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THE EFFECTS OF PHOSPHORUS APPLICATION ON SHOOT DRY MATTER AND UPTAKE OF PHOSPHORUS, CALCIUM AND ZINC IN TWO WHEAT CULTIVARS GROWN IN A HIGH CLAY SOIL

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Abstract

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Interactions of phosphorus (P) with calcium (Ca) and zinc (Zn) in different plant species have received a great deal of attention recently. A glasshouse pot experiment with different rates of P application (0, 30, 60, 90 and 120 mg P kg^{-1} soil) was conducted to investigate these interactions in two wheat varieties (Ege-88 and Gun-91). Increased application of P reduced shoot Zn concentration significantly. Shoot Ca concentration was also reduced by P application but the reduction was disproportionate to P application rate. These results demonstrate that P application could be one of the reasons for Zn and Ca deficiency. Therefore, the level of P application should be determined carefully in order to maximize yield.

Key words: phosphorus, calcium, zinc, uptake, clay soil

Introduction

Phosphorus (P) is less abundant in soils than nitrogen (N) and potassium (K). Total P in soil surface soils varies from 50-1500 mg kg^{-1} soil. Although prairie soils are often high in total P, many of them are characteristically low in plant available P. Therefore, understanding the relationships and intractions of the various forms of P in soils and the numerous factors that influence P availability is essential to efficient P management (Havlin et al., 2005). The P within the plant is taken up as an orthophosphate anion ($H_2PO_4^-$ or HPO_4^{-2}) and phosphate esters play an important role in energy metabolism (Kacar and Katkat, 2011). Recent studies have demonstrated antagonistic relationships of P with Zn and Ca (Brady and Weil, 2008).

In soil solutions and plants, P can bind to Zn thus forming insoluble zinc-phosphate complexes. This in turn would inhibit both the uptake of Zn by the root and the movement of Zn in the plant. Field and glasshouse studies showed that increased P fertilization enhanced plant P uptake but reduced Zn uptake thereby causing Zn deficiency (Burleson et al., 1961; Robson and Pitman, 1983; Kacar and Katkat, 2011; Zhao et al., 2007). It has been reported that increased P application to calcareous soils increased Zn adsorption and calcium carbonate played an important role in the adsorption of Zn (Sead, 2004). In this study, the highest Zn adsorption was observed in a soil with the highest calcium carbonate content. Other studies reported that increased P fertilization increased dry matter and P concentration in the plant (Li et al., 2003).

In an other study, compared to the control treatment, increasing soil P supply increased shoot P concentration (2.7 - 3.0 fold), while decreased shoot dry matter (10 and 23%) and shoot Zn concentration (75 and 82%) (wheat and maize, respectively). In wheat, the reduction in shoot dry matter was associated with Zn concentrations below the critical level indicating P-induced Zn deficiency as being the main cause of reduced shoot growth. In maize, the reduction in shoot dry matter was accompanied by higher than adequate shoot P concentrations and lower than adequate shoot Zn concentrations suggesting P toxicity and Zn deficiency as the main contributing factors for reduced shoot growth (Kizilgoz and Sakin, 2010). In acid soils, calcium carbonate-P interactions of positive nature were also reported (Friesen et al., 1980). Zn plays an important role in most of the enzymes (ie. superoxide dismutase).

Excessive use of phosphate fertilizers in soils imposes deficiency of micronutrients in the plants. Accordingly, concentration of micronutrients will decline in dry matter and crop

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yield. High concentrations of P in soil solutions can reduce solubility of Zn. Similarly, high concentrations of P in the plant can reduce Zn concentration and hence induce Zn deficiency (Marschner, 1997). Increased P fertilization has been shown to reduce Zn concentration in rice (Kacar et al., 1993). P/Zn ratios in the plants are used to assess P and Zn status of the plants. Ratios of 106 – 151 in young leaves are considered adequate for optimum growth (Raimi and Bussler, 1975), while P/Zn ratios above 231 indicate Zn deficiency. The objective of this study was to determine the effects of increased soil P application on shoot growth and concentrations of Zn and Ca in two wheat varieties grown in a high clay soil.

In calcareous soils, phosphorus (or phosphate) sorption to $CaCO_3$ may be of equal or greater importance than sorption to aluminum and iron oxides (Porter and Sanchez, 1992). In a laboratory investigation with pure calcite, Cole et al. (1993) concluded that the reaction of phosphorus with $CaCO_3$ consisted of initial sorption reactions followed by precipitation with increasing concentrations of phosphorus. In calcareous soils, an acidic fertilizer solution would dissolve calcium, and it is anticipated that most of the added phosphorus fertilizer would precipitate initially as dicalcium phosphate dihydrate and dicalcium phosphate (Terman et al., 1958; Lindsay and Stephenson, 1959). These products are only moderately stable and undergo a slow conversion into compounds such as octacalcium phosphate, tricalcium phosphate, or one of the apatites.

Materials and Methods

Bread wheat cultivar (cv.) Gun-91 and durum wheat cultivar (cv.) Ege-88 were used in the present study. The soil was dried, sieved and placed into polyethylene pots of 2 kg capacity. To ensure maximum growth, N and K were also added to each pot (350 mg N as NH_4NO_3, and 250 mg K as K_2SO_4 (Hakerlerler et al., 1997). The physical and chemical properties of this soil are given in Table 1.

The seeds of both cultivars were sown into pots (20 seeds per pot). Once seedlings reached 5 cm height, they were thinned to 10. After six weeks of growth, shoots were harvested at 5 cm above the soil surface. Shoot samples were rinsed first in tap water then in de-ionized water. The samples were oven-dried at 70°C for determination of shoot dry matter. Dry shoot samples were ground, ashed 550°C and dissolved in 3.3% HCl (Cakmak et al., 1996). P and Zn concentration in the ash was determined according to Olsen and Sommers (1982) and Lindsay and Norvell (1978). The experiment was set up as randomized complete block design with four replications.

The analysis of variance was conducted using GENSTAT statistical program, and pair-wise comparisons of the means were made using Least Significance Difference (LSD) test at P=0.05.

Results and Discussion

The effects of P fertilization on shoot dry matter and concentrations of P, Zn and Ca in two wheat varieties are given in Table 2. Shoot dry matter increased up to a P application of 60 mg kg^{-1} soil, and this increase was similar in both cultivars. Compared to nill treatment, the increase in shoot dry matter was approximately 20%. This result is similar to those reported earlier (Kizilgoz and Sakin 2010). When P application exceeded 90 mg kg^{-1} soil, there was a reduction of 16% in both cultivars. The Liebig's Law of the Minimum could explain this (Aktas, 1994). However, there were no interactions involving P application and cultivars.

Shoot P concentrations of both cultivars were also increased by P application up to 90 mg kg^{-1} soil. However, the increase in shoot P concentration up to 60 mg P kg^{-1} soil was still inadequate to alleviate P deficiency as indicated by shoot P concentrations (0.25%) below the critical deficiency concentration (Reuter and Robinson, 1997). Compared to nill treatment, at 120 mg P kg^{-1} soil, the increase in shoot P concentration was approximately 200% in both cultivars. These results are in accordance with earlier reports (Havlin et al., 2005; Kizilgoz and Sakin, 2010). However, the increases in shoot P concentration over the soil P application range were not proportional with greater increases occurring up to 90 mg P kg^{-1} soil.

Shoot Zn concentrations of both cultivars varied depending on P application rate. In general, Zn concentration was reduced by soil P supply over the entire range of soil P application. Compared to nill treatment, this reduction was 39% and 52% in durum wheat cv. Ege-88 and bread wheat cv. Gun-91, respectively. This could have been resulted from an antogonistic interaction between P and Zn (Brady and Weil, 2008). In addition, it is well known that P application to calcareous

Table 1
The physical and chemical properties of the soil used in the present study

Sand, %	Silt, %	Clay, %	pH, 1:2.5	EC, dS m^{-1}	CEC, cmol kg^{-1}	Organic matter, %	Av. P, mg/kg	Av. Zn, mg/kg	Av. Ca, mg/kg
21	26	53	7.6	1.8	51.3	1	6.8	0.45	1648

Table 2
Effects of increasing soil P supply on shoot DW, shoot P, Ca and Zn concentrations in wheat cultivars

P application, mg/kg soil	Shoot DW, g plant^{-1}			Shoot P, %		
	Ege-88	Gun-91	Mean	Ege-88	Gun-91	Mean
0	0.63	0.56	0.6	0.12	0.13	0.13
30	0.65	0.64	0.65	0.16	0.18	0.17
60	0.74	0.69	0.72	0.23	0.29	0.26
90	0.7	0.69	0.7	0.33	0.41	0.37
120	0.62	0.58	0.6	0.32	0.43	0.38
Mean	0.67	0.63		0.23	0.29	
$LSD_{0.05}$						
P		0.05			0.04	
Cultivar		ns			0.03	
P x Cultivar		ns			ns	
	Shoot Zn, mg kg^{-1} DW			Shoot Ca, %		
	Ege-88	Gun-91	Mean	Ege-88	Gun-91	Mean
0	11.3	12.8	12.1	0.34	0.32	0.33
30	10.8	12.2	11.5	0.32	0.32	0.32
60	9.8	10.3	10.1	0.33	0.28	0.31
90	8.5	8	8.3	0.28	0.25	0.27
120	6.9	6.2	6.6	0.26	0.23	0.25
Mean	9.5	9.9		0.31	0.28	
$LSD_{0.05}$						
P		0.3			0.02	
Cultivar		0.2			ns	
P x Cultivar		0.5			ns	

ns=non-significant

soils increases Zn adsorption (Sead, 2004) thus making Zn less plant-available. Our results are also supported by other studies (Kizilgoz and Sakin, 2010). It is interesting to note that cultivar by soil P application interaction was only significant for Zn. Bread wheat cv. Gun-91 maintained a higher shoot Zn concentration than durum wheat cv. Ege-88 when soil P application increased up to 30 mg kg^{-1} soil beyond which both cultivars showed a similar trend.

Conclusion

Similar to shoot Zn concentration, shoot Ca concentrations of both cultivars were also reduced by increased soil P application. The reduction in shoot Ca concentration was similar in both cultivars averaging 10.6%. This could be a result of P and Ca interaction (Porter and Sanchez, 1992; Cole et al., 1993; Kacar and Katkat, 2011). In addition, as negatively charged P anions are not adsorbed onto negatively charged clay particles, this could increase plant available P in soil solution (Ince, 1995). In this study, soil P application had significant effects on shoot P and Ca concentrations. These results suggest that given the negative effects of P application on Ca and Zn nutrition of wheat the optimum P application rate for wheat should be determined carefully in order to maximize yield.

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