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Full Length Research Paper

The effects of increased phosphorus application on shoot dry matter, shoot P and Zn concentrations in wheat (*Triticum durum* L.) and maize (*Zea mays* L.) grown in a calcareous soil

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Zinc (Zn) deficiency is a worldwide nutritional problem resulting in significant reduction in crop yields. It is often observed in calcareous soils and also after heavy doses of phosphorus (P) fertiliser applications, the latter being termed P-induced Zn deficiency. For management purposes, it is important to understand how crops with different root architecture would respond to P-induced Zn deficiency. This glasshouse study was aimed at determining the effects of increased P application on shoot dry matter, shoot P and Zn concentration in wheat and maize grown in a calcareous soil supplied with five rates of P (0, 30, 60, 90 and 120 mg kg^{-1} soil). 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. The results suggest that heavy applications of P fertilizers can induce not only Zn deficiency but also P toxicity depending on the crops thus P application rates should be chosen carefully.

Key words: Calcareous soil, phosphorus, dry matter, zinc, zinc deficiency.

INTRODUCTION

Phosphorus is the third most abundant macronutrient in plants after nitrogen and potassium. In soils, it is present in organic and inorganic forms. In surface soils, the concentration of P is in the range of 50 - 1500 mg kg^{-1} soil, while in soils rich in organic matter, it is present as organic complexes. P is adsorbed by clay colloids, carbonates and particularly Fe-oxides. In soil solutions, the main forms of P are HPO_4^{2-} and $H_2PO_4^-$, and the plant absorption of HPO_4^{2-} is slower than that of $H_2PO_4^-$ (Havlin et al., 2005). P concentration in soil solutions range from 3-300 parts per billion, while P concentration in most cultivated plants vary between 0.3 and 0.6% (Bergmann, 1988; Jones et al., 1991).

Similar to P, zinc (Zn) also is adsorbed by organic matter, carbonates and oxides. As a micronutrient, it is found in low concentrations in soil solutions (2 - 70 parts per billion) and it is taken up by the plant in the form of Zn^{2+} (Tisdale et al., 1993). The concentration of Zn in the plant in most cultivates species is in the range of 20 - 70 mg kg DW^{-1} (Bergmann, 1988; Jones et al., 1991).

Plants take up most of the required nutrient elements by their roots and to a smaller extent by their above-ground organs. However, plants differ in their root systems and the way they absorb and transport water and nutrients. The distance over which the water and nutrients are transported can be as much as 6 m from the root tip

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Abbreviations: DW, Dry weight; **P,** phosphorus; **Zn,** zinc.

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

Sand (%)	Silt (%)	Clay (%)	pH	EC ($dS\ m^{-1}$)	Cation exchange capacity ($cmol\ kg^{-1}$)	$CaCO_3$ (%)	Organic matter (%)	P ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
31.7	28.9	39.4	7.73	578	42.3	27.9	1.08	3.98	0.46

Table 2. Effects of increasing soil P supply on shoot DW, shoot P and Zn concentrations and P/Zn ratios in wheat and maize.

P application ($mg\ kg^{-1}$ soil)	Shoot DW ($g\ plant^{-1}$)		P (%)		Zn ($mg\ kg^{-1}$)		P/Zn	
	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
0	0.576	3.040	0.15	0.30	13.5	28.1	111	107
30	0.551	2.910	0.23	0.48	10.3	23.5	223	204
60	0.541	2.750	0.36	0.61	9.0	16.7	400	365
90	0.532	2.630	0.45	0.76	7.5	12.2	600	623
120	0.518	2.350	0.55	1.23	3.3	5.1	1666	2411
Mean	0.556	2.900	0.35	0.68	8.7	17.1	402	397

DW = Dry weight; P = phosphorus; Zn = zinc.

to the soil surface (Taiz and Zeiger, 2008; Kacar et al., 2002). Nutrients can significantly affect root development. For example, P can stimulate development of lateral roots (Brady and Weil, 2008) and Zn can influence P metabolism of the roots (Loughman et al., 1982). P-Zn interactions have been reported to originate in the roots such that they retard translocation of each other to the upper parts of the plant (Khan and Zende, 2004).

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 fertilisation enhanced plant P uptake but reduced Zn uptake thereby causing Zn deficiency (Burleson et al., 1961; Robson and Pitman, 1983; Kacar and Katkat, 1998; 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 corbante content. Other studies reported that increased P fertilisation increased dry matter and P concentration in the plant (Li et al., 2003). In acid soils, calcium carbonate-P interactions of positive nature were also reported (Friesen et al., 1980).

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 fertilisation 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 aim of this study was to determine the effects of increased P application on shoot dry matter, shoot P and Zn concentration in wheat and maize grown in a calcareous soil.

MATERIALS AND METHODS

A durum wheat cv. Zenit and maize cultivar DK711 were used in the present study. The soil was collected from Birecik location (Sanliurfa, Turkey), dried, sieved and placed into polyethylene pots of 4 kg capacity. To ensure maxium growth, N, P and K were also added to this soil (650 mg NH_3NO_3, 530 mg KH_2PO_4 and 530 mg 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 (25 seeds per pot). Once seedlings reached 5 cm height, they were thinned to 15 and 10 in wheat and maize, respectively. 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-ionised 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 study was set up as randomised complete block design with four replications. The analysis of variance was conducted using statistical software Minitab 14. Significant differences were declared at 0.01 probability level.

RESULTS AND DISCUSSION

Increasıng soil P supply reduced shoot dry matter in both wheat and maize, but the extent of the reduction varied with cultivar and soil P supply (Table 2). Compared to control treatment, shoot dry matter was decreased by approximately 4, 6, 8 and 10% in wheat and 4, 9, 13 and 23% in maize at 30, 60, 90 and 120 mg kg^{-1} soil P supply, respectively. Although both crops showed significant

Table 3. Effects of increasing soil P supply on shoot P and Zn content in wheat and maize.

P application (mg kg^{-1} soil)	P content (mg $plant^{-1}$)		Zn content (µg $plant^{-1}$)	
	wheat	maize	wheat	maize
0	0.864	9.060	7.8	84.8
30	1.267	13.968	5.7	68.2
60	1.948	16.775	4.8	46.0
90	2.394	19.988	4.0	32.2
120	2.849	28.905	1.7	11.9
Mean	1.864	17.739	4.8	48.6

P = Phosphorus; Zn = zinc.

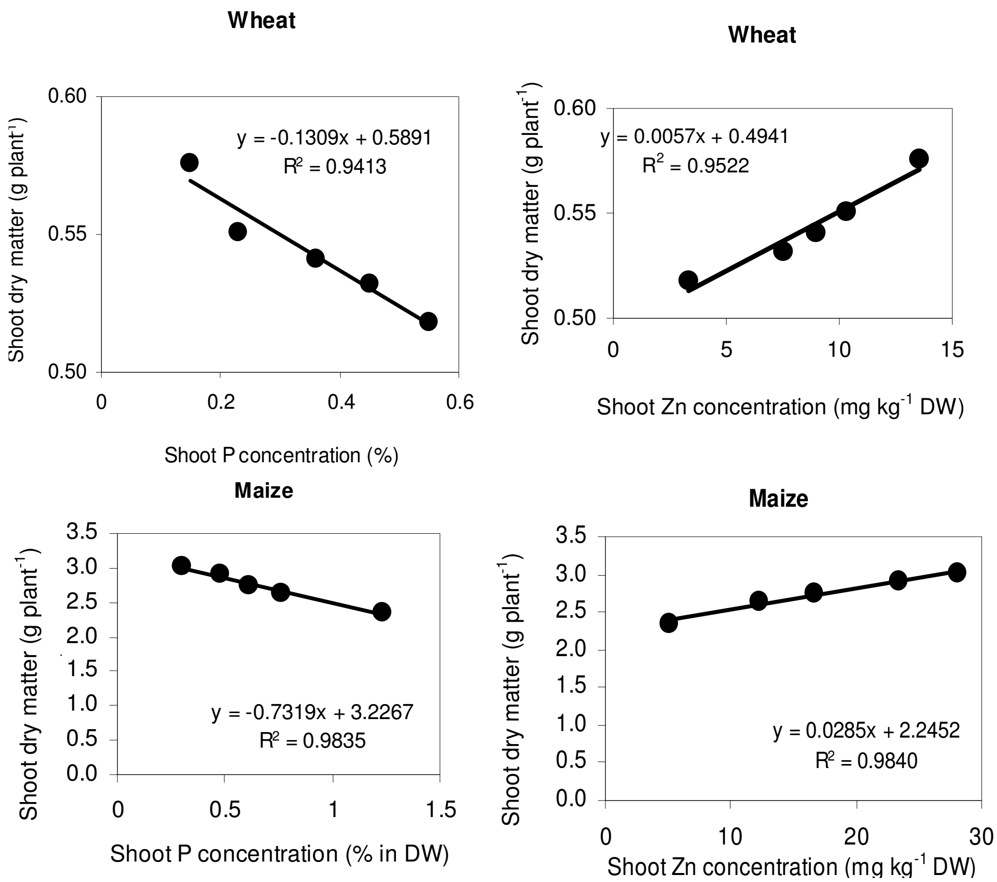

Figure 1. The relationships between shoot dry matter and P or Zn concentratons in the shoots in wheat and maize.

reductions in shoot dry mater when P application exceeded 60 mg kg^{-1} soil, maize suffered greater dry matter loses than wheat.

In contrast to shoot dry matter, increasing soil P supply increased shoot P concentration significantly in both cultivars (Table 2). Compared to the control treatment, shoot P concentration was increased by approximately 53, 140, 200 and 267% in wheat and 60, 103, 153 and 310% in maize at 30, 60, 90 and 120 mg kg soil P supply, respectively. In general, maize appeared to accumulate more P than wheat, which may be attributed to its extensive root system (Kacar et al., 2002; Li et al., 2003; Taiz and Zeiger, 2008). When shoot P concentrations in the present study were compared to those previously published, it appears that at all levels of P supply, shoot P concentrations in wheat were within the adequate range (0.3 - 0.6%; Reuter and Robinson, 1997), while those in maize especially at the highest soil P supply (1.23%) were well above the adequate levels (0.4 - 0.8%; Reuter and Robinson, 1997) indicating potential P toxicity. Shoot P content followed a similar trend to shoot P concentration (Table 3).

As opposed to shoot P concentrations, increasing soil P supply reduced shoot Zn concentrations drastically. The reductions equated to approximately 24, 33, 44 and 75% in wheat and 16, 40, 56 and 82% in maize at 30, 60, 90 and 120 mg kg soil P supply, respectively. If 20 - 25 mg kg Zn is considered as critical deficiency concentration for wheat and maize at seedling stage (Reuter and Robinson, 1997), it appears that both wheat and maize suffered from Zn deficiency when soil P supply was above 30 and 90 mg kg^{-1} for wheat and maize, respectively (Table 2). Shoot Zn content showed similar responses to shoot Zn concentration (Table 3). P/Zn ratios increased in a linear fashion in both cultivars as soil P supply increased (Table 2). At 60 mg kg^{-1} soil P supply, higher than adequate P/Zn ratios (106 - 151; Raimi and Bussler, 1975) indicated potential for Zn deficiency and this finding was further supported by the shoot low Zn concentrations (Table 2).

Conclusively, in wheat, high soil P supply induced Zn deficiency which was the main cause for reduced shoot growth (Figure 1). In maize, high soil P supply resulted in reduced shoot growth, and higher than adequate shoot P concentrations and lower than adequate shoot Zn concentrations suggested that P toxicity and Zn deficiency were the main contributing factors for reduced shoot growth (Figure 1). These results suggest that heavy applications of P fertilizers can induce Zn deficiency and/ or P toxicity depending on the crops, thus P application rates should be chosen carefully.

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