grain yield was increased by 6.4 and 8.2%, straw yield was increased by 7.92 and 12.1% respectively over the NPK (Table 2). The positive effect of FYM on wheat yield mainly attributed to the additional supply of secondary micronutrients (Dwivedi *et al.* 2009, Meena *et al.* 2012) along with balanced application of major nutrients. The lowest yield as obtained in the control plots associated with the reduction in soil fertility mainly due to continuous cultivation without fertilizers and manure (Rathod *et al.* 2012). On the other hand, 150% NPK registered higher grain and straw yields mainly due to higher availability of major nutrients such as N, P and K which accelerate overall growth and development of plant (Chaudhary *et al.* 2019).

Zinc content and uptake by wheat: Zinc content and its uptake were significantly higher under all fertilizer treatments particularly Zn treated plot as compared to control (Table 2). Zinc content in wheat grain ranged from 29.8 to 42.2 mg/kg, whereas the values varied between 11.2 to 18.3 mg/kg in case of wheat straw. Highest Zn content in grain as well as straw was observed under NPK+Zn treatments. The treatments 150% NPK and NPK+FYM were at par in respect of Zn content in grain and straw.

Table 2 Effect of long-term nutrient management options on Zn content and uptake by wheat

Treatment	Yield (t/ha)		Zn content (mg/kg)		Uptake (g/ha)		
	Grain	Straw	Grain	Straw	Grain	Straw	Total
Control	1.95 ^d	3.23 ^f	30.5 ^{cd}	11.5 ^c	59.4 ^d	37.1 ^e	96.5 ^e
N	4.62 ^c	5.31 ^e	29.8 ^d	12.3 ^c	137 ^c	65.3 ^d	203 ^d
NP	4.80 ^c	6.52 ^d	30.3 ^d	13.2 ^{bc}	145 ^c	86.4 ^c	231 ^c
NPK	5.13 ^b	6.94 ^c	30.7 ^{cd}	11.2 ^c	158 ^c	78.1 ^{cd}	236 ^c
150% NPK	5.58 ^a	7.96 ^a	34.5 ^{bc}	14.5 ^b	193 ^b	115 ^b	308 ^b
NPK+Zn	5.46 ^a	7.49 ^b	42.2 ^a	18.3 ^a	231 ^a	137 ^a	368 ^a
NPK+FYM	5.55 ^a	7.78 ^{ab}	36.5 ^b	14.5 ^b	202 ^b	113 ^b	315 ^b

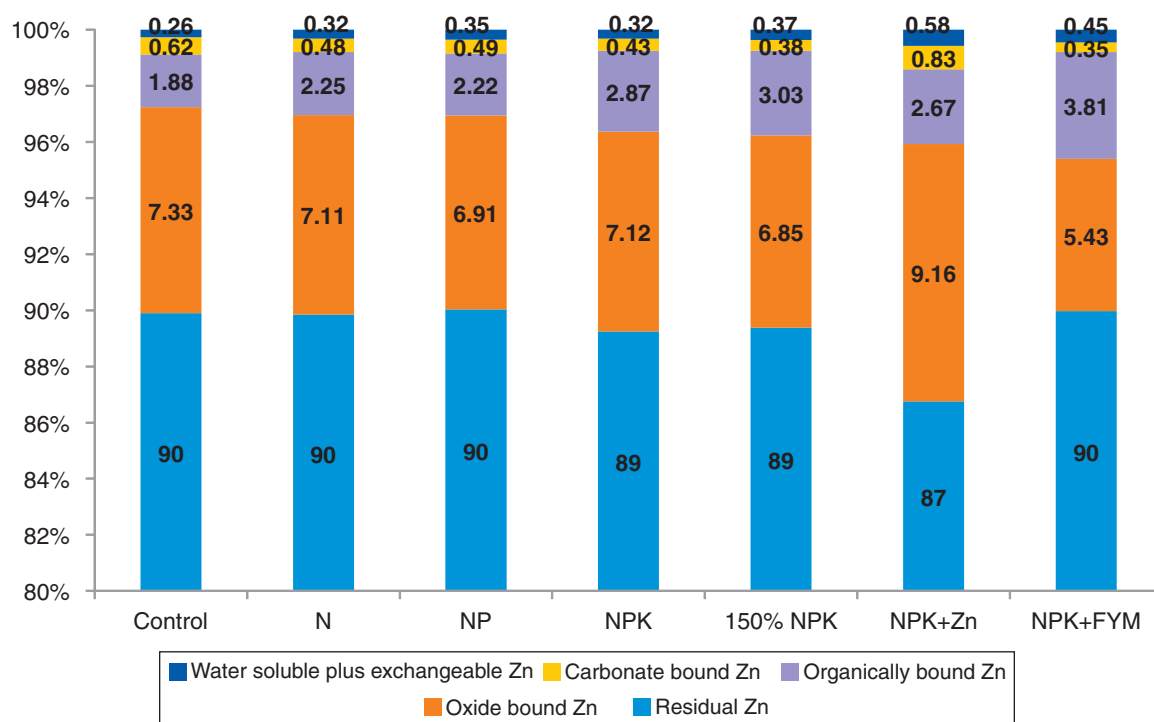


Fig 2 Effect of different nutrient management options on percentage distribution of different fractions of zinc.

Uptake of Zn by wheat ranged from 96.5 g/ha for control to 368 g/ha for NPK+Zn (Table 2). Compared with control, Zn uptake by grain and straw was significantly higher in all other treatments. The inclusion of Zn in fertilization schedule (NPK+Zn) significantly increased Zn content and uptake by wheat as compared to all other treatments. Behera *et al.* (2008) reported that continuous cultivation of crops with or without application of NPK fertilizers led to lower uptake of Zn in plots devoid of applied Zn as compared to treatments receiving Zn fertilization. Increased uptake of Zn by wheat with the application of Zn was also observed by Rathod *et al.* (2012). The Zn uptake under 150% NPK (308 g/ha) and NPK+FYM (315 g/ha) were significantly higher as compared to that of NPK. This indicates that application of fertilizer and manure either alone or in combination promoted the Zn uptake (Meena *et al.* 2006a, Veni *et al.* 2020).

Distribution of soil Zn in different fractions: Percentage distribution of Zn in different fractions is influenced by long-term (47 years) application of Zn fertilizer and FYM along with different combination of NPK fertilizers (Fig 2). Out of all Zn fractions, water soluble plus exchangeable contributed 0.26-0.58% of total Zn, highest in case of Zn treated plots followed by FYM treated plots, and least in case of control. The results of this study further showed that majority of Zn was present in residual (87-90%) and crystalline Fe-oxides bound pools (5.4-9.2%) whereas other two fraction such as organic matter bound Zn (1.9-3.8%) and carbonate bound fraction Zn (0.35-0.83%) were present in small amount. Percentage of carbonate bound Zn (0.83%), oxide bound Zn (9.2%) was highest under treatment which

receive Zn fertilization. It was previously reported that soluble Zn transformed gradually into various fractions (Mishra *et al.* 2019), and most of the applied Zn in soil was transformed into oxides bound Zn, organic matter bound Zn and carbonate bound Zn (Behera *et al.* 2008).

The current study with a 47 years long-term nutrient management experiment demonstrated crop response to Zn fertilization. Therefore, in the intensively cultivated Indo-Gangetic plains, Zn should invariably be included in the fertilizer scheduling in the low and moderate soil Zn supply condition. The results of this study also reveal that major portion of soil Zn associated with residual fraction, and fertilization and manuring has negative impact on carbonate bound and oxide bound Zn. Uptake of Zn by wheat significantly influenced by NPK+Zn and NPK+FYM, suggesting the importance of balanced fertilization and integrated nutrient management for long-term sustainability of crop production and grain quality.

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