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Assessment of P-Zn Interaction in Corn Grown on Calcareous Soil

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Abstract. Studies were carried out in the greenhouse and laboratory to elaborate the interaction between P-Zn in the nutrition of corn (*Zea mays* L.). The greenhouse experiments were conducted by using two highly calcareous soils differing in their texture (sandy and loamy). Their $CaCO_3$ contents were 23.8 and 36.9%; respectively. Treatments comprised wide combinations of phosphorus and zinc namely four levels of phosphorus as P_2O_5, O(P_0), 75(P_1), 150(P_2), 300(P_3) kg ha^{-1} and three levels of zinc sulfate ($ZnSO_4$ $7H_2O$); 0 (Zn_1), 25 (Zn_2) and 50 (Zn_3) kg ha^{-1}. The laboratory experiment was initiated by using the heavier textured soil to conduct an incubation experiment. The treatments consisted of four levels of Zn; 0,2,5 and 10 mg Zn kg^{-1} and four levels of P; 0,10,15,25 mg P kg^{-1}. The incubation intervals were 24 hr., 3 days, 1,2,4 and 6 weeks.

Data obtained from the greenhouse experiments suggested that P applications enhanced Zn absorption by the plant and promoted its growth. Elevating the rate of applied P from P_0 to P_3 resulted in increasing Zn uptake from 159.1 to 229.1 µg/pot and dry matter yield from 2.52 to 5.36 g/pot. The results also demonstrated that Zn applications at the lower rates of applied P (P_1 and P_2) would decrease P uptake by the plant parts. Nonetheless, the incubation experiment indicated that irrespective of incubation intervals and applied Zn, increasing P levels caused a significant increase in the extractable P. Also, it caused non significant increase in the extractable Zn when it was associated with the lowest rate of applied P. However, higher applications of P caused a significant decrease in the extractable Zn. The data from this work indicate that plant capability to take up and assimilate Zn seems to be the limiting factor rather than P inducing Zn deficiency.

Introduction

Plants grown on calcareous soils, frequently suffer from zinc deficiency. Higher calcium carbonate content of soil and its subsequent effect on the soil pH greatly affect zinc availability [1-3]. Added phosphorus fertilizer may also induce zinc deficiency in plant [4]. However, the nature of such relationship is not fully understood and brought about much debate. Many investigators tried to interpret this phenomenon. Some have suggested that this phenomenon is related to the formation of zinc phosphate compounds in soil, such as $Zn_3 (PO_4)_2 4H_2O$ which reduces the concentration of available zinc in the soil to a deficiency level [5]. However, Mahmoud [6] and Lindsay [7] invalidated this assumption and reported that formation of this compound could hardly be considered a deterrent to Zn uptake by plant due to the relatively high solubility of this compound. Nevertheless, some workers attributed this problem to physiological disorder in the plant. For instance, they claimed that there is a sort of antagonism which takes place within the roots [8]. Also it has been suggested that metabolic disorder within plant cells may be caused by imbalance between P and Zn or interference of P with the metabolic function of Zn at certain sites in the cells [9].

Corn yield reductions or poor growth of plants due to P-Zn interactions have been attributed to disturbed Zn nutrition as a result of P fertilization [10]. Yields from other studies were unaffected despite depressed Zn concentrations associated with high tissue concentrations of P. Recently Dibb *et al.* [11] pointed out that some of the most severe antagonistic P-Zn interactions have been observed in the production of corn where high application rates of P were superimposed on marginal or deficient Zn level in the soil.

In view of the aforementioned considerations and as fertilizer P is commonly applied together with Zn for corn grown on the calcareous soils in Saudi Arabia, the current study was conducted to elucidate: (1) the interaction between P and Zn in corn plants grown thereon and (2) the relationship between P and Z in the calcareous soil.

Materials and Methods

Soils studied

Greenhouse and laboratory experiments were carried out at the College of Agriculture, King Saud University. Two soil samples representing Dirab area; 25 Km southwest of Riyadh (24°25′,46°34′E) Saudi Arabia, were collected from the surface layers (0-30 cm). The collected soils were highly calcareous, differing in their texture. The lighter textured soil was hyperthermic typic torripsamments whilst the heavier textured soil was hyperthermic typic torriorthents. The main characteristics of these soils are given in Table 1. They were determined following the methods described by Richards [12].

Table 1. The main characteristics of soils of Dirab area

Soil property	Light textured soil	Coarse textured soil
pH paste	7.15	7.8
EC dSm^{-1} (saturation extract)	0.9	1.2
$CaCO_3$ (%)	36.9	23.8
Organic matter %	0.25	0.1
Available P mg Kg^{-1}	1.82	6.13
Available Zn mg Kg^{-1}	0.38	0.28
Clay %	20	6
Silt %	35	3
Sand %	45	91
Soil texture	loam	Sand

The greenhouse experiment

The light and heavy textured soils were utilized to conduct pot experiments in the greenhouse. The soils were used to fill plastic pots having 20 cm diameter, depth of 20 cm and capacity of 6 kg. Six seeds of corn (C.V. Pioneer 3732) were planted in each pot and after ten days of germination, seedlings were thinned to three. Soon after thinning, phosphorus was applied at 4 levels 0(P_0), 75(P_1), 150(P_2), 300(P_3) P_2O_5 kg ha^{-1} in the form of Diammonium phosphate (DAP). Zinc was applied in the form of $ZnSO_4$ $7H_2O$, at 3 levels 0(Zn_1), 25(Zn_2), and 50(Zn_3) kg ha^{-1}. Urea, potassium sulfate, Fe EDDHA, Mn EDTA, Cu EDTA were applied to all pots as a basal treatment. The equivalent amounts applied were 250 kg N ha^{-1}, 50 kg K_2O ha^{-1}, 4 mg Fe kg^{-1}, 4 mg Mn kg^{-1} and 2 mg Cu kg^{-1}, respectively. The treatments were replicated 3 times and randomly distributed in a completely randomized design. Shoots were harvested and roots were separated after 6 weeks of planting. The plant materials were washed twice with distilled water and dried for 24 hr. in a forced air oven at 70°C and the dry weight was recorded. Half gram of the plant materials were wet digested by sulfuric and perchloric acids mixture [13]. Thereafter, zinc and phosphorus contents were determined. Determination of Zinc was done by using an atomic absorption spectrophotometer (Perkin Elmer 2380), while phosphorus was detected colorimetrically by using ascorbic acid according to the method outlined by Page [14].

Laboratory experiment

An incubation experiment was carried out by using the heavy textured soil of Dirab, containing 36.9% $CaCO_3$. The treatments comprised four levels of Zn:(Zn_0), (Zn_1), (Zn_2) and (Zn_3); applied as $ZnSO_4$. $7H_2O$ to give 0,2,5, and 10 mg Zn kg^{-1} soil and four levels of P in the form of KH_2PO_4. $P_{(0)}$, (P_1), (P_2) and (P_3) to give 0,10,15, and 25 mg P kg^{-1} soil. All possible combinations between P and Zn were considered and treatments were replicated 3 times. Twenty grams of the soil were incubated at 30°C in plastic containers having 4 cm diameter and 8 cm height. The moisture was kept constant at 70% of W.H.C. After 24 hr, 3 days, 1,2,4 and 6 weeks of incubation the samples were taken for analysis. Zinc and P were extracted by using AB-DTPA where 10 g of soil were shaked with 20 ml of the extractant for 15 minutes following the method described by Soltanpour and Schwab [15]. Phosphorus and Zinc were detected as previously mentioned.

The data of the greenhouse and laboratory experiments were analyzed by using statistical analysis system-Anslysis of Variance (SAS-ANOVA) (statistical analysis system institute [16] with least significant difference (LSD) for the mean separation.

Results and Discussion

The greenhouse experiment

The response of corn grown on two different soils to various levels of P and Zn is presented in Table 2. Statistical analysis revealed that regardless of P and Zn effects shoots of corn grown on the heavy textured soil significantly exercised higher dry matter yield and P uptake compared to the light one. Nevertheless, Zn uptake of shoots grown on the light textured soil was comparatively higher. Roots grown in such soil exhibited significantly higher values of dry matter, P and Zn uptake compared to those recorded for the heavy textured one (Table 3).

In absence of Zn effect, all levels of the applied P significantly increased dry matter and P uptake. These results are in consonance with those reported by other investigators [17,18]. However, the higher levels of applied P caused no significant differences in P uptake by the shoots. Such levels significantly elevated the Zn uptake. Although the lowest level of applied P increased Zn uptake yet this increase was not significant (Table 4). The data suggest that phosphorus enhanced Zn absorption. The findings of Orabi *et al.* [19] and Mawardi *et al.* [20] support this view. They pointed out that the application of P to soils enhances Zn uptake by plant and simultaneously promotes growth. Table 4 also shows that as P level increased, dry matter of the roots significantly increased. It is clear that the applied P at the lower and higher levels significantly increased Zn uptake by the roots.

Table 2. Dry matter yield of the plant parts and their uptake of P and Zn as affected by P, Zn levels in different soils

Soil	P, Zn levels		Dry matter yield g/pot		P uptake mg/pot		Zn uptake μg/pot	
	P	Zn	shoots	roots	shoots	roots	shoots	roots
		Zn_0	2.57	1.57	2.89	1.26	90.8	58.7
	P_0	Zn_1	3.50	1.60	3.74	1.30	203.7	93.1
		Zn_2	2.33	1.45	2.51	1.35	137.1	93.5
		Zn_0	3.42	2.09	4.53	2.39	86.7	75.1
	P_1	Zn_1	3.47	1.96	4.75	1.84	190.1	121.4
Loam		Zn_2	2.35	2.07	2.92	1.82	147.6	125.1
		Zn_0	5.64	2.63	9.47	2.45	129.6	92.1
	P_2	Zn_1	4.84	1.94	5.64	2.01	248.5	104.7
		Zn_2	5.75	3.60	6.67	2.95	348.6	223.4
		Zn_0	4.19	2.03	6.97	2.35	116.3	70.3
	P_3	Zn_1	5.17	3.18	5.19	2.97	206.0	166.7
		Zn_2	7.59	4.29	8.30	4.14	336.0	304.3
		Zn_0	2.47	5.99	2.60	2.95	74.9	233.0
	P_0	Zn_1	2.45	2.47	2.22	2.08	243.9	203.6
		Zn_2	2.65	2.05	3.44	2.51	204.1	224.7
		Zn_0	3.02	5.08	4.59	3.06	84.0	203.2
	P_1	Zn_1	3.16	3.12	2.09	1.36	274.7	377.5
Sandy		Zn_2	3.54	5.08	4.66	2.98	298.7	454.5
		Zn_0	2.52	3.00	4.37	3.32	69.2	105.2
	P_1	Zn_1	4.47	3.89	6.95	5.49	236.8	288.4
		Zn_2	3.56	3.68	2.41	2.05	199.9	329.2
		Zn_0	3.56	4.33	3.82	4.96	110.4	157.8
	P_3	Zn_1	5.84	6.44	3.83	3.41	321.5	478.0
		Zn_2	5.83	5.74	5.44	4.60	284.3	449.2
LSD(0.05)			0.89	1.63	1.36	1.31	78.2	167.8

Table 3. Dry matter yield of the plant parts and their uptake of P and Zn as affected by soil variability

Soil	Dry matter yield g/pot		P mg/pot		Zn µg/pot	
	shoots	roots	shoots	roots	shoots	roots
Loam	4.23	2.37	5.30	2.26	186.7	127.4
Sandy	3.59	4.30	3.90	3.23	200.2	292.0
LSD (0.05)	0.26	0.47	0.39	0.38	22.6	44.8

Table 4. Dry matter yield of the plant parts and their uptake of P and Zn as affected by P levels

Levels	Dry matter yield g/pot		P uptake mg/pot		Zn uptake µg/pot	
	shoots	roots	shoots	roots	shoots	roots
P_0	2.66	2.52	2.90	1.91	159.1	151.1
P_1	3.16	3.35	3.98	2.24	180.3	273.3
P_2	4.46	3.12	5.91	3.04	205.4	190.5
P_3	5.36	4.34	5.59	3.74	229.1	271.1
LSD (0.05)	0.37	0.66	0.56	0.53	32.0	68.5

The effect of Zn treatments, regardless of P applications, is shown in Table 5. Obviously, Zn treatments significantly increased dry matter and Zn uptake of the shoots. Similar results were obtained by Mahmoud *et al.* [21]. Such treatments have had an adverse effect on P uptake. The results are in harmony with those reported by Amin *et al.* [22] on broad bean grown on calcareous soil. On the contrary, Abdel Aziz *et al.* [23] demonstrated that P uptake of corn significantly increased by applying Zn. The current results indicated that Zn uptake by roots increased significantly with increasing the level of applied Zn. However, Zn application had neither effect on dry matter nor phosphorus uptake of the roots.

The interaction between P and Zn, in absence of the soil effect, is shown in Table 6. It is clear that there is an increase in Zn uptake by shoots with increasing P levels. Such increase was significant at the level of 300 kg P_2O_5 ha^{-1}. Also Zn uptake by the roots showed similar results. In contrast to our findings, P enhanced Zn uptake, Safaya [24] stated that increasing the level of applied P up to 75 mg kg^{-1} soil let the plants suffer from Zn deficiency. He added that phosphate decreased tissue Zn concentration and Zn flux through the roots.

As for the effect of Zn levels on P uptake by shoots, it seemed generally that applying Zn would decrease P uptake by the shoots. In the meanwhile, P uptake by the roots was also decreased due to Zn application, except at the highest rate of applied P. This was confirmed by many workers who pointed out that increased levels of Zn are associated with a decreased P content in plant tissues [17,25,26].

Table 5. Dry matter yield of the plant parts and their uptake of P and Zn as affected by Zn levels

Levels	Dry matter yield g/pot		P uptake mg/pot		Zn uptake µg/pot	
	shoots	roots	shoots	roots	shoots	roots
Zn_0	3.42	3.24	4.95	2.84	95.2	124.4
Zn_1	4.11	3.07	4.30	2.56	240.7	229.2
Zn_2	4.20	3.59	4.54	2.80	244.5	310.8
LSD .05	0.31	N.S.	0.48	N.S.	27.7	59.3

Table 6. Dry matter yield, P and Zn uptake of corn plants as affected by P and Zn levels

Levels		Dry matter yield gm/pot		P uptake mg/pot		Zn uptake µg/pot	
		shoots	roots	shoots	roots	shoots	roots
P_0	Zn_0	2.52	3.78	2.75	2.11	82.8	145.9
	Zn_1	2.98	2.03	2.98	1.69	223.8	148.4
	Zn_2	2.49	1.75	2.98	1.93	170.6	159.1
P_1	Zn_0	3.22	3.58	4.74	2.73	85.4	139.1
	Zn_1	3.31	2.54	3.42	1.60	232.4	249.5
	Zn_2	2.94	3.94	3.79	2.40	223.1	431.3
P_2	Zn_0	4.08	2.82	6.92	2.88	99.4	98.6
	Zn_1	4.65	2.91	6.25	3.75	242.7	196.6
	Zn_2	4.65	3.64	4.54	2.52	274.3	276.3
P_3	Zn_0	3.88	3.18	5.40	3.65	113.3	114.1
	Zn_1	5.51	4.81	4.51	3.19	263.8	322.4
	Zn_2	6.71	5.02	6.87	4.37	310.2	376.7
LSD(0.05)		0.63	1.15	0.96	0.92	55.3	118.6

The incubation experiment

Data presented in Table 7 show the values of extractable P and Zn as affected by their added amounts and incubation intervals. The effect of incubation intervals on extractable P and Zn, notwithstanding their adding amounts is shown in Fig. 1. Data clear up that the values of the extractable P were sharply declined within three days of incubation. The extractable P pertaining to the other incubation intervals, except that obtained after two weeks, showed the same declined trend. Similar trend has been shown earlier by other workers [27,28]. Recently, Falatah and Nadiem [29], using calcareous soil demonstrated that as the incubation time increased the extractable P decreased to reach its minimal values after 56 days. They further indicated that a portion of the retained P might release with time, probably due to slight changes of some chemicals reactions in soil. Their results are in agreement with those described here.

As time of incubation elapsed, the extractable Zn significantly decreased. As in the case of P, the data indicated that Zn fixation took place within 3 days after addition. Nonetheless its value, soon after two weeks of incubation, was much higher than those obtained after one or four weeks. This was the same pattern which the extractable P exhibited. This indicates that the release of the retained forms of P and Zn; presumably due to microbial activity. The decline in Zn availability with time, when the applied Zn was incubated in calcareous soil, has been reported by other researchers [29,30].

Irrespective of incubation intervals and applied Zn, increasing P levels caused a significant increase in the extractable P (Fig. 2). Also, it caused non significant increase in the extractable Zn when it was associated with the lowest rate of applied P. However, higher applications of P caused a significant decrease in the extractable Zn. The data revealed that Zn solubility might be decreased beyond a certain level of applied P(P_2 and P_3). These results coincide with those reported by Spencer [31]. He pointed out that Zn is immobilized in soil by phosphate and lime. But according to Saeed [32] P fertilization increases Zn availability. It is noteworthy to mention that his work was carried out by using a comparatively lower level of Zn *i.e.*, 1 mg kg^{-1} soil. In a study on the solubility of Zn in soils treated with low to high rates of fertilizer P, Brown *et al.* [33] concluded that the rate of applied P did not greatly affect extractable Zn, but tended to increase Zn rather than to decrease it.

Testing the sole effect of added Zn on extractable P revealed that it has no significant effect on the availability of P (Fig. 3). These results resemble those obtained by Kalyanasundaram and Mehta [5]. But as expected, increasing the levels of Zn

Table 7. The extractable amounts of P and Zn (mg/kg) as affected by their added amounts and incubation intervals

		T1		T2		T3		T4		T5		T6	
P level	Zn level	Ext. P	Ext. Zn	Ext. P	Ext. Zn	Ext. P	Ext. Zn	Ext. P	Ext. Zn	Ext. P	Ext. Zn	Ext. P	Ext. Zn
	Zn_0	1.48	0.37	1.59	0.32	1.71	0.17	1.83	0.23	1.71	0.23	1.44	0.42
P_0	Zn_1	1.48	1.99	1.65	1.91	1.48	1.14	1.65	1.37	1.88	1.19	1.44	1.39
	Zn_2	1.48	5.10	1.71	3.99	1.59	3.72	1.76	4.19	2.09	3.14	1.55	3.33
	Zn_3	1.62	9.39	1.77	10.05	1.53	3.17	1.77	7.17	1.98	6.34	1.59	6.36
P_1	Zn_0	6.78	0.41	5.24	0.35	5.16	0.19	5.40	0.20	5.25	0.16	5.00	0.41
	Zn_1	5.06	2.01	5.46	2.07	4.9	1.11	5.47	1.51	5.50	1.07	4.46	1.47
	Zn_2	6.58	4.57	5.34	4.31	4.91	3.27	5.47	3.40	5.18	2.75	5.09	3.21
	Zn_3	5.38	10.38	5.34	8.92	5.31	7.97	5.31	6.90	4.74	5.64	4.52	6.71
P_2	Zn_0	7.17	0.41	7.46	0.37	6.08	0.24	7.27	0.19	7.46	0.16	6.91	0.41
	Zn_1	7.63	2.11	6.50	1.94	6.57	0.80	7.17	1.11	6.54	1.03	6.76	1.52
	Zn_2	7.63	5.05	7.10	3.6	7.15	3.49	7.46	2.82	6.54	2.79	6.60	3.14
	Zn_3	7.21	8.79	7.46	8.75	7.32	3.66	8.32	7.30	6.69	5.67	7.23	7.39
P_3	Zn_0	10.75	0.43	9.86	0.28	10.19	2.24	11.20	0.27	9.40	0.14	8.90	0.32
	Zn_1	11.17	2.01	8.82	1.39	9.93	1.11	11.18	1.41	9.37	1.06	9.65	1.38
	Zn_2	11.48	5.03	9.97	3.61	9.55	2.53	11.58	3.07	10.41	2.60	9.70	3.63
	Zn_3	10.12	9.68	9.57	7.92	9.73	4.83	10.52	7.23	9.58	5.43	10.39	7.51
LSD.05		0.92	0.61	0.92	0.61	0.92	0.61	0.92	0.61	0.92	0.61	0.92	0.61

T1(24 hrs), T2 (3 days), T3 (1 week), T4 (2 weeks), T5 (4 weeks) and T6 (6 weeks)

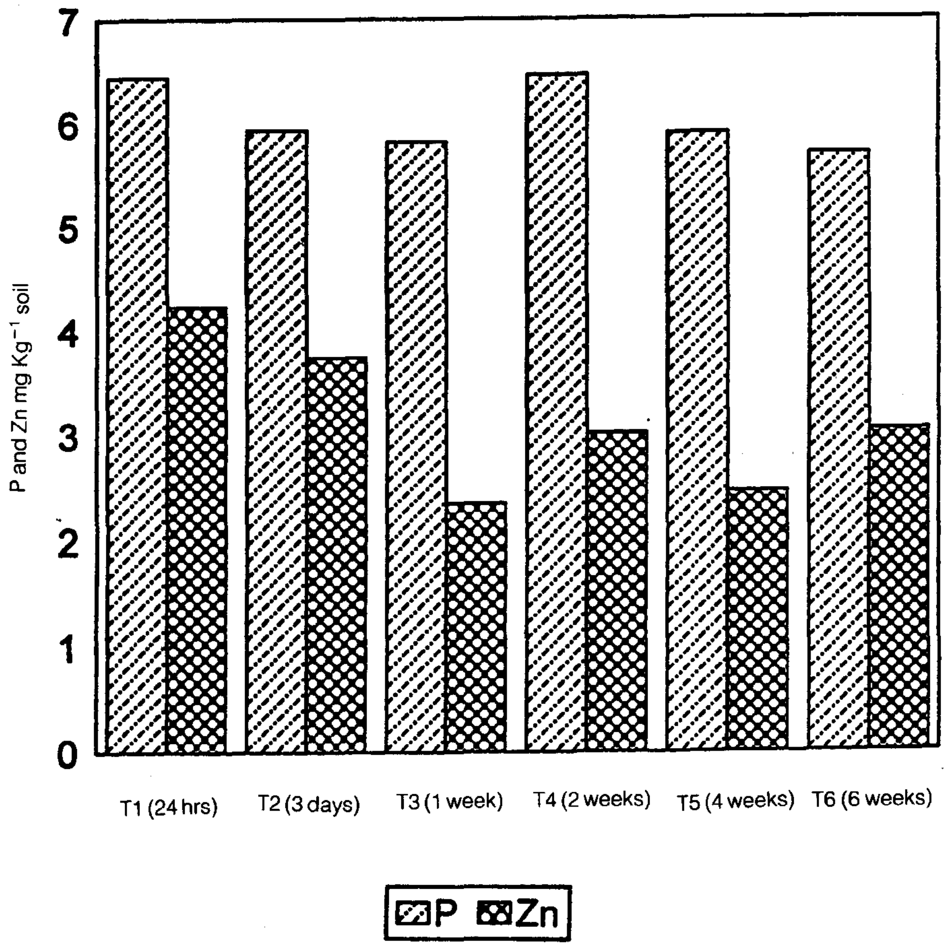

Fig. 1. Effects of incubation intervals on extractable P and Zn.

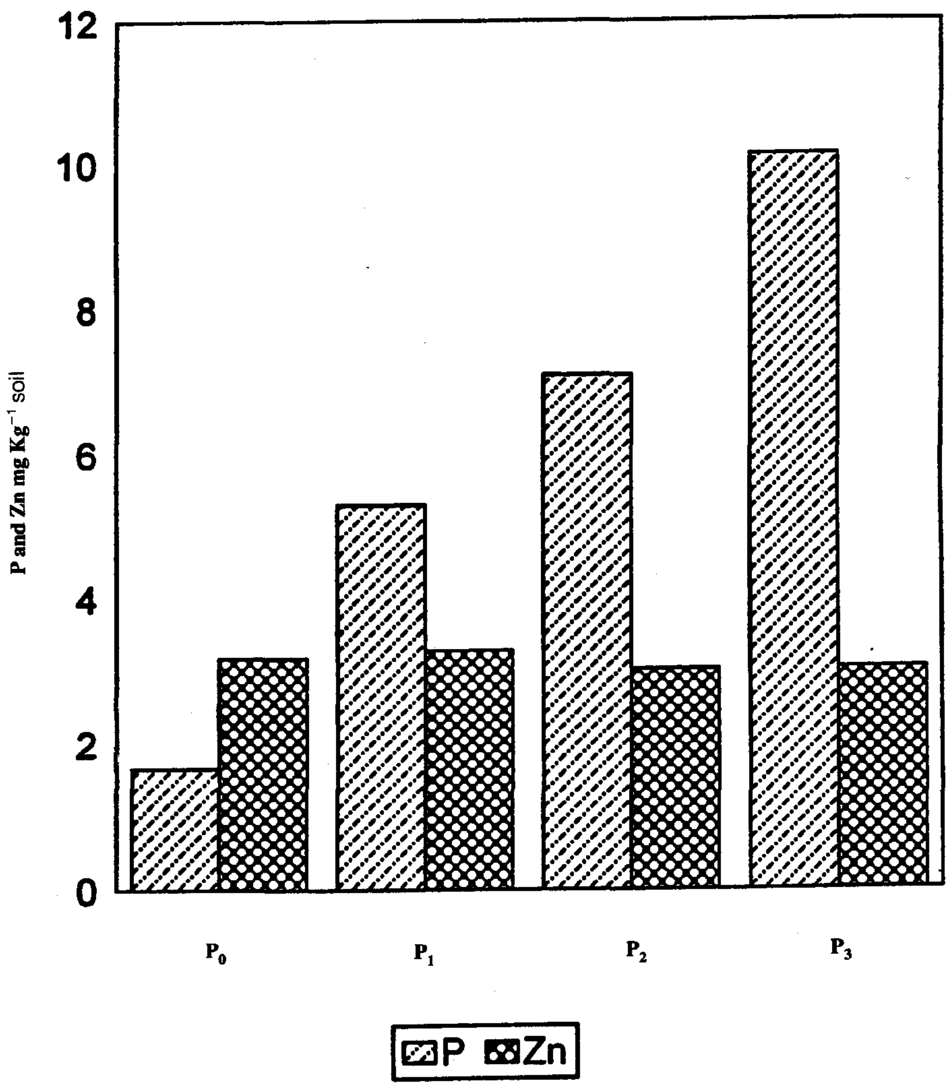

Fig. 2. Effects of applied P on extractable P and/or Zn.

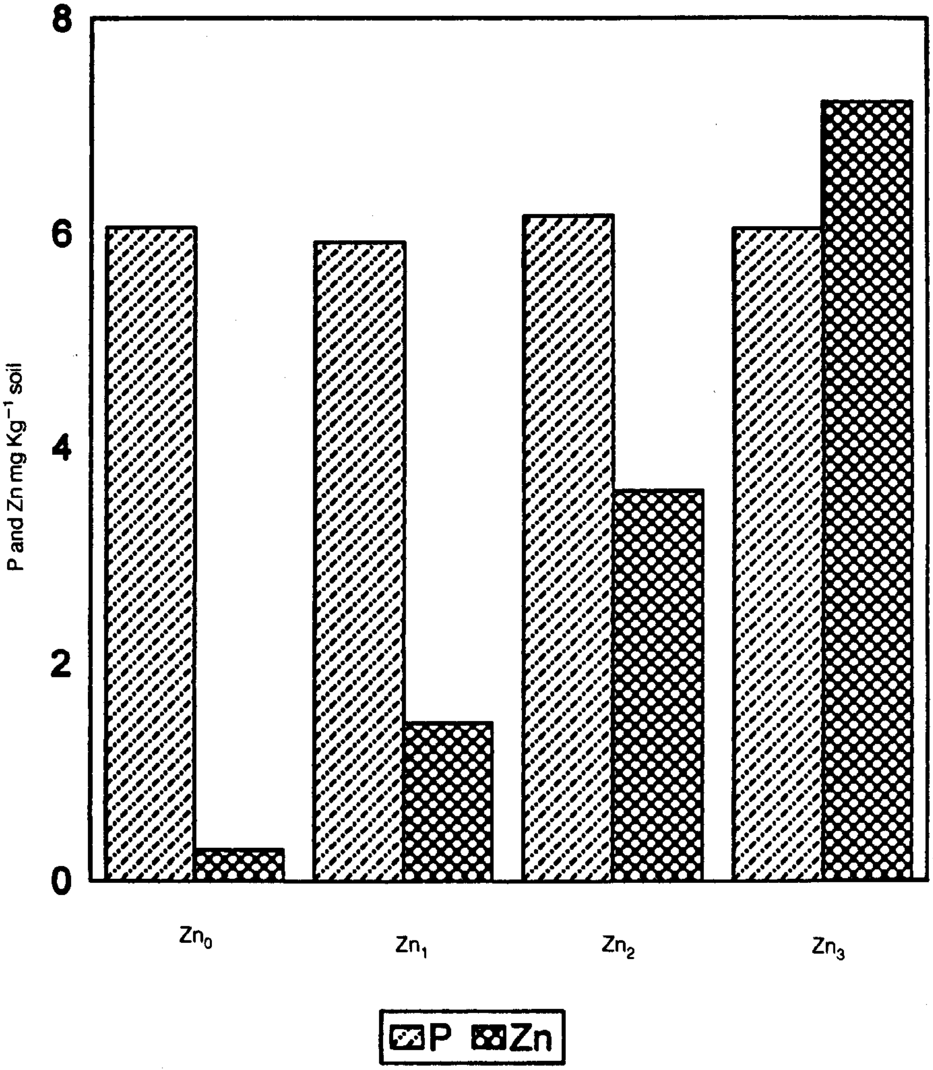

Fig. 3. Effects of applied Zn on extractable P and/or Zn.

applied elevated its extractable values in an ascending order. The current results show that at the beginning and the end of the incubation experiment there was only a minor change in available P and/or Zn of the control treatment (Table 7). Considering that the investigated soil contained extremely low content of organic matter (0.10%), one might expect that mineralization of their organic forms is negligible.

Comparing the interrelationships between P and Zn in soil medium and that where the plant is thereon discloses that they are diverse. The incubation experiment revealed that P applications at comparatively higher rates may immobilize Zn in soil, while the results of the greenhouse experiment suggested that P enhanced Zn absorption by plant.

From the present data, it may be concluded that the plant's capability to take up and assimilate Zn seems to be the limiting factor rather than P inducing Zn deficiency. It is interesting to note that Lindsay [7] held the view that Zn taken up by plants differs among plant species growing in identical environment.

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تقييم التفاعل بين الفوسفور والزنك على نمو الذرة الشامية النامية في الترب الجيرية

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ملخص البحث. أجـريت تجربة في الصوبة الزجاجية وأخرى في المعمل لدراسة التفاعل بين عنصري الفـوسفور والزنك وتأثيرهما على تغذية نبات الذرة الشامية. أجريت تجربة الصوبة الزجاجية باستخدام تربتين جيريتين مختلفتين في قوامها (رملية وطميية) حيث كان محتواهما من كربونات الكالسيوم ٢٣,٨ و٣٦,٩٪. واشتملت المعاملات على مدى واسع من معاملات الفوسفور والزنك حيث استخدم أربعة مستويات من الفوسفور وهي صفر (P_0)، ٧٥ (P_1)، ١٥٠ (P_2)، و٣٠٠ (P_3) P_2O_5 كجم/ هكتار وثلاث مستويات من كبريتات الزنك ($ZnSO_4 7H_2O$) صفر (Zn_0) و٢٥ (Zn_1) و٥٠ (Zn_2) كجم/ هكتار. استخدمت التربة الثقيلة القوام في إقامة تجربة التحضين في المعمل واشتملت المعاملات على أربعة مستويات من الزنك صفر، ٢، ٥، ١٠ مجم/ كجم وأربعة مستويات من الفوسفور صفر، ١٠، ١٥، و٢٥ مجم/ كجم وكانت فترات التحضين ٢٤ ساعة، ٣أيام، أسبوع، و٦أسابيع.

دلت النتـائج المتحصل عليها من تجارب الصوبة على أن إضافات الفوسفور شجعت امتصاص الزنك وكذا النمو النباتي أدى إلى رفع معدل إضافة الفوسفور من P إلى P3 إلى زيادة في امتصاص الزنك من ١٥٩,١ إلى ٢٢٩,١ ميكـروجـرام/ أصص وكـذلـك زيادة محصـول المـادة الجـافـة من ٢,٥٢ إلى ٥,٣٦ جرام/ أصص دلت النتائج على أن إضافات الزنك تحت المعدلات المنخفضة من إضافة الفوسفور قد تخفض من الكمية الكلية الممتصة من الفوسفور. أظهرت نتائج تجربة التحضين أن إضافات الفوسفور خاصة بمعدلات عالية تقلل كمية الزنك المستخلصة من التربة. كذلك أظهرت تلك التجربة أنه بغض النظر عن مدة التحضين وكمية الزنك المضاف فإن زيادة مستويات الفوسفور تؤدي إلى زيادة معنوية في الفوسفور المستخلص، بينما لم يكن لها تأثير على الزنك الميسر تحت المستوى المنخفض من إضافة الفوسفور. أما الإضافات العالية من الفوسفور فإنها تؤدي إلى نقص معنوي في الزنك المستخلص.

أظهرت تلك الدراسة أن مقدرة النبات على امتصاص الزنك والاستفادة الحيوية منه هي العامل المحدد وليس تأثير الفوسفور المحفز لنقص الزنك.