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Long-term effect of high phosphorus doses on zinc status of maize on a non-calcareous loamy soil

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ABSTRACT

The long-term effect of 87.3 kg/ha P on the yield elements and nutrient content of maize was studied at the National Long-Term Fertilization Experiment of the Karcag Research Institute in Hungary. The soil of the experiment site is non-calcareous Luvic Phaeosem, and its soluble phosphorus (P) and zinc (Zn) content in 0–20 cm soil layer are: ammonium lactate P: 141.1 mg/kg and diethylene triamine pentaacetic acid (DTPA) Zn: 0.85 mg/kg, respectively. The effect of foliar Zn fertilization was studied at three levels of nitrogen (150, 200 and 250 kg/ha) and under 87.3 kg/ha P and 82.6 kg/ha K application in four replications. The applied Zn amount was 700 g/ha. We measured the grain yield and the thousand-kernel weight. Leaf and grain samples were analyzed for phosphorus, zinc, potassium, calcium, magnesium and manganese content. Foliar Zn application did not increase the yield significantly, but it enhanced the thousand-kernel weight. The element content did not change significantly – neither in leaves nor in kernels. Under the examined habitat circumstances even the long-term application of 87.3 kg/ha P dosage did not cause Zn deficiency to such an extent which would lead to significant yield depression of maize.

Keywords: micronutrient; crop production; Zn availability; critical value; *Zea mays* L.

Zinc (Zn) deficiency is one of the most common micronutrient deficiencies and it is becoming increasingly significant in crop production (Mengel and Kirkby 1987). Nearly 27% of the soils in Hungary are Zn deficient (Elek and Patócs 1984, Kádár 2005).

Zinc deficiency occurs due to two reasons: either the soil total Zn content is low or the Zn availability is inhibited for the plant. Most often the total Zn content is high enough, but the Zn availability is reduced by several factors. The most important limiting factors are the high soil pH and the excessive supply of phosphorus (P) (Martens and Lindsay 1990). It is generally proven that the phosphorus-zinc antagonism is not primarily due to precipitated zinc phosphate, but it rather has a plant physiological origin (Stukenholz 1965, Ragab 1980, Cakmak and Marschner 1986).

Zinc status and phosphorus zinc antagonism are often characterized by the following factors: soluble Zn and P content of the soil, its P/Zn ratio, and Zn and P content of plant samples collected in certain developmental stages and its P/Zn ratio. Our experiment was evaluated in the light of the above parameters, thus results were compared with critical values from several literature sources.

In Hungary the zinc-phosphorus antagonism has been studied by several researchers in long-term experiments for maize. Csathó et al. (1989) found that on calcareous chernozem soil yield depression occurs if the P doses exceed 21.8 kg/ha in a year (ammonium-lactate P (AL-P) > 38.5 mg/kg). In contrast, Izsáki (2011) did not experience yield loss due to Zn deficiency in acidic clay loam soil with 69.8–157.3 mg/kg AL-P content. The different observations of Csathó et al. (1989) and Izsáki (2011) can be explained by the various pH conditions of the studied areas.

The aim of our study is to investigate if the long-term use of 87.3 kg/ha P doses causes Zn deficiency and yield depression in case of maize on this certain habitat.

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MATERIAL AND METHODS

The effect of foliar Zn application on the yield elements and element content of maize (*Zea mays* L.) was studied in 2011 in a National Long-Term Fertilization Experiment at the Karcag Research Institute, Hungary. The plot field experiment was established in 1968 with split plot arrangement in four replications; the gross plot size was 50 m^2. The sequence in the crop rotation is: winter wheat-maize-maize-winter wheat.

The soil of the experimental site is a Luvic Phaeosem with loamy clay texture, solonetzic in the deeper layers. The soil characteristics of the upper 0–30 cm soil layer are the following: clay content is 35% and the texture is loamy clay, Hu% = 3.09, pH_{H_2O}= 6.13, $pH_{1\ mol/L\ KCl}$ = 5.34.

The soluble Zn and P content were determined in 0–60 cm soil layer. The P content was determined according to the Hungarian Standard, where ammonium-lactate solution (AL) was used as an extractant (MSZ 20135, 1999). The Zn content was determined with DTPA-$CaCl_2$-TEA extractant according to Lindsay and Norvell (1978). The AL soluble P contents decreased in the following trend: in 0–20 cm depth 157.1 mg/kg, in 20–40 cm depth 126.6 mg/kg and in 40–60 cm depth 95.7 mg/kg. At the same time, the DTPA-$CaCl_2$-TEA soluble Zn contents increased with the depth: in 0–20 cm it was 0.85 mg/kg, in 20–40 cm depth 2.15 mg/kg and in 40–60 cm depth 2.81 mg/kg.

The upper 0–30 cm soil layer was also characterized with the help of 0.01 mol/L $CaCl_2$ extractant and it produced the following values (Houba et al. 1990): 6.85 mg/kg Mn, 210 mg/kg Mg, 80 mg/kg K, 6.59 mg/kg orthophosphate-P. The nitrate-N contents were: 5.4 mg/kg NO_3^--N at the plots with 150 kg/ha N, 8.6 mg/kg NO_3^--N by 200 kg N/ha fertilization doses and 9.9 mg/kg NO_3^--N by 250 kg N/ha doses.

Ammonium nitrate, potassium-chloride, and superphosphate were used as fertilizers. The NPK fertilization treatments are summarized in Table 1. P and K fertilizers are applied in one dose before fall plowing, while N fertilizer doses were shared equally between fall and spring. The Zn treatment was used in the plots that were treated with 87.3 kg P/ha/year; at these plots Zn deficiency symptoms can be observed regularly for maize at its 4–10 leaf stage in spring.

The maize was sown on 21st April 2011. The plant density was 71 000 plants/ha. The foliar Zn fertilization was carried out on 31st May at 8–10 leaf stage of development of the maize. 700 g/ha Zn was used as ZintracTM 700 that contains zinc oxide and zinc sulphate suspension. Within the plots one line was treated (the fifth to the right), and another line was selected as control (the fifth to the left).

Leaf samples of maize were collected at early silk. Zn, Mn, Ca and Mg content of the leaf and grain were measured with nitric acid digestion by FAAS technique (Varian Spectr. AA-20, Palo Alto, USA). K content was measured with sulphuric acid digestion with flame photometer (UNICAM SP95B, Orpington, UK). The P content was determined with sulphuric acid digestion with ammonium molybdenate vanadate UV-VIS spectrophotometry method (Thamm et al. 1968).

The grain yield and the thousand-kernel weight of the air-dried samples were also determined. All statistical analyses were carried out using the statistical package of SPSS (version 13). Significant differences were examined by two-way ANOVA. The yield of the lines was converted to t/ha. At the conversion the following data were taken into account: 26 maize plants were in a row on average and 71 000 plants/ha was the plant density.

Table 1. Applied fertilization doses (kg/ha) of the treatments (1987–2010)

Treatment	N	P	K
$N_2P_4K_1$	150	87.3	82.6
$N_3P_4K_1$	200	87.3	82.6
$N_4P_4K_1$	250	87.3	82.6

RESULTS AND DISCUSSION

Zn and P supply of the soil. The DTPA soluble Zn content in the 0–20 cm layer is slightly larger than 0.8 mg/kg (the critical value of Lindsay and Norwell (1978)), but in lower layers the Zn supply is appropriate. The P supply of the soil is very high in 0–60 cm soil layer according to Buzás et al. (1979).

Extractable Zn content alone is not appropriate to characterize the Zn availability of a plant. As it was observed before, the extractable Zn in soils had not decreased at all, or only slightly at high P supply (Warnock 1970, Marschner 1993). In our former greenhouse experiment (Kremper and Seres 2010) we also observed that Zn deficiency occurred even at high extracted Zn content when

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Table 2. The effect of zinc and nitrogen fertilization on the yield elements of maize

	Nitrogen rate (A) (kg/ha)	Fertilizer treatment (B)		Mean (A)	*LSD* (A)	*LSD* (B)
		NPK	NPK + Zn			
Yield (kg/line)	150	3.19	3.52	3.36		
	200	3.97	3.77	3.87	0.45	ns
	250	3.87	4.30	4.08		
	mean (B)	3.68	3.86	–		
Yield (kg/ha)	150	8.7	9.6	9.2		
	200	10.9	10.3	10.6	1.2	ns
	250	10.6	11.7	11.2		
	mean (B)	10.1	10.6	–		
Thousand-kernel weight	150	318	325	321		
	200	305	315	310	ns	10.4
	250	306	324	315		
	mean (B)	309	321	–		

ns – not significant; *LSD* – least significant difference

the P content was also high. Potarzycki and Grebitz (2009) experienced Zn deficiency on maize on Luvisol soil with high P content at 2.86 mg/kg DTPA extractable Zn content on average in Poland.

The effect of treatments on the yield elements of maize. The effect of Zn and nitrogen (N) treatments on the yield and on the thousand-kernel weight is demonstrated in Table 2. We did not find significant interaction between Zn and N treatment in case of either yield elements. Therefore we presented the main effect of one variable through the mean yield values of the other variable.

According to Table 2, it can be stated that Zn fertilizer spraying in the average of N treatments did not increase the maize yield significantly, although a trend of yield rise was experienced. Our result is in accordance with that of Blaskó and Zsigrai (1998), who studied the effect of Zn fertilizer spraying on the yield of maize in the same research area.

The yield increased with the increasing dose of N. The yields at the plots of 200 and 250 kg/ha N dose were significantly different from the yield of 150 kg/ha dose plot.

Table 3 represents the element content of leaves and grains. There was no significant interaction between Zn and N treatments in either element content; thus, we can analyze the main effect of treatments through the marginal mean values. It can be seen that the Zn content is slightly greater in the leaf than in the grain, whereas the P content is similar in the leaf and in the grain. However concerning the other tested elements the element content in the grain was much lower than in the leaf. Ca and Mn were present in the grains in such small amounts that it could not be measured by FAAS technique.

The Zn content of leaves without Zn treatment was 14.5 mg/kg on average of the N treatments. According to Jones (1967) the critical value of Zn is 15 mg/kg in the maize leaf at the time of flowering. Based on this, the maize sample in the experimental plots can be classified as Zn deficient, although no visible deficiency syndromes were found at the time of sampling. Contrary to our expectations, there was no significant effect of foliar Zn fertilization on the Zn content of the leaf samples, since the Zn content in the leaf of the treated plants exceeded only slightly that of control treatment (16.1 mg/kg). Foliar Zn fertilization did not affect the Zn content of grain significantly.

Phosphorus is also of great importance from the aspect of the experiment. Several authors (Loneragan et al. 1982, Cakmak and Marschner 1986, Kaya and Higgs 2001) reported that in the case of phosphorus-induced Zn deficiency the P content of leaves increases significantly, which can cause P toxicity as well. In our experiments the P content of the leaves decreased as a result of Zn fertilization. From the data of Table 3, it can be stated that the plants had not excessive P content based on the critical values of Jones (1967). He considers the P supply appropriate between 0.25% and 0.46% P content of the leaves. These data do not indicate a phosphorus-induced Zn deficiency during the sampling period. Zinc spraying fertilization did not alter significantly the P content of the leaves.

Another indicator of phosphorus-induced Zn deficiency is the P/Zn ratio of the leaf. Bergmann and Neubert (1976) and Csathó et al. (1989) proposed Zn fertilization if the P/Zn ratio exceeds 200 in leaf samples collected at flowering. According to Izsáki (2011) the critical P/Zn ratio is 330. In our experiment, P/Zn ratios in the untreated and treated plots were 209.5 and 186.3, respectively. The Zn content and P/Zn ratio in the leaf was close to the critical values given by Elek and Kádár (1980). Based on the yields however phosphorus-induced Zn deficiency cannot be stated, and consistently deficiency symptoms were not observed on the leaves at tasseling.

The Zn spraying fertilization did not have a significant effect on the content of other elements,

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Table 3. The effect of zinc and nitrogen fertilization on the element content of leaves and kernels in maize

Element content	Plant part	Nitrogen rate (A) (kg/ha)	Fertilizer treatment (B) NPK	NPK + Zn	Mean (A)	*LSD* (A)	*LSD* (B)
Zn (mg/kg)	leaves	150	16.3	16.9	16.6	ns	ns
		200	14.3	16.4	15.3		
		250	13.1	15.0	14.0		
		mean (B)	14.5	16.1	–		
	kernels	150	13.5	12.9	13.2	ns	ns
		200	14.5	13.2	13.8		
		250	12.2	11.5	11.9		
		mean (B)	13.4	12.5	–		
P (%)	leaves	150	0.28	0.29	0.28	ns	ns
		200	0.31	0.27	0.29		
		250	0.32	0.31	0.31		
		mean (B)	0.30	0.29	–		
	kernels	150	0.31	0.28	0.30	ns	ns
		200	0.30	0.30	0.30		
		250	0.30	0.28	0.29		
		mean (B)	0.30	0.29	–		
K (%)	leaves	150	2.05	2.01	2.03	ns	ns
		200	2.35	2.23	2.29		
		250	2.01	2.01	2.01		
		mean (B)	2.14	2.08	–		
	kernels	150	0.51	0.46	0.48	ns	ns
		200	0.46	0.48	0.47		
		250	0.51	0.46	0.48		
		mean (B)	0.49	0.46	–		
Mg (%)	leaves	150	0.35	0.30	0.32	ns	ns
		200	0.35	0.31	0.33		
		250	0.37	0.32	0.34		
		mean (B)	0.36	0.31			
	kernels	150	0.15	0.14	0.15	ns	ns
		200	0.16	0.14	0.15		
		250	0.14	0.13	0.13		
		mean (B)	0.15	0.14			
Ca (%)	leaves	150	1.30	1.21	1.25	ns	ns
		200	1.30	1.29	1.30		
		250	1.28	1.26	1.27		
		mean (B)	1.29	1.25			
	kernels	150–250	below measurable range				
Mn (mg/kg)	leaves	150	102.2	101.7	101.9	24.9**	ns
		200	147.0	104.2	125.6		
		250	146.8	125.3	136.0		
		mean (B)	134.7	110.4			
	kernels	150–250	below measurable range				

**$P < 0.01$; ns – not significant; *LSD* – least significant difference

neither in the leaves nor in the grain yield. Increasing the N doses the manganese content only raised significantly in leaf samples. This can be explained by the fact that the increasing doses of N raised the acidity of the soil that increased the Mn availability for the plants. Nitrogen fertilization had no effect on the element content of grain for the studied elements.

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According to our results it can be concluded that with regular application of 87.3 kg/ha P in the studied slightly acidic habitat the degree of Zn deficiency is so small that it does not result in yield loss, despite the observed Zn deficiency symptoms in the early development of maize. As a consequence, a positive effect of an additional foliar Zn fertilization on the yield cannot be expected.

The regular application of 87.3 kg/ha P increased the P content of the upper soil layer, which caused Zn deficiency at 6–10 leaf stage of maize. The P induced deficiency symptoms disappeared over time, as roots penetrated lower soil layers, where the P fertilization no longer had an effect on Zn supply.

Based on our results it can be stated that the numerical value of soluble Zn content in the upper layer does not answer if Zn deficiency is present. The element content of deeper soil layers has to be taken into account as well. The soil Zn status can only be characterized in the collective knowledge of soluble Zn content soluble P content and soil pH or lime content.

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