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The effect of zinc and boron interaction on residual available phosphorous and zinc in the soil after corn harvest

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Abstract

For the purpose of studying the effect of Zn and B on the residual available P and Zn in the soil after corn harvest, a field trial was conducted in 2004 at Fars Neyriz region of Iran. Treatments including five levels of Zn (0, 15, 30 and 45 kg ha^{-1} and Zn foliar spray) and four levels of B (0, 4 and 8 kg ha^{-1} and B foliar spray) in a completely randomized block design. A corn variety Single Cross 401 was the test crop. In most treatments, the residual P in the soil increased compared to its initial level (before culture). The application of the Zn spray recorded the highest residual Zn and lowest P relative to other treatments except control; and the control treatment yielded the lowest amount of residual Zn and highest P. At B control, the amount of residual available P in the soil was lower than other B levels. Boron application had no effect on the residual available Zn in the soil relative to the non B level. At Zn control, B application increased available P remaining in the soil relative to no B use, but at other Zn levels, it had no effect on the soil's P content. Therefore, the presence of Zn prevented from increase of the available P remaining in the soil by B use. Zinc application to the soil, though a less amount of Zn was absorbed by the plant but the Zn used remained and was used by the plant for later cultures. Also, the P fertilizer is fixed in the soil and will be used by the next plants. .

Key words: Interaction, Zinc, Boron, Phosphorous, Soil, Corn

Introduction

The mean amount of Zn in the lithosphere is about 80 and that in the soil is about 10 to 300 mg kg^{-1} (Mengel and Kirkby, 1987; Karimian and Ghanbari, 1990; Cuihong *et al*, 1997). In spite of the fact that the total soil Zn content is relatively high, but a small fraction of it is available to the plant (Mandal *et al*., 1992). Zinc is present in the structure of the cell wall (in the pectinase component). Therefore, in its deficit, the P transfer from the superficial root cells to xylem are not controlled and the P level in airborne parts of plants increases (Christensen and Jackson, 1981; Loneragan *et al*., 1982; Marschner, 1995). The Zn- P antagonism has been reported by many authors (Singh *et al*., 1988; Tisdale *et al*., 1993; Morghan, 1994; Marschner, 1995). In the soil, Zn and P can form less soluble and resistant compounds that reduce the amount of Zn available to the plant (Tisdale *et al*., 1993). In fact, P intensifies Zn uptake in the soil relative to oxides and hydroxides of iron, aluminum and calcium carbonate (Loneragan *et al*., 1982). This can be due to surplus negative charges or formation of complex forming sites by PO_4^{-3} uptake at the oxide surfaces. By adding Zn to the soil, insoluble forms of Zn increase and if super phosphate and animal manure are added to the soil, the amount of exchange Zn is reduced (Cuihong *et al*., 1997). Tisdale *et al*. (1993) stated that in soils in which Zn deficiency is probable, excessive use of phosphate fertilizers leads into P toxicity in the plant. Singh el al. (1988) suggest that for overcoming the nutrition challenge caused by using phosphate fertilizer, Zn containing fertilizers must be added to the soil. Moreover, there are many reports given by authors on the P- Zn synergism in plants (Fornasieri *et al*., 1994; Gupta and Vyas, 1994). Zinc deficiency lowers plant growth and thereby an increase in P content without any increase in its total absorption (Marschner, 1995, Singh *et al*., 1988). Morgan and Mascagni (1991) suggest that there is a phosphors- B synergism such that a high P level can accumulate B in the plants and even increase the B to toxic levels.

Darajeh *et al*. (1991) suggest that though the total amount of Zn in most crop soils is at a level that it can meet the plant needs for many years, but the climatic factors and soil conditions affect the availability of this element in such a way that only a small fraction of it is available in each farming season. Mullins *et al*. (1982), by studying the effect of zinc sulfate on Zn forms in a silty clay soil with a pH of 6.7, reported that the use of 290.4 kg ha^{-1} Zn in the form of zinc sulfate during 15 years in corn culture did not increase soluble and exchangeable forms in the soil and the total amount of these forms was less than 0.1 mg kg^{-1}. Yasrebi *et al*. (1994), by analyzing the effect of the residual Zn on soils downstream of Fars Doroudzan dam of Iran, reported that 58-60 percent of the Zn used in the soil turns into carbonate form.

The critical level of Zn in the soil in mg kg^{-1} by DTPA extraction, has been reported by Darajeh *et al*. (1991) for corn to be 0.8, by Agrawala (1992), 0.8, Sharma and Lal (1993), 0.6, Terhan and Gerval (1995), 0.75. Lindsay and

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Norwell (1978), using DTPA extraction introduced critical limits of the soil Zn content as low if less than 0.5 mg kg^{-1}, medium if between 0.5 to 1 mg kg^{-1} and sufficient if more than 1 mg kg^{-1}. Kabata-Pendias and Pendias (1984), reported the normal Zn level based on studies made at different points of the world as 4-270 microgram per liter depending on the type of soil and the methods used for extraction. The critical limit of soil P content is specified as 18 mg kg^{-1} by Karimian and Ghanbari (1990).

By measuring the residual nutrients in the soil after harvesting the crop, we can use many desired relations for better management in the culture. If the amount of the residual available element in the soil is at a high level, this represents less uptake by the plant or less fixation by soil particles and if it is at a low level, this represents more uptake by the plant or more fixation by soil particles. Of course, in addition to uptake and fixation, other factors such as uptake of elements from unavailable form to available form or vis versa as well contribute to the amount of residual available element in the soil. Zinc and B deficiency play an effective role in patchiness of the ear. Therefore, the objective of the study was examination of the effect of Zn and B on the residual available P and Zn in the soil after harvesting corn so that we are able to plan for Zn and B use in the next cultures.

Materials and Methods

A field experiment was conducted at the farm of Sange Sefid, Jahan Abad village, in Neyriz, Fars province of Iran, on the corn (*Zea mays* L.), cultivar "Single Cross 401" during 2005 cropping season. Neyriz is located on latitude 29°12'N and longitude 54°19'E and 1600m altitude. The soil at the experimental site is a loam (Calciargids). This experiment included 20 treatments and 3 replications in the form of completely randomized block design and factorial that combinations of five levels Zn (0, 15, 30 and 45 kg ha^{-1} Zn, and Zn foliar spray) and four levels of B (0, 4, and 8 kg ha^{-1} and B, and B foliar spray). Nitrogen: P: K used @ 400, 160 and 160 kg ha^{-1} according to the recommendation, from sources of urea, triple super phosphate and potassium sulfate, respectively, were added to all treatments (plots). Moreover, 50% of the urea was used when planting and the remainder two times: At vegetative growth (35 days after planting) and when the corn ears were formed. Potassium and P used before planting. Zinc and B, from zinc sulfate and boric acid sources, respectively, were used by two methods, adding to the soil and spraying. Addition to the soil was made at the time of plantation and the sprayings were made at 5 per thousand (0.5%) Zn sulfate and 3 per thousand (0.3%) B two times: one at vegetative growth stage and the other after corn ears formation. The Zn and B were both applied to the leaves with uniform coverage at a volume solution of 2500 L ha^{-1} using a knapsack sprayer. Each experimental plot was 8m length and 3m width, had 5 beds and 4 rows, equally spaced, and seeds 20cm apart on the rows. At the end of the growth stage (4.5 months after planting) the grain yield, dry matter and the residual available phosphorus and Zn in the soil after corn harvest were measured .

Analysis of the leaf, the grain and the soil was carried out using common lab procedures (Soil and Plant Analysis Council, 2004). Phosphorous was measured by Olsen method, available potassium by Ammonium Acetate extraction method and potassium assessment in the extract by flame photometer, organic carbon by the Walkley and Black method. Available Fe, Zn, Mn and Cu in the soil were first extracted by DTPA and then were read by atomic absorption (Shimatzu Model AA-670). The soil's available B was extracted by hot water and then was measured by spectrophotometer by curcamin method, considering the intensity of the color produced. Digestion method by dry burning was used to measure Fe, Mn, Zn and Cu and then they were measured by atomic absorption setup. Statistical analysis of data was made using MSTATC and SAS software with Duncan test and regression equations via the SPSS program.

Results and Discussion

The results of soil analysis before culture are summarized in table 1. The phosphorous, potassium and Zn in the soil were below the critical level but B was at the medium to deficiency level. Manganese, Cu and Fe of the soil were at higher than the critical level. Karimian and Ghanbari (1990) reported the critical P level by Olsen method in calcareous soils to be 18 mg kg^{-1} and critical K level by Ammonium Acetate was 250 mg kg^{-1}. Sims and Johnson (1991), reported the critical limits of soil's Fe, Zn, Mn and Cu by the DTPA extraction method and B by the hot water method to be 2.5-5. 0.2-2, 1-5, 0.1-2.5 and 0.1-2 mg kg^{-1}, respectively. Agrawala (1992) reported the critical level of Fe, Zn, Mn and Cu in the soil by the DTPA extraction to 2.5, 0.8, 5.5 and 0.75 mg kg^{-1} soil, respectively.

The soil P content after harvest

The soil P content (mg kg^{-1}) before culture was 11.6 mg kg^{-1} and its value after harvesting is shown in table 2; an almost increase in all treatments, due to some residual P added to the soil in the form of a fertilizer. Also, it is possible that some amount of the total soil P content has been available to the plant after culture and operations on the soil.

The main effect of Zn on the soil P content after culturing was significant at 5% (Table 2). the maximum soil

P content after harvesting was 16.48 mg kg^{-1} at Zn control and had no significant difference from 30 and 45 kg ha^{-1} and Zn spraying levels. There was a negative relation between the leaf P content and the soil P content after harvesting. so that at Zn control, the minimum leaf P and Zn content was seen but with Zn application, the leaf P and Zn content increased. That is, there was a synergism between the P and the Zn and thereby, less P remained in the soil. The P-Zn synergism has been reported by different authors (Fornasieri *et al*., 1994; Gupta and Vyas, 1994). The minimum residual P in the soil (11.77 mg kg^{-1}) was seen at 15 kg ha^{-1} Zn; At this Zn level, the leaf P content was maximal and consequently, less P remained in the soil (Table 4). In addition to the effect of Zn on P uptake by the plant that indirectly affects the residual P in the soil, the Zn present in the soil forms insoluble or less soluble compounds with phosphorus and, consequently, the available P is reduced. At no Zn and Zn spray levels, since Zn was not applied to the soil, such less soluble compounds did not form in the soil and the P available in the soil increased; while at levels of Zn applied to the soil, due to formation of less soluble zinc phosphorous compounds, the available P in the soil decreased. Many authors have reported the formation of less soluble zinc phosphorous compounds (Tisdale *et al*., 1993). At the Zn spray level, the residual P in the soil (16.12 mg kg^{-1}) showed no significant difference from the Zn control (16.48 mg kg^{-1}). The highest and the lowest mean soil P content after harvesting, 16.48 and 11.77 mg kg^{-1} (28.58 percent reduction relative to Zn control), wore seen at Zn control and 15 kg ha^{-1} Zn level, respectively. Of course, the antagonism between phosphorus and Zn has been reported by many authors such that the excess soil Zn content prevents from P uptake by the plant and consequently increase in the residual P in the soil (Christensen and Jackson, 1981; Marschner, 1995). Zn deficiency can increase the plant P content up to toxicity (Christensen and Jackson, 1981; Loneragan *et al*., 1982; Marschner, 1995).

The effect of application of different levels of B on the soil P content after harvesting was significant at 5% level. There was an antagonism between the leaf P content and the soil P content after harvesting. B use reduced leaf P content (Table 4) and consequently, the soil P content after harvesting increased; so that the highest leaf P content was seen at B control and at the same level, the soil P content after harvesting was the least (12.27 mg kg^{-1}). In fact, an antagonism was there between B and P. Our results arte in confirmed from thefindings of Fornasieri, *et al*., 1994 and Gupta and Vyas, 1994. Boron application to a certain level (4 kg ha^{-1} B) reduced the leaf P content and consequently, increased the residual P in the soil and beyond that level, 8 kg ha^{-1} B had no significant effect on the leaf P content and the residual P in the soil relative to the 4 hg/ha B level. Application of 8 kg ha^{-1} and spraying B increased the soil P content after harvesting, from 12.27 at B control, to 15.39 and 16.12 mg kg^{-1}, respectively (25.42 and 11.38% increase relative to the B control, in that order), but no significant difference was seen between these two B levels. The 4 kg ha^{-1} B level, though increased the residual P in the soil relative to the non B level, but showed no significant difference from it. Boron spraying significantly reduced leaf P content relative to the B control and, consequently, the soil P content after harvesting increased relative the B control. B spraying has no significant effect on the leaf P content as well as the soil P content after harvesting relative to where B was applied to the soil.

The effect of Zn and B interaction on the soil P content after harvesting shows that the B use only at Zn control increased soil P content after harvesting relative to the no B use and at other Zn levels, it had no significant effect on the soil P content (Christensen and Jackson, 1981; Gupta and Vyas, 1994). At Zn control, the use of 4 kg ha^{-1} and spraying of B, increased the soil P content after harvesting from 11 to 18 and 19.33 mg kg^{-1}, respectively (63.63 and 75.72% Increase relative to no B use at this Zn level), but application of 8 kg ha^{-1} B had no significant effect.

Application of 15 kg ha^{-1} Zn at B spraying level, reduced the residual P in the soil from 19.33 to 9 mg kg^{-1} (53.44% reduction relative to no Zn use) while at other B levels, it had no significant effect on the residual P in the soil.

The minimum soil P content after harvesting, 9 mg kg^{-1}, was obtained by joint use of 15 kg ha^{-1} Zn and B spraying which showed a 18.8 percent reduction relative to the control with a 11 mg kg^{-1} soil P content, but that reduction was not significant. The sole B spraying made the highest increase in soil P content after harvesting (19.33 mg kg^{-1}), which showed a 75.72% increase relative to the control.

The soil Zn content after harvest

The Zn amount before harvesting was 0.28 mg kg^{-1} and increased after harvesting in all treatments (Table 3). The increase in Zn after harvesting was due to some residual fertilizer added to the soil as well as availability of a part of the total Zn in the form of available Zn by root secretions, weather and operations carried out on the soil. The variation in soil Zn content by the culture method, soil improvement and elapse of time has been reported by different authors (Sarkar and Deb, 1985; Steinhilber and Boswell, 1983).

The main B effect on the soil Zn content after harvesting was insignificant at 5% level; however, different Zn levels showed a significant effect on the soil Zn content. At no Zn and spraying Zn level where Zn fertilizers was not applied to the soil, the soil Zn content after harvesting (0.39

Table 1. The results of soil analysis

B	Cu	Zn	Mn	Fe	K	P	T.N.V (%)	Organic matter (%)	EC (ds m^{-1})	pH	Soil texture	Depth of soil (cm)
mg kg^{-1}												
0.81	0.5	0.28	7.76	1.8	234	11.6	31	0.62	2.33	8.1	Loam	0-30

and 0.84 mg kg^{-1}, respectively) was less than that of other levels. Taking note of the fact that the soil Zn content after harvesting at no Zn and Zn spraying levels where Zn was not applied to the soil, has been more than the initial soil Zn content, one can conclude that a part of the Zn added to the soil was due to availability of Zn to the total soil Zn content. At levels where Zn was applied to the soil, increase in soil Zn content, in addition to availability of total Zn, is also due to some residual Zn fertilizer added to the soil. Of course, availability of the total Zn may be affected by application of Zn fertilizer. In fact, not all the Zn fertilizer added to the soil was absorbed by the plant, that Zn will be available to the plant in the next cultures. Use of 30 and 45 kg ha^{-1} Zn significantly increased the soil Zn content after harvesting from 0.39 at Zn control, to 5.44 and 5.83 mg kg^{-1}, respectively (1294 and 1394% increase in that order), but there was no significant difference between these two levels. Application of 15 kg ha^{-1} Zn, at a 3.14 mg kg^{-1} soil Zn content, showed a 70% increase relative to Zn control, which was insignificant. The lowest and the highest mean soil Zn content after harvesting, were seen at no Zn and 45 kg ha^{-1} Zn levels, respectively.

Table 2. The effect of Zn and B on residual available P in the soil after corn harvest (mg kg^{-1})*

B (kg ha^{-1})	Zn (kg ha^{-1}) 0	15	30	45	Foliar Spray	Mean
0	11	10.93	11.67	14.13	13.6	12.27
	BC	BC	BC	ABC	ABC	B
4	18	12.6	13.07	13.6	15.8	14.61
	A	ABC	ABC	ABC	ABC	AB
8	17.6	14.53	15.13	13.87	15.8	15.39
	AB	ABC	ABC	ABC	ABC	A
Foliar Spray	19.33	9	15.07	17.93	19.27	16.12
	A	C	ABC	AB	A	A
Mean	16.48	11.77	13.73	14.88	16.12	
	A	B	AB	AB	A	

CV = 15.23

*Means with same letters lack a significant difference at 5% level by Duncan's test

Boron application; 8 kg ha^{-1} B at 30 and 45 kg ha^{-1} Zn levels, lowered the soil Zn content after harvesting, from 7.66 to 3.81 mg kg^{-1} (50.26% reduction) and from 6.91 to 2.38 mg kg^{-1} (65.56% reduction), while other B levels had no significant effect. At other Zn levels, B use had no significant effect on the residual B level in the soil.

Zinc application at 0, 4 kg ha^{-1} B (low B levels) and B foliar spray, significantly increased the soil Zn content after harvest while at high B level (8 kg ha^{-1} B), it had no significant effect. The use of 30 and 45 kg ha^{-1} Zn at B control, increased the soil Zn content after harvesting from 0.42 to 7.66 and 6.91 mg kg^{-1}, respectively (1724 and 1545% increase, in that order). At B spraying level, application of 30 and 45 kg ha^{-1} Zn increased the Zn in the soil after harvesting from 0.41 to 4.35 and 8.29 mg kg^{-1} (961 and 1922% increase relative to no Zn use). Also at the 4 kg ha^{-1} B level, the use of 30 and 45 kg ha^{-1} Zn, increased the soil Zn content after harvesting from 0.33 to 5.92 and 5.72

Table 4. The effect of Zn and B on P concentration in the leaf

B (kg ha^{-1})	Zn (kg ha^{-1})					
	0	**15**	**30**	**45**	**Foliar Spray**	**Mean**
0	0.22	0.26	0.24	0.23	0.24	0.24
	BCDEF	A	AB	BCD	ABC	A
4	0.22	0.22	0.23	0.23	0.22	0.22
	CDEFG	BCDEF	BCDE	BCDEF	BCDEF	B
8	0.20	0.22	0.22	0.21	0.23	0.22
	G	BCDEF	BCDEF	FG	BCDE	B
Foliar Spray	0.21	0.22	0.23	0.23	0.21	0.22
	EFG	BCDEF	BCDE	BCDEF	DEFG	B
Mean	0.21	0.23	0.23	0.22	0.23	
	B	A	A	A	A	

CV= 5.25

*Means with same letters lack a significant difference at 5% level by Duncan's test

mg kg^{-1}, respectively (1694 and 1633 percent increase relative to no Zn use).

Treatments with 0, 15 kg ha^{-1} and spraying Zn spraying levels showed no significant effect on the soil Zn content after harvesting relative to the control. But treatments with high Zn levels, 30 and 45 kg ha^{-1} Zn, had a significant difference relative to the control. The highest soil Zn content after harvesting (8.29 mg kg^{-1}) was obtained by joint application of 45 kg ha^{-1} Zn and B spraying, showing 1874% increase relative to the control treatment with soil Zn content of 0.42 mg kg^{-1}. The minimum soil Zn content after harvesting (0.33 mg kg^{-1}) showed no significant difference relative to the control.

Sims (1986) applied zinc sulfate fertilizer to the soil and observed an increase in the soil's exchangeable Zn. Yasrebi *et al*. (1994), after studying the effect of the residual zinc sulfate in the soil reported that 58 to 60 percent of the Zn applied to the soil turns into carbonate form and attributed the main effect of the residual zinc sulfate to the carbonate form of Zn. There are many studies made on the effect of Zn containing fertilizers on the amount and forms of the residual Zn in the soil (Mullins *et al*., 1982; Sarkar and Deb, 1985; Sims, 1986; Liang *et al*., 1991).

The correlation between the soil P and Zn content after harvesting and other variables

The correlation coefficients (R) between different variables by the Pearson method and the relevant equations were obtained by the step by step method using the SPSS software. One can use each of the following equations depending on what are the variables measured and R and R^2, but the last equation derived, is the most complete equation containing dependent and independent variables and we must measure more variables to derive that equation. The symbols * and ** in equations and correlation coefficients (R or R^2), are significance at 5% $(\alpha = 0.05)$ and 1% $(\alpha = 0.01)$ levels.

The soil P content after harvesting

The soil P content after harvesting was positively related with soil Fe content after harvesting (R=0.5*) and Cu (R=0.43), the leaf Fe content (R=0.42), the grain nitrogen content (R=0.4), the percentage of grain in the ear (R=0.49*), the grain protein content (R=0.4) and dry matter (0.4); and negatively related with the leaf nitrogen content (R=-0.48*), P (R=-0.52*), Mn (R=-0.56**) and Cu (R=-0.49*) and the grain P content (R=-0.47*). The relevant equations were.

l) PS = 24.931 - 0.775MnL $R = 0.564^{**}$
2) PS = 43.545 - 0.076MnL - 56.656PG $R^2 = 0.525^{**}$
3) PS = 71.183 - 0.0662MnL - 67.516PG - 11.083NL $R^2 = 0.736^{**}$
4) PS = 68.239 - 0.0504MnL - 83.109PG - 11.746NL + 0.0503NUG $R^2 = 0.827^{**}$

PS, MnL, PG, NL, and NUG denote the soil P content after harvesting (mg kg^{-1}), the leaf Mn content (mg kg^{-1}), the grain P content (%), the leaf nitrogen content (%) and the grain's nitrogen uptake (kg ha^{-1}).

The soil Zn content after harvesting

The soil Zn content after harvesting was positively related with the leaf nitrogen content (R=0.34), and P (R=0.36); the uptake of P (R=0.34), Zn (R=0.4) and Cu (R=0.32) by the grain; ear weight (R=0.51*), grain weigh in ear (R=0.52*); grain yield (R=0.4); number of grain across the length diameter (R=0.47*) and the number of grain across the ear diameter (R=0.42); and negatively correlated with the leaf Fe content ($R=-57^{**}$) and B content ($R=-0.35$). The equations were:

1) $ZnS = 19.633 - 0.146FeL$ $R = 0.573^{**}$
2) $ZnS = 5.003 - 0.132FeL + 0.608GW$ $R^2 = 0.53^{**}$
3) $ZnS = -12.625 - 0.0928FeL + 0.0881GW + 0.054MnL$ $R^2 = 0.649^{**}$

ZnS, FeL, GW, and MnL denote the soil Zn content after harvesting (mg kg^{-1}), the leaf Fe content (mg kg^{-1}), the grain weight in the ear(g) and the leaf Mn content (mg kg^{-1}).

Conclusion

Both P and Zn increased after harvesting as compared with their levels before culture, which are used in the next cultures. Zinc application led into reduction in the residual available P and increase in the residual available Zn in the soil; thus, when Zn fertilizer is added to the soil, in the next cultures, one should add more P and less Zn to the soil. Mere B application increases the P level while joint use of B and Zn decrease the residual available P and Zn in the soil. Therefore, if mere B fertilizer is added to the soil, in the next cultures we should add less P to the soil but if B fertilizer is added in the presence of Zn, one should add more P and Zn fertilizers in the next cultures.

References

Agrawala, H.P. 1992. Assessing the micronutrient requirement of winter wheat. *Communication in Soil Science and Plant Analysis* 23: 2555-2568

Christensen, N.W. and T.L. Jackson. 1981. Potential for phosphorus toxicity in zinc-stressed corn and potato. *Soil Science Society of America Journal* 45: 904-909.

Cuihong, W., Y. Zhenhua and J. Jiarong. 1997. Studies on the distribution of zinc fractionation in several arable red soils of Hunan province. *The Journal of Hunan Agricultural University* 23(4): 320-325.

Darajeh, Z., N. Karimian, M. Maftoun, A. Abtahi and K. Razmi. 1991. Correlation of five Zn extractants with plant responses on highly calcareous soils of Doroodzan Dam area Iran. *Iran Agricultural Research* 10: 29-45.

Fornasieri, F.O., E.L. Coutinbo, V.M. Vieira and L.B. Lemos. 1994. Response of popcorn *(Zea mays L.)* to phosphorus and zinc fertilizer. *Jaboticabal* 22: 205-215 [Field crop Abstract 22: 4574(1996)].

Gupta, P.K. and K.K. Vyas. 1994. Effect of phosphorus, zinc and molybdenum on the yield and quality of soybean. *Legume Research* 17: 5-7.

Kabata-pendias, A. and H. Pendias. 1984. Trace element in soils and plant. CRC press, Boca Raton, Florida.

Karimian, N. and A. Ghanbari. 1990. Evaluation of different extractants for prediction of plant response to applied P fertilizer in highly calcareous soils. Abstract 10th World Fertilizer Congress. CIEC, Nicosia, Cyprus. p. 25.

Liang, J., R.E. Karamanos and J.W.B. Stewart. 1991. Plant availability of Zn fractions in Saskatchewan soils. *Canadian Journal of Soil Science* 71: 507-517.

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* 42: 421-428.

Loneragan, J.F., D.L. Grunes, R.M. Welch, E.A. Aduayi, A. Teugah, V.A. Lazar and E.E. Cary. 1982. Phosphorus accumulation and toxicity in leaves in relation to zinc supply. *Soil Science Society of America Journal* 46: 345-352.

Mandal, L.N., D. Dutta and B. Mandal. 1992. Availability of zinc in submerged soil and zinc nutrition of rice. *Journal of the Indian Society of Soil Science* 40: 119-124.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. Academic Press. London. p. 301-306.

Mengel, K. and E.A. Kirkby. 1987. Principles of Plant Nutrition. 4th International Potash Institute, Bern, Switzerland. p. 525-535.

Morghan, J.T. 1994. Accumulation of zinc, phosphorus and magnesium by navy bean seed. *Journal of Plant Nutrition* 17: 1111-1125.

Mullins, G.L., D.C. Martens, S.W. Gettier and W.P. Miller. 1982. Form and availability of copper and zinc in a rhodic paleudult following long-term $CaSO_4$ and Zn application. *Journal of Environmental Quality* 11: 316-320.

Sarkar, A.K. and D.L. Deb. 1985. Fate of fertilizer zinc in a black soil (Vertisol). *The Journal of Agricultural Science*, *Cambridge* 104: 249-251.

Sharma, S.K. and F. Lal. 1993. Estimation of critical limit of DTPA zinc for wheat in pellusterts of southern Rajasthan. *Journal of the Indian Society of Soil Science* 41: 197-198

Sims, J.T. 1986. Soil pH effects on the distribution and plant availability of manganese, copper, and zinc. *Soil Science Society of America Journal* 50: 367-373.

Sims, J.T. and O.V. Johnson. 1991. Micronutrient soil test. P. 427-472. In: Micronutrient in Agriculture. J.J.

Mortvedt, F.R. Cox, L.M. Shuman and R.M. Welch (eds.). Soil Science Society of America. Madison, WI.

Singh, J.P., R.E. Karamanos and J.W.B. Stewart. 1988. The mechanism of phosphorus - induced zinc deficiency in bean *(Phaseolus vulgaris L.)*. *Canadian Journal of Soil Science* 68: 345-358.

Soil and plant analysis Council. 2004. Soil Analysis, Hand Book of Reference Methods, CRC press, USA

Steinhilber, P. and F.C. Boswell. 1983. Fractionation of Ni, Cu, Zn, Cd, and Pb in solid phases. *Soil Science Society of America Journal* 46: 260-264.

Tisdale, S.L., W.L. Nelson and J.B. Beaton. 1993. Soil Fertility and Fertilizers. 5th edn. Macmillan Publication Co, New York.

Yasrebi, J., N. Karimian, M. Maftoun, A. Abtahi and A.M. Sameni. 1994. Distribution of zinc forms in highly calcareous soils as influenced by soil physical and chemical properties and application of zinc sulfate. *Communication in Soil Science and Plant Analysis* 25: 2133-2145.