Effects of phosphorus and zinc fertilizers on their contents in soil, plant and grains of corn

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ABSTRACT

Experiments were conducted for two seasons 2000/01 and 2001/02 to study the effects of phosphorus and zinc fertilizers and their interactions on their soil extractable forms, their contents in corn (*Zea mays* L.) leaf tissue, and their grain uptake. The study was conducted on Remaitab soil series **(**fine, smectitic, isohyperthermic, typic Haplusterts) at the Gezira Research Station Farm, Agricultural Research Corporation, Wad Medani, Sudan. Phosphorus was applied as triple superphosphate at three rates (0, 43 and 86 kg P_2O_5 ha^{-1}). Zinc was added to the soil as zinc sulphate ($Zn SO_4.7H_2O$) at three rates (0, 5 and 10 kg Zn ha^{-1}). The experiments were arranged in a split-plot design with four replicates. The main plots were assigned to phosphorus rates and the sub plots were assigned to those of zinc. The treatments were completely randomized within each replicate. The results indicated that application of both nutrients significantly ($P \leq 0.05$) increased most of the parameters studied. Extractable soil Zn measured at 14 and at 70 days after sowing (DAS) and available soil P measured at 70 DAS were significantly reduced by the interaction of soil application of phosphorus and zinc fertilizers and both nutrients tended to reduce the concentration of each other in leaves especially when one of them was not added, and this was more pronounced in the cases of added P treatments on leaf tissue content of Zn. The results indicated that the major P-Zn interaction did not take place in the plant but in the soil where the availability of Zn was reduced by P and this was readily corrected by application of Zn. Application of both phosphorus rates in combination with zinc improved grain uptake of both nutrients, compare-ed to treatments receiving the same amounts of phosphorus but without zinc or treatments receiving no phosphorus with or without zinc applic-ation.

INTRODUCTION

Excessive levels of P in alkaline soils are known to cause nutritional disorders related to Zn and this interaction is not only a culture–solution and small pots phenomenon, but it is also a recognized field problem (Olsen, 1991). This disorder is commonly associated with high levels of soil available or applied P when the soil test levels of Zn are low to marginal (Longeragan *et al.*, 1979). On the other hand, Brown *et al*. (1970) using different rates of P and Zn on alkaline soils found that the P rates tended to increase the extractable Zn rather than decrease it. The effects of P treatment on plant response to Zn are numerous and complex involving a number of discrete phenomena which may operate separately or together depending on plant species and environmental conditions. These may be due to either P or Zn reactions in the soil (Loneragan *et al.*, 1979; Marschener, 1995) or within the plant tissues (Lu *et al.*, 1998).

Imbalance between P and Zn within plant cells interferes with the metabolic function of Zn at certain sites in the cells, with Zn concentra-tion *per se*/ is not the direct cause of the growth disorder (Olsen, 1991). Norvell *et al*. (1987) reported that major interactions of Zn and P occur at the level of plant metabolism and appear to involve the uptake, translocation and utilization of Zn. Zinc may play an important role in maintaining the integrity and selectivity of root membranes and that when Zn is too low, excessive quantities of other ions such as P may enter and disrupt normal plant metabolism (Loneragan *et al*., 1979).

It has been well documented that continuous cropping may cause removal of Zn where there is no application of zinc fertilizers. High application of phosphates in Gezira soil, which is calcareous and deficient in zinc (Dawelbeit *et al*., 1995), may increase the severity of the zinc deficiency problem. Although micronutrient studies are well verified all over the world, yet in the Sudan they are still limited. However, much of the earlier work neither did not study the effect of application of zinc, nor its interactions with phosphorus. So there is a lack of information about P-Zn interactions in Gezira soils, particularly with regard to the effect on the availability of these two elements as measured by soil and plant analyses. Therefore, the present work is undertaken to study the effect of added phosphorus and zinc and their interaction on their soil extractable forms, from Remaitab soil series. In addition, P and Zn uptake by corn (*Zea mays* L.) leaf tissue will be correlated to their respective soil extractable forms.

MATERIALS AND METHODS

The experiments were conducted during the cropping seasons of 2000/01 and 2001/02 at the Gezira Research Station Farm, Agricultural Research Corporation, Wad Medani, Sudan, latitude 14º 24/ N, longitude 33º 31/ E and altitude 411 masl. The climate of the study area is classified as arid. The soil of the site is Remaitab soil series, “fine, smectitic, isohyperthermic, Typic Haplusterts” (Soil Survey Staff, 1999). The Soil is invariably calcareous with an average $CaCO_3$ content of about 1.5%. The calcium carbonate concretions are sometimes impregnated with secondary iron and manganese oxides that may also affect the nutr-ients status, particularly with regard to its interaction with phosphorus. The pH (2:5 soil: H_2O) ranges from 8.0 to 9.0 .The available phosphorus was 2 μg Pg^{-1} soil. DTPA extractable Zn was 0.23 ppm (Table 1).

Seeds of corn (*Zea mays* L.) cultivar Mugtamaa 45(introduced from Egypt) were sown on mid July each season at a rate of two seeds per hole, thinned to one plant per hole after two weeks from germination. Irrigation was applied at intervals of 14 days as supplements for the rains during July, August and September. The spacing was 30 cm between holes and 80 cm between rows. Basal dose of nitrogen fertilizer was applied as urea at a rate of 86 kg N ha^{-1}. Hand weeding was done as required. The crop was manually harvested in mid November.

The experiments were arranged in a split-plot design with 9 treatments and four replicates .The main plots were assigned to phosphorus fertilizer applied as triple super phosphate as follows: No Phosphorus (0P), 43 kg P_2O_5 ha^{-1} (1P) and 86 kg P_2O_5 ha^{-1} (2P).The subplots were assigned to

Table 1. Some physical and chemical properties of the studied soil.

Depth (cm)	Particle size distribution (%)			Ca CO_3 (%)	O.C (%)	N (%)	Avail.P (mg kg^{-1} soil)	Tot. P (mg kg^{-1} soil)	DTPA Zn (mg kg^{-1} soil)
	Sand	Silt	Clay						
0–30	22	20	58	1.5	0.22	0.034	2.0	340	0.23

Table 1. (continued).

pH		ECe dSm^{-1}	ESP	CEC cmol kg^{-1} soil	Soluble cations and anions Meq l^{-1} in saturation extract					
Paste	1:5 H_2O				K	Na	Ca	Mg	Cl	HCO_3
8.3	9.1	0.50	8	48	0.60	3.6	2.4	1.5	2.3	1.4

zinc fertilizer applied as zinc sulphate (Zn $SO_4.7H_2O$) as follows: No Zinc (0Zn), 5 kg Zn ha^{-1} (1Zn) and10 kg Zn ha^{-1} (2Zn). Fertilizers were banded in the soil on opposite sides of the rows at sowing. Available soil phosphorus was determined by the Olsen *et al*. method (1954) 14 and 70 days after sowing (DAS) and the concentration of P was determined by Murphy and Riley method (1962). Available soil zinc was extracted by DTPA 14 and 70 DAS according to Lindsay and Norvell (1978) and Zn was determined using the atomic absorption spectrophotometer (AAS Perkins Elmer type 3110). The entire fully developed leaf at the ear node at silking stage was sampled as recommended by Jones *et al*. (1990) for determining the nutrient status of corn. Plant tissue samples were dried in a forced-air electric oven at $65C^0$ for 48 hours, and then finely ground, sieved and ashed. An aliquot of the solution was analyzed calorimetrically for P and another one for Zn by AAS. The same procedure was followed for determining the concentration of P and Zn in the grains.

Statistical analysis of data was done by using the standard analysis of variance (ANOVA) procedure. In the cases of significant F values, Duncan's Multiple Range Test (DMRT) at P = 0.05 was used to compare treatment means.

RESULTS AND DISCUSSION

Soil available P at 14 DAS increased significantly ($P\leq0.05$)with increase-ing level of applied P (Table 2). Thomas and Peaslee (1973) postulated that the addition of P raised the soil available P to a level which is sufficient to maintain available soil P levels needed for corn. This might be due to the banding method of application and the form of the granules of the added P fertilizer which may reduce phosphate reversion (Fuerhning, 1973). There was a slight reduction in available soil P associated with soil application of Zn. The measurements obtained for available P 70 DAS were lower than those obtained 14 DAS and negatively significantly ($P\leq0.05$) influenced by P and Zn interaction. The percent reduction of 0P, IP and 2P were 4.5, 14.5 and 25.2, respectively, for treatments receiving 1 Zn; and 3.0, 28.1 and 24.2 for treatments receiving 2 Zn, when comparing these treatment means to those receiving no Zn (Table 2). These findings were in conformity with those of Brady (1999) who considered that part of P and Zn interaction was found in the soil with more pronounced mechanism that most of the added P was adsorbed. Zinc may be linked to soil and/or root surfaces through adjacent phosphate molecules forming insoluble zinc phosphates (Sparr *et al.*, 1965).

Table 2. Effects of P and Zn and their interactions on available soil P (mg P kg $soil^{-1}$).

	0 Zn	1 Zn	2 Zn	Main P effect
		14 DAS		
0P	3.0^{e}	3.1^{e}	3.0^{e}	3.0^{c}
1P	7.0^{c}	6.5^{d}	6.7^{d}	6.7^{b}
2P	11.3^{a}	11.2^{a}	10.9^{b}	11.1^{a}
Main Zn effect	7.1^{a}	6.9^{a}	6.9^{a}	
CV (%)		11.07		
		70 DAS		
0P	3.1^{e}	3.0^{e}	3.5^{d}	3.2^{c}
1P	4.5^{b}	4.1^{c}	3.4^{de}	4.0^{b}
2P	5.5^{a}	4.3^{bc}	4.1^{c}	4.6^{a}
Main Zn effect	4.4^{a}	3.8^{b}	3.7^{b}	
CV (%)		13.15		

Means followed by different letters are significantly different, $P\leq0.05$.

The DTPA extractable soil zinc measured at 14 DAS were highly significantly ($P \leq 0.01$) increased by application of zinc (Table 3). These results agreed with those obtained by Abunyewa and Mercer–Quarshie (2004). However, application of both levels of P resulted in significant ($P \leq 0.05$) reduction in extractable Zn as compared to 0P treatments. The highest value of DTPA Zn was obtained by 0P2Zn, while the lowest value was obtained equally by IP0Zn and 2P0Zn. These low values obtained when applying 1P or 2P indicated that the soil contains low amounts of indigenous zinc to react with the phosphates. Measurements at 70 DAS showed a negatively significant ($P \leq 0.05$) interaction effect. The values were low ranging from 0.32 to 0.60 mg Zn kg^{-1} soil. The high values of soil extractable Zn were obtained by increasing the level of applied Zn. However, these values were reduced by increasing level of added P (Table 3). These results indicated that application of phosphorus fertilizers to Remaitab soil, which is deficient in zinc (Dawelbeit *et al.*, 1995), presumably increase the severity of Zn deficiency. This result is explicable by the fact that P enhances Zn adsorption in the soils to Fe and Al hydroxides and oxides and to $CaCO_3$ (Longeragan *et al.*, 1979) or by formation of insoluble zinc phosphates (Sparr *et al.*, 1965). However, Brown *et al.*, (1970) working with an alkaline soil showed that phosph-orus addition tended to increase the extractable zinc. Also, Saeed (1977) found that phosphate fertilizers decreased the ability of calcareous soils to retain Zn.

Table 3. Effects of P and Zn and their interactions on extractable soil Zn (mg Zn kg $soil^{-1}$).

	0 Zn	1 Zn	2 Zn	Main P effect
		14 DAS		
0P	0.42^{e}	2.48^{b}	2.76^{a}	1.89^{a}
1P	0.41^{e}	2.02^{cd}	2.08^{c}	1.50^{b}
2P	0.41^{e}	1.98^{d}	2.07^{c}	1.49^{b}
Main Zn effect	0.41^{c}	2.16^{b}	2.30^{a}	
CV (%)		10.88		
		70 DAS		
0P	0.35^{de}	0.50^{b}	0.60^{a}	0.48^{a}
1P	0.36^{d}	0.33^{e}	0.40^{c}	0.36^{b}
2P	0.32^{e}	0.40^{c}	0.42^{c}	0.38^{b}
Main Zn effect	0.34^{c}	0.41^{b}	0.47^{a}	
CV (%)		10.65		

Means followed by different letters are significantly different, $P \leq 0.05$.

The percentage of phosphorus of the entire leaf at the ear node at the silking stage was positively highly influenced by the level of the added P to the sufficient concentration as considered by Hanway and Olson (1980) and Jones *et al*.(1990). Table (4) shows significant difference ($P \geq 0.05$) in leaf P between 0P treatment on one hand and 1P and 2P treatments on the other hand, without significant difference between the two latter treatments. The results showed no significant difference due to P and Zn interaction. The effect of applied Zn was inconsistent with slight reduction in % P of the tissue. A significant increase in the Zn content of leaf tissue due to addition of Zn was obtained ($P \leq 0.05$). Comparing the present results with those obtained by Jones (1991), it may be concluded that the application of zinc led to a sufficient level of this nutrient in the leaf tissue. Zinc content of the leaf tissue was statistically unaffected by P and Zn interaction (Table 5). The highest value was obtained with the high level of added Zn with no phosphorus while the lowest values were obtained with each of 1P and 2P without Zn addition. The results showed that both nutrients tended to reduce each other only when one of them is not added. This is because the soil is deficient in the available forms of both nutrients and their application readily enhances their concentrations in the plant tissue.

Table 4. Effects of P and Zn and their interactions on leaf P (%).

	0 Zn	1 Zn	2 Zn	Main P effect
0P	0.094 e	0.088 ef	0.085 f	0.089 [b]
1P	0.260 b	0.250 c	0.251 c	0.253 [a]
2P	0.286 a	0.241 d	0.244 d	0.257 [a]
Main Zn effect	0.213 [a]	0.193 [b]	0.19 3 [b]	
CV (%)		14.31		

Means followed by different letters are significantly different, $P \leq 0.05$.

Table 5. Effects of P and Zn and their interactions on leaf DTPA extractable Zn (mg Zn kg-1 DM).

	0 Zn	1 Zn	2 Zn	Main P effect
0P	9.7 e	25.5 b	33.4 a	22. 9 [a]
1P	8.5 f	18.8 d	22.9 c	16.7 [b]
2P	8.5 f	19.0 d	22.4 c	16.6 [b]
Main Zn effect	8.9 [c]	21. 1 [b]	26.2 [a]	
CV (%)		12.44		

Means followed by different letters are significantly different, $P \leq 0.05$.

The results indicated that soil and plant analyses strongly support the view that the major P-Zn interaction does not take place in the plant but in the soil where the availability of Zn is noticeably reduced by large P supply (Marschener, 1995). This can be corrected by addition of Zn fertilizers (Olsen, 1991).

The results in Table (6) indicated that the analysis of variance of P and Zn interaction showed significant difference ($P \leq 0.05$) in P: Zn ratio in plant leaf among treatment means. The highest value (P: Zn 351:1) was obtained with 2 P0Zn treatment. Lu *et al*. (1998) correlated deficiency symptoms of Zn with its ratio to P. Adams *et al.* (1982) found that the critical P: Zn ratio in leaves ranged from 350:1 to 250:1. However, Marshcener (1995) stated that the P: Zn ratio in plants *per se* has no physiological importance.

Table 6. Effects of P and Zn and their interactions on leaf P: Zn ratio.

	0 Zn	1 Zn	2 Zn	Main P effect
0P	98 [d]	35 [e]	26 [e]	53 [c]
1P	202 [b]	111 [c]	98 [d]	137 [b]
2P	351 [a]	112 [c]	104 [cd]	189 [a]
Main Zn effect	217 [a]	86 [b]	76 [b]	
CV (%)		11.20		

Means followed by different letters are significantly different, $P \leq 0.05$.

The grain removal of P (kg ha^{-1}) was highly affected by application of P (Table 7). The data showed significant ($P \leq 0.05$) difference in grain P between 0P on one hand and IP and 2P on the other hand, but with no significant difference in grain P between 1P and 2P. The amount of P removed in the harvested grains was in accord with that obtained by Hanway and Olsen (1980) who found that the average P removal by corn grain varied from 7 to 15kg P ha^{-1}. The data showed significant difference ($P \leq 0.05$)

in grain uptake of P (kg ha^{-1}) between treatment means due to P and Zn interaction. The amounts of P removed by maize grains at each rate of added P was significantly ($P \leq 0.05$) higher when combined with any rate of soil applied Zn as compared to treatments receiving the same rate of P combined with 0Zn (Table 7). Grain uptake of Zn (g ha^{-1}) was significantly increased ($P \leq 0.05$) by zinc application (Table 8). The analysis of variance of P and Zn interaction on Zn removed by corn grains showed significant difference ($P \leq 0.05$). The results showed that at any rate of added P, high rate of applied Zn gave the highest values of grain removal of Zn. The results of grain uptake of both nutrients agreed with the results obtained by Sunder and Chaudhary (2002), who found that uptake of P and Zn by tissues and grains, were improved by application of P and Zn to the soil. Moreover, these results indicated that application of phosphorus together with zinc promoted better utilization of nutrients.

Table 7. Effects of P and Zn and their interactions on grain P uptake (kgha^{-1}).

	0 Zn	1 Zn	2 Zn	Main P effect
0P	5.2 ^{d}	5.3 ^{d}	5.1 ^{d}	5.2 ^{b}
1P	10.9 ^{c}	14.3 ^{b}	18.2 ^{a}	14.5 ^{a}
2P	10.5^{c}	18.1 ^{a}	14.8 ^{b}	14.5 ^{a}
Main Zn effect	8.9 ^{b}	13.9 ^{a}	12.5 ^{a}	
CV (%)		12.34		

Means followed by different letters are significantly different, $P \leq 0.05$.

Table 8. Effects of P and Zn and their interactions on grain Zn uptake (gha^{-1}).

	0 Zn	1 Zn	2 Zn	Main P effect
0P	22 ^{fg}	57 ^{e}	56 ^{e}	45 ^{b}
1P	25 ^{f}	67 ^{d}	109 ^{a}	67 ^{a}
2P	16 ^{g}	74 ^{c}	99 ^{b}	63 ^{a}
Main Zn effect	21 ^{c}	66 ^{b}	88 ^{a}	
CV (%)		10.97		

Means followed by different letters are significantly different, $P \leq 0.05$.

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تأثير سمادي الفسفور والزنك على محتواهما في التربة والنبات
وغلة الذرة الشامية

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الخلاصة

أجريت هذه الدراسة خلال موسمي 01/2000 و02/2001 بمزرعة محطة بحوث الجزيرة ، هيئة البحوث الزراعية, وادمدني، السودان وذلك وفقاً لتصميم القطع المنشقة لدراسة تاثير اضافة سمادى الفسفور والزنك وتفاعلاتهماعلى مستوياتهما المتاحة فى التربه ومحتوى اوراق وامتصاص حبوب الذره الشامى لكل منهما. شملت المعاملات ثلاث جرعات من الفسفور، الذي أضيف في شكل سيوبر فوسفات ثلاثي عند الزراعة ، وهي صفر، 43 كجم P_2O_5/هكتار، 86 كجم P_2O_5/ هكتار. وثلاث جرعات من الزنك في شكل ملح كبريتات الزنك المميأة عند الزراعة هي صفر، 5 كجم زنك /هكتار و10كجم زنك/هكتار. تم إجراء التحليل الروتيني للتربة في موقع التجربة للموسمين قبل الزراعة.أوضحت نتائج التجربة أن إضافة الفسفور لها أثر إيجابي في زيادة الفسفور المتاح للتربة وزيادة محتوى الفسفور في الأوراق وإمتصاص الحبوب للفسفور. كما أبانت الدراسة أن إضافة جرعتين من الفسفور لم تنجم عنهما فروقات معنوية مقارنة مع إضافة جرعة واحدة .أوضحت النتائج أن إضافة الزنك قد زادت من كمية الزنك المستخلص من التربة بالإضافة إلى زيادة محتواه في الأوراق وإمتصاص الحبوب للزنك. أوضحت الدراسة أن إضافة العنصرين للتربة أدى لنقص واضح في كمية الزنك المستخلص من التربة وكمية الفسفور المتاح للتربة خصوصاً عند نهاية الموسم. كما أوضحت الدراسة أن إضافة أحد العنصرين دون الأخر يؤدي الى نقص العنصر الأخر في أنسجة النبات.