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Effect of potassium and zinc fertilizer on crop yield, nutrient uptake and distribution of potassium and zinc fractions in Typic Ustipsamment

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ABSTRACT

A field experiment was conducted to study the effect of potassium and zinc fertilizer on status and content of potassium and zinc fractions and their effect on crop yield, nutrient uptake and nutrient availability in the soil. Significant increase in grain yield, straw yield, K uptake, and different K fractions in the soil (exchangeable K, water soluble K, Morgan's extractable K, lattice K and total K in the soil) were recorded with increase in K levels from 0 to 60 kg K/ha. Zinc fertilization in wheat also significantly increased crop yield and Zn uptake but interaction between K and Zn was not found to be significant in respect of yield, uptake, and various K and Zn fractions. Water-soluble K showed significant and positive correlation with exchangeable K (r= 0.928), Morgan's extractable K (r= 0.983) and lattice K (r= 0.969), indicating rapid equilibrium establishment between these forms. Step wise regression analysis using different pools of K revealed the importance of water soluble K and lattice K influencing crop yield, K uptake by wheat. Similarly, application of 9 kg Zn/ha increased the Zn fractions present in soil and correlation data indicated that these fractions are in a state of dynamic equilibrium with each other. In the present study, DTPA-Zn accounted for 65% and 70% of the variation in grain yield and Zn uptake by wheat, indicating that DTPA-Zn was efficient in providing Zn nutrition to wheat.

Key words: Nutrient uptake, Soil K fractions, Soil Zn fractions, Wheat, Yield

With application of chemical fertilizers in developing management practices, it is imperative to understand the nutrient transformations that can lead to more efficient use of fertilizers. Potassium (K), the third major and most dynamic nutrient with diverse roles to play in plant metabolism, is required in large amount by crops. Already a fall in productivity in the absence of K treatment has been proven from long-term experiment (Swarup *et al.* 1998). It interacts with different nutrients to affect crop yield and quality and the interaction may be in the soil or in the plant. It exists in soil in different forms in a state of quasi equilibrium with each other and availability in different forms depends upon the soil moisture content, temperature, concentration of bivalent cations in solution and the various intrinsic and extrinsic properties such as mineralogy, texture, CEC, clay content, organic matter etc. A large portion of the total K in soil is unavailable to plants as it occurs as structural component of soil minerals. Plants can use only the exchangeable K found on the surface of soil particles and the K dissolved in soil water and this often constitutes the small fraction of total soil K. The dynamics of K in soils depends on the magnitude of equilibrium among various forms and thus, knowledge on distribution of K fractions in soil proves to be the best approach in understanding and manipulation of the applied K fertilizers.

The normal yield of crops could not be achieved despite judicious use of NPK fertilizers due to deficiency of micronutrients in general and that of zinc (Zn) in particular. Zn is an essential micronutrient but available Zn is very low in Indian soils and it has emerged as one of the major constraints to crop productivity. Overall, Zn deficiency in India has increased from 42-49% in past four decades and it is expected to increase up to 63% by 2025 (Singh 2009). One third of the world population is reported at the risk of Zn malnutrition due to inadequate dietary intake of Zn (Chamak 2009). Zn is known to occur in soil in a number of discrete chemical forms differing in their solubility and thus availability to plants. Among various Zn fractions in soil, water soluble, exchangeable and adsorbed pools are believed to be in reverse equilibrium with one another, with equilibrium being established quickly. The availability of applied Zn to plants is largely influenced by the amount and rate of their transformations in soils. Amount of nutrients added, reaction time in soil, rate of extraction by roots, nature and amount of clay minerals, organic matter content

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are the governing factors affecting the extent and nature of these transformations. Plants absorb Zn from soil solution which is replenished by various Zn fractions. Therefore, suitable appraisal of different K and Zn forms, their relationships and uptake is imperative for sustainable crop productivity on a long term basis. Hence, the present investigation was carried out to study the effect of K and Zn fertilization on K and Zn fractions in Typic Ustipsamment soil of Jaipur, Rajasthan.

MATERIALS AND METHODS

Field experiment was carried out during *rabi* seasons of 2007-08 and 2008-09 at the experimental farm (26°5' N latitude, 75°28' E longitude), SKN College of Agriculture, Jobner, located at an altitude of 427 meters above mean sea level in Jaipur district of Rajasthan, representing Western arid zone of India. The experimental site is characterized by sub-tropical climate, with extreme temperature during summer (30° to 46 °C) and winter (as low as –3 °C) and low rainfall (400-500 mm and most of which is received in rainy season from July to September). The soil of the experimental field was loamy sand, alkaline in reaction *p*H (1: 2.5) 8.2, EC 0.17 dS/m, low in organic carbon 0.2%, low in available N 132 kg/ha, medium in available P 18.2 kg/ha and available K 144 kg/ha and DTPA zinc 4.2 mg/kg at the commencement of the experiment (*rabi* 2007-08). Wheat (variety Raj 3077) was planted on 27 and 26 November and harvested on 20 and 18 April in first year (2007-08) and second year (2008-09) of experimentation, respectively. Potassium @ 0, 20, 40 and 60 kg K/ha and Zn @ 0, 3, 6 and 9 kg Zn/ ha was applied through muriate of potash and zinc sulphate, respectively, in all possible combinations. A basal application of 60 kg N and 50 kg P_2O_5 was made through urea and DAP. The treatments were replicated four times. The crop at maturity was harvested and seed and straw yield were recorded.

The whole plants were separated into roots and shoots, washed thoroughly in succession with tap water, 0.01 N HCl and deionized water. Plant samples were air dried, oven dried at 65°C, ground in a Willey mill having stainless steel blades to pass through 40 mm mesh sieve, and digested in a diacid mixture of HNO_3- $HClO_4$ (4:1) for analysis of K and Zn. Nutrient uptake in grain and straw were calculated by determining nutrient concentration in relation to dry matter production, i e the nutrient uptake was worked out by multiplying the yield with nutrient content and dividing by 100.

After the harvest of the crop, soil samples were collected, air-dried, processed and analysed for available K (Pratt 1982) and DTPA-Zn (Lindsay and Norvell 1978). Water soluble potassium was extracted by shaking the soils with water in 1:5 (soil: water) ratio for five minutes. Exchangeable potassium was obtained by subtracting the water soluble potassium from available potassium. Morgan's extractable potassium was extracted by shaking the soils with Morgan's extract. Total potassium in soil was analysed by digesting the soil samples with a HF-$HClO_4$ mixture using platinum crucibles and lattice K was extracted with boiling HCl in the ratio of 1:20 following the procedure outlined by Jackson (1956).

Different zinc pools, viz. water soluble plus exchangeable (WSEX-), adsorbed Zn (Ads Zn), zinc associated with organic matter (Oc-Zn), occluded Zn and Zn bound by carbonates and other acid soluble minerals (Occ-Zn) were estimated in a sequential fractionation procedure proposed by Iyengar and Deb (1977) and Chandi and Takkar (1982) (Fig 1). Extraction with various reagents, prepared in all double distilled water using 1:4 soil: solution ratio was carried out by shaking on a rotary shaker for 2, 4, 2 and 1 hours respectively. For zinc associated with organic matter (OC-Zn) fraction, the soil residue was allowed to react with 5 ml of 30 % H_2O_2 and placed on a hot water bath over night and the contents in the tube were maintained at 75°C + 2°C. Soil suspension at different stages was centrifuged at 2500 rpm, filtered and the filtrate from each stage was used for the determination of Zn fractions, but the soil residue was used for the next step. The concentration of zinc in the extracts was estimated using AAS. Total zinc in soil was estimated on AAS by digesting the soil samples with a mixture of HF and $HClO_4$. Residual mineral fraction (Res-Zn) was obtained by deducting all the fractions of zinc from the total zinc in soil.

Statistical analyses were performed using analysis of variance (ANOVA) for randomized block design as per Gomez and Gomez (1984). For treatment comparisons in

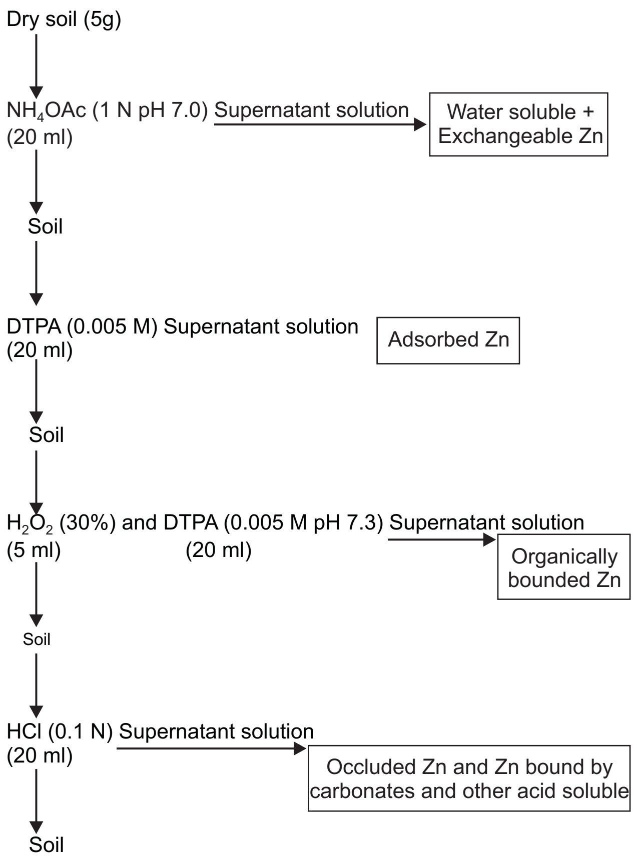

Fig 1 Flow sheet for sequential extraction of different Zn fraction

the field experiments, the 'F-test' was used. Correlation and step wise regression were carried out using SPSS software package.

RESULTS AND DISCUSSION

Yield

The grain and straw yields of wheat were significantly influenced with K and Zn fertilization (Table 1). The application of 40 kg K/ha, being at par with 60 kg K/ha recorded the highest grain yield (3.08 tonnes/ha) and straw yield (4.61 tonnes/ha) of wheat. The application 20, 40 and 60 kg K/ha registered the 18, 28 and 33% increase in grain yield and 13, 22 and 27% increase in straw yield, respectively over control. The increased yield with K fertilization might be due to increased availability, absorption and translocation of K nutrient. As the K is essential for grain development, the favourable effect of high doses of K on growth and yield attributes was mainly responsible for higher grain and straw yields. Significant effect of K application in sesame, mustard, groundnut and wheat were reported by Yadav *et al*. (2012).

With successive increase in Zn levels grain yield (3.06 tonnes/ha) and straw yield (4.60 tonnes/ha) of wheat increased significantly up to 6 kg Zn/ha and further increase in Zn levels had no significant effect. The application of 3, 6 and 9 kg Zn/ha registered the 13, 24 and 30% increase in grain yield and 11, 21 and 26 % increase in straw yield, respectively over control. This may be attributed to the fact that Zn is main yield limiting plant nutrient in Zn deficient soils of Rajasthan. Zn is reported to enhance the absorption of native as well as added major nutrients such as N and P, thereby improved overall growth and development of plants and ultimately the grain and straw yield. These findings of present investigation are supported by Varshney *et al*. (2008).

Table 1 Effect of K and Zn fertilization on yield and nutrient uptake of wheat (pooled data of two years)

Treatment	Yield (t/ha)		K uptake (kg/ha)			Zn uptake (g/ha)		
	Grain	Straw	Grain	Straw	Total	Grain	Straw	Total
K levels (kg/ha)								
K_0	2.41	3.77	13.4	50.9	64.3	54.0	62.5	116.5
K_{20}	2.84	4.27	16.9	60.7	77.7	66.3	74.1	140.4
K_{40}	3.08	4.61	19.3	68.3	87.6	74.4	83.6	158.0
K_{60}	3.20	4.80	20.7	73.3	94.0	79.5	89.2	168.7
SEm±	0.06	0.09	0.48	1.45	1.67	1.72	1.82	2.90
CD (*P*=0.05)	0.18	0.25	1.4	4.1	4.8	4.9	5.2	8.3
Zn levels (kg/ha)								
Zn_0	2.47	3.81	13.7	51.1	64.8	52.9	61.2	114.0
Zn_3	2.80	4.24	16.8	60.7	77.5	64.9	73.3	138.2
Zn_6	3.06	4.60	19.2	68.8	88.1	75.2	84.3	159.6
Zn_9	3.21	4.81	20.6	72.6	93.1	81.2	90.6	171.9
SEm±	0.06	0.09	0.48	1.45	1.67	1.72	1.82	2.90
CD (*P*=0.05)	0.18	0.25	1.4	4.1	4.8	4.9	5.2	8.3
CV (%)	8.8	8.0	11.0	9.2	8.3	10.0	9.4	7.9

K and Zn uptake

The K and Zn uptake in grain and straw of wheat were significantly increased with K and Zn fertilization (Table 1). The significantly highest K uptake in wheat grain (20.7 kg/ha), straw (73.3 kg/ha) and total uptake (94.0 kg/ha) was recorded under 60 kg K/ha. The application of 60 kg K/ha registered 54, 44 and 46 % increase in K uptake in grain, straw and total uptake, respectively over control. The increased K uptake by wheat due to K fertilization might be due to combined effect of increased dry matter yield and higher K concentration in grain and straw (Abedin *et al*. 1998). The better nutritional environment helped the plant to absorb more K from soil consequently leading to higher photosynthates and their translocation to different plant parts would have enhanced the K content in both seed and straw. Similar results were observed in wheat by Yadav *et al*. (2012).

Similary, the highest Zn uptake in wheat grain (81.2 g/ha), straw (90.6 g/ha) and total uptake (171.8 g/ha) was recorded under 9 kg Zn/ha and it registered 54, 48 and 51% increase in Zn uptake in grain, straw and total uptake, respectively over control. The beneficial role of Zn in increasing CEC of roots helped in increasing absorption of nutrients from the soil. Further, the favourable effect of Zn on photosynthesis and metabolic process augmented the production of photosynthates and their translocation to different plant parts including seed which ultimately increased the Zn concentration in seed and straw. Similar results were also reported in wheat by Jain (2004).

Soil K fractions

The interaction between K and Zn fertilizer application was not found to be significant in any respect of any form of K; hence only individual effects of these inputs on different K fractions are given in Table 2. In general, the total K content in soil ranged from 0.17 to 0.19%. The content of total K increased significantly with increase in K application rate up to 40 kg K/ha. Among all the forms of K, water soluble K was the least dominant form, indicating almost negligible contribution to the total K of soil. The water soluble K content in soil varied from 3.71-4.28 mg/kg and 3.95-4.07 mg/kg with different levels of K and Zn, respectively. The low concentration of water soluble K might be attributed to the fact that the K in the soil solution is more easily utilized by the crop (Sparks 1980). Due to application of higher amount of K, the highest water soluble K (4.28 mg/kg) was recorded under 60 kg K/ha. Water soluble and exchangeable K are considered to be readily available to plants and these forms of K are in equilibrium with the non-exchangeable and mineral K. When the solution and exchangeable K are depleted by plant removal or leaching the former are replenished by non-exchangeable

Table 2 Effect of K and Zn fertilization on K transformation in soil (pooled data of two years)

Treatment	Total K (%)	Water soluble K	Ex-change-able K	Morgan's extract-able K	Lattice K
		mg/kg soil			
K levels (kg/ha)					
K_0	0.17	3.71	48.5	87.8	478.4
K_{20}	0.18	3.97	53.4	92.8	519.2
K_{40}	0.19	4.14	56.7	96.6	547.6
K_{60}	0.19	4.28	59.3	99.7	565.7
SEm±	0.002	0.045	0.65	1.09	5.98
CD (*P*=0.05)	0.01	0.13	1.8	3.1	17.0
Zn levels (kg/ha)					
Zn_0	0.18	3.95	53.5	92.7	517.4
Zn_3	0.18	4.01	54.4	94.1	526.4
Zn_6	0.19	4.05	54.8	94.9	532.4
Zn_9	0.19	4.07	55.0	95.3	534.7
SEm±	0.002	0.045	0.65	1.09	5.98
CD (*P*=0.05)	NS	NS	NS	NS	NS
CV (%)	4.3	4.5	4.8	4.6	4.5

K. Some non-exchangeable K held in the inter layers of expandable 2:1 type clay minerals such as illite and vermiculite can be released easily to provide a substantial portion of the K removed by the crop. The exchangeable K varied from 48.5 to 59.3 mg/kg and 60 kg K/ha recorded the maximum exchangeable K (59.3 mg/kg) followed by 40 K/ha (56.7 mg/kg) and 20 kg K/ha (53.4 mg/kg). This variation in exchangeable K content among different K levels is due to variation in labile pool of K. Maximum Morgan's extractable K (99.7 mg/kg) was also recorded in 60 kg K/ha, while the minimum (87.8 mg/kg) was in control. The content of lattice K with different K levels varied from 478.4 -565.7 mg/kg and the contribution of this form to total K was maximum compared to other fractions. This showed that with passage of time, a part of water-soluble and exchangeable K was converted to non-exchangeable forms, besides their utilization by growing plants. However, increase in Zn levels had no significant effect on total K and any K fraction over control.

Interdependence among various K fractions and relationship with yield and K uptake

The values of various K fractions were correlated to identify their interdependence (Table 3). Total K had positive and significant correlation with all the fractions of K. Water-soluble K showed significant and positive correlation with exchangeable K (r= 0.928), Morgan's extractable K (r= 0.983) and lattice K (r= 0.969), indicating rapid equilibrium establishment between various forms.

Data (Table 4) reveals that water-soluble K had highest significant relationship with grain yield (r = 0.747), K uptake by grain (r = 0.773) whereas the lattice K showed highest significant relationship with straw yield (r = 0.749), K uptake by straw (r = 0.773). Thus, crop yield and K uptake were significantly influenced by the K fractions however, water soluble K and lattice K were the dominant K fractions contributing K nutrition to wheat.

Contribution of various K fractions to the grain yield and total (grain+straw) K uptake of wheat through step down regressions (Table 5) indicated that water-soluble K was the most important fraction contributing to K nutrition of wheat, because it yielded the highest and most significant

Table 3 Simple correlation coefficients (r) among various fractions of soil K

Variables	Total K	Water soluble K	Ex-change-able K	Morgan's extract-able K	Lattice K
Total K	1.00	0.882**	0.825**	0.865**	0.924**
Water soluble K		1.00	0.928**	0.969**	0.983**
Exchangeable K			1.00	0.909**	0.933**
Morgan's extractable K				1.00	0.953**

** Significant at 1% probability level

Table 4 Simple correlation coefficient (r) between different soil K fractions and yield and K uptake by wheat

Soil K fractions	Grain yield	Straw yield	K uptake grain	K uptake straw
Total K	0.698**	0.707**	0.715**	0.722**
Water soluble K	0.747**	0.719**	0.773**	0.747**
Exchangeable K	0.683**	0.675**	0.736**	0.717**
Morgan's extract-able K	0.714**	0.688**	0.749**	0.716**
Lattice K	0.743**	0.749**	0.771**	0.773**

** Significant at 1% probability level

Table 5 Step wise regression data for the relationship between plant growth parameters 'Y' and soil K fractions

Step No.	Variable on which 'Y' is regressed	R^2
Wheat grain yield		
1.	Exchangeable K, water soluble K, Morgan's extractable K and lattice K	0.580**
2.	Water soluble K, Morgan's extractable K and lattice K	0.576**
3.	Water soluble K, Morgan's extractable K	0.570**
4.	Water soluble K	0.558**
K-uptake by wheat		
1.	Exchangeable K, water soluble K, Morgan's extractable K and lattice K	0.630**
2.	Water soluble K, Morgan's extractable K and lattice K	0.630**
3.	Morgan's extractable K and lattice K	0.627**
4.	Lattice K	0.625**

** Significant at 1% probability level

correlation with crop yield. From the K nutrition point of view, another important K fraction was lattice K. The R^2 value indicates that about 62% of the total variation in total K uptake by wheat was contributed by lattice K alone. The availability of soil K to the plant may be a function of the soluble and amounts of all or of certain forms of K present in soil. In the present study, in comparison to other fractions of soil, water-soluble K and lattice K was observed to be very efficient in providing K nutrition to wheat, which may explain as to why these two K fractions had higher coefficient of correlation with yield and K uptake. The higher coefficient of correlation between water-soluble K and yield; lattice K and K uptake is understandable as K is absorbed by plant roots only in water-soluble K form and easy replenishment of available form of K, upon depletion from lattice K, indicating its prominent contribution to available K pool.

Soil Zn fractions

Data of Zn fractions analysis indicate that K levels did not influence significantly the proportion of Zn fraction, however, different Zn fractions, except, Occ-Zn were significantly influenced by different Zn levels (Table 6). With increase in Zn application the amount of the total Zn in the soil was increased significantly and it was ranged from 66.7 to 76.9 mg/kg. Due to higher application of Zn fertilizer Zn @ 9 kg/ ha recorded highest total Zn content (76.9 mg/kg) in soils. In addition to this, possibly higher solubility, diffusion and mobility of the applied inorganic Zn fertilizer might be the reason leading to increased Zn status of soil.

Residual Zn was the most dominant fraction, followed by organically bound Zn, occluded Zn, adsorbed Zn, DTPA Zn while water soluble plus exchangeable Zn was the least dominant fraction. The increased residual Zn in the Zn applied soils was due to the conversion of some amount of labile Zn into non-labile forms. This fraction is mainly associated with minerals. Deb (1997) reported that under upland condition, bulk of the fertilizer Zn accumulates in Occ-Zn and Res-Zn fractions and accumulation in water soluble and exchangeable fractions is found negligible. Similar results were also obtained by Singh *et al*. (1999). The lowest content of residual Zn was recorded under control treatment (26.9 mg/kg) because cropping without addition of Zn caused removal of Zn through uptake by crop.

The organically bound Zn fraction has been found to be lower than residual form but higher than water soluble plus exchangeable and Occ-Zn in soil. There was a significant difference between the Zn levels with respect to organically bound Zn fraction. The application of Zn @ 9 kg/ha recorded highest organically bound Zn fraction in the soil (26.4 mg/kg). This might be because of higher plant biomass production and root development in soil.

The effect of application of Zn on occluded Zn content in soils was found to be non-significant, but the increasing trend was observed due to increasing levels of Zn fertilization. Adsorbed Zn was found significantly enhanced with Zn application over no application. The maximum content of adsorbed Zn was recorded at 9 kg Zn/ha and it got depleted in treatments not receiving Zn application. Depletion of adsorbed Zn might be due to continuous uptake of Zn by crops without supplementation through external sources.

Table 6 Effect of K and Zn fertilization on transformation of Zn in soil

Treatment	Total Zn	WSEX-Zn	DTPA-Zn	Ads Zn	OC-Zn	OCC-Zn	Res-Zn
	mg/kg soil						
K levels (kg/ha)							
K_0	71.2	0.246	0.426	4.50	24.1	13.6	28.8
K_{20}	72.2	0.251	0.434	4.58	24.5	13.7	29.2
K_{40}	72.9	0.254	0.438	4.63	24.8	13.8	29.4
K_{60}	73.3	0.255	0.441	4.66	24.9	13.8	29.6
SEm±	0.78	0.0027	0.0052	0.054	0.29	0.16	0.34
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS	NS
Zn levels (kg/ha)							
Zn_0	66.7	0.187	0.345	3.94	22.2	13.5	26.9
Zn_3	71.3	0.241	0.427	4.49	24.1	13.7	28.7
Zn_6	74.7	0.274	0.470	4.88	25.6	13.8	30.1
Zn_9	77.0	0.301	0.495	5.04	26.4	13.9	31.3
SEm±	0.78	0.0027	0.0052	0.054	0.29	0.16	0.34
CD (*P*=0.05)	2.2	0.008	0.015	0.15	0.8	NS	1.0
CV (%)	4.3	4.2	4.8	4.7	4.8	4.6	4.7

Water soluble plus exchangeable (WSEX-); adsorbed Zn (Ads Zn); zinc associated with organic matter (OC-Zn); occluded Zn and Zn bound by carbonates and other acid soluble minerals (Occ-Zn); residual Zn (Res-Zn)

Table 7 Correlation coefficients (r) among various fractions of soil Zn

Zn fractions	Total Zn	WSEX—Zn	DTPA-Zn	Ads-Zn	Occ-Zn	OC-Zn	Res-Zn
Total Zn	1.00	0.941**	0.955**	0.957**	0.866**	0.999**	0.992**
WSEX—Zn		1.00	0.987**	0.977**	0.806**	0.946**	0.907**
DTPA-Zn			1.00	0.985**	0.829**	0.961**	0.922**
Ads-Zn				1.00	0.846**	0.965**	0.917**
Occ- Zn					1.00	0.860**	0.831**
OC- Zn						1.00	0.988**

** Significant at 1% probability level

Table 8 Step wise regression data for the relationship between plant growth parameters 'Y' and soil Zn fractions

Step No.	Variable on which 'Y' is regressed	R^2
Wheat grain yield		
1.	WSEX- -Zn, Ads-Zn, Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.841**
2.	Ads-Zn, Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.828**
3.	Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.826**
4.	OC-Zn, Res-Zn, DTPA-Zn	0.783**
5.	Res-Zn, DTPA-Zn	0.775**
6.	DTPA-Zn	0.652**
Zn-uptake by wheat		
1.	WSEX- -Zn, Ads-Zn, Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.844**
2.	Ads-Zn, Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.834**
3.	Occ-Zn, OC-Zn, Res-Zn, DTPA-Zn	0.832**
4.	OC-Zn, Res-Zn, DTPA-Zn	0.799**
5.	Res-Zn, DTPA-Zn	0.784**
6.	DTPA-Zn	0.702**

** Significant at 1% probability level

Interdependence among Zn fractions and relationship with grain yield and total Zn uptake by wheat

The values of various Zn fractions were correlated and found that total Zn had positive and significant correlation with all the Zn fractions (Table 7), suggesting the existence of dynamic equilibrium among the different forms of Zn. Similar results had also been reported earlier by Singh (2004) and Choudhary and Raina (2008). From the values of coefficients of correlation, it is quite evident that almost all the Zn fractions are dependent upon each other. A positive correlation of WSEX-Zn of soil with Ads-Zn (r = 0.977**), Occ-Zn (r = 0.806**), Oc-Zn (r = 0.946**), Res-Zn (r =0.907**), DTPA-Zn (r = 0.987**) and total-Zn (r = 0.941**) indicates the influence of these fractions on availability of soil Zn to plants as also reported by Jakhar (2006). The Ads-Zn was found to be positively correlated with Occ-Zn (r = 0.846**), Oc-Zn (r = 0.965**), Res-Zn (r =0.917**), DTPA-Zn (r = 0.985**) and total-Zn (r = 0.957**). These findings are in line with those of Singh (2004). Occ-Zn was found to be positively correlated with Oc-Zn (r = 0.860**), Res-Zn (r =0.831**), DTPA -Zn (r = 0.829**) and Total-Zn (r = 0.866**). Oc-Zn was found to be positively correlated with Res-Zn (r =0.988**), DTPA-Zn (r = 0.961**) and total-Zn (r = 0.999**). Similar observations were made by Sarkar and Deb (1982). Res-Zn was found to be positively correlated with DTPA-Zn (r = 0.922**) and total-Zn (r = 0.992**). DTPA-Zn was found to be positively correlated with total-Zn (r = 0.955**).

To assess the relative contribution of various Zn fractions to grain yield and total Zn uptake by wheat, stepwise regression equations were computed (Table 8). Perusal of data indicates that DTPA-Zn was the most important Zn fraction contributing to Zn nutrition of wheat. In the present study, DTPA-Zn accounted for 65% and 70% of the variation in grain yield and Zn uptake by wheat, respectively. Whereas, the inclusion of other fractions of Zn did not affect the regression significantly, indicating that DTPA-Zn had significant role in Zn nutrition of wheat.

The result of the study indicated that in coarse textured soil medium in K and deficient in Zn, application of K and Zn is required to maintain optimum crop yields with concomitant increase in their uptake in wheat crop. Step wise regression analysis revealed the importance of water soluble K and lattice K influencing crop yield, and uptake of K by wheat. Correlation data indicated that different fractions of soil Zn are in dynamic equilibrium with each other and DTPA-Zn fraction accounted for most variations in Zn nutrition of wheat. Better yield and nutrient uptake response of wheat at higher levels of fertilization confirmed the need for proper nutrient management in arid and semi arid regions.

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